International Critical Tables of Numerical Data, Physics, Chemistry and Technology

*Prepared under the Auspices of the International
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National Academy of Sciences*

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Introduction

International Critical Tables is the result of the cooperative labors of a large number of specialists, each of whom has been charged with the responsibility for the critical compilation of the quantitative information available on his topic. The word "critical" in this connection means that the Cooperating Expert was requested to give in each instance the "best" value which he could derive from all the information available, together, where possible, with an indication of its probable reliability.

Through a cooperative arrangement with International Annual Tables, the Board of Editors has been able to place in the hands of each Cooperating Expert the literature references belonging to his topic for the years 1910-1923 inclusive, as compiled by the staff of International Annual Tables. For the period preceding 1910, each Cooperating Expert was directed to collect the necessary literature references from the various published handbooks, special treatises, works of reference, and other sources known to him as a specialist in the field. No attempt has been made to systematically cover the literature since 1923, although a certain amount of information published since then has been utilized.

In preparing the various sections, the Cooperating Experts were instructed,—

1. To include in the bibliography only *(a)* the sources of the data upon which their reported values actually rest, and (6) the sources of available data of the same kind pertaining to those systems for which no numerical value is given. It is not intended to be a complete bibliography of the field.
2. To omit from the tables of numerical data all those systems for which the available data (a) were of slight scientific or practical interest, or (o) were so discordant as to be of little, if any, value.
3. To set forth the results of their work in the form of text, equations, tables, graphs, or charts, as seemed most appropriate under the circumstances, having regard to the necessity of space economy.
4. To give only selected samples illustrating types in the case of very large and heterogeneous fields, such as colloids, chemical kinetics, and certain classes of industrial materials.
5. To restrict the accompanying explanatory text to the amount necessary for the intelligent use of the data. (Under this restriction, the Expert is given no opportunity to present a general discussion of his subject or of the methods by which he obtained the values given.)

In preparing the textual material for publication the Editors have been compelled, in the interest of economy of space, to enforce the restrictions imposed by sections 3 and 5 of the preceding paragraph and have freely rearranged and rewritten the text, whenever it was evident that a compression or an improvement in logical order could be so secured. With few exceptions, which are duly noted, the final form of the rewritten text was submitted to the Expert and was accepted by him.

In preparing the numerical data for publication the Editors have made no change except in their arrangement and in their mode of presentation. In making such changes the Editors have been guided by the necessity of saving space. The numerical data are in all cases those submitted by the Expert, excepting that (a) a few additional values, all duly indicated, have been inserted, and (b) when an Expert has submitted a number of values for the same nominal quantity, these have been grouped so as to make a single entry with an indication of the range covered by the values submitted, whenever such grouping seemed justifiable. In these cases, the final manner of grouping was in every case where possible submitted to and accepted by the Expert. The exceptional cases are noted as they occur.

Owing to the method of publication, *i.e.,* one volume at a time, a strictly logical arrangement of subject matter is not always followed. Among such a large number of Cooperating Experts a few instances of greatly delayed reports, arising from illness, accident, or other unforeseen causes, are to be expected; and certain sections or parts of sections, therefore, may not appear in their logical places but will be found in a later volume. The whole set of volumes is very completely indexed, however, and the user who consults the index should have no difficulty in locating any information given.

Chemical compounds are arranged in the tables by formula according to a definite system, called the " Standard Arrangement." This system is based upon a set of key numbers for the chemical elements and is fully explained in Volume One.

In order to find a given substance in the longer tables it is therefore necessary to know its chemical formula, at least approximately. If only the name is known, the formula, for most organic compounds or minerals, may be found with the aid of the name indices in Volume One, p. 174 and 280.

International Critical Tables of Numerical Data, Physics, Chemistry and Technology

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Volumes I - VII

INTRODUCTION

In order to facilitate the use of the Index to the seven volumes of International Critical Tables, the following statement is made regarding its arrangement and contents.

Arrangement. A straight alphabetical arrangement is used throughout, with the one exception that, under the names of the chemical compounds, the properties of the compounds are listed first and are followed by the systems (the second component being in italics) of which this compound is one component.

In systems of two or more components the *main entry* under which the data appears is the compound which would appear first in an alphabetical arrangement, without regard to the percentage composition or to the manner in which the systems are listed in the Tables. Thus data for a solution of acenaphthene in acetone will be found under acenaphthene, while those for a solution of naphthalene in acetone will be found under acetone.

According to the plan adopted for this Index, the data for a given system are listed only once, and as it is often desirable to know all the systems in which a specified compound appears there are given, after the properties of each compound, cross references to the system of which it is a component, but which, according to the alphabetical arrangement, appear in the earlier part of the Index. These cross references are in italics and carry an asterisk (*) after the component under which, in the main alphabet, the data will be found. Following the cross references are data for all other systems of which this compound is the first alphabetical component. For example, under ethyl alcohol are given, after the properties of the pure substance, nearly three columns of cross references to systems containing ethyl alcohol, for which data will be found in the main alphabet under the name carrying the *. Thus the entry, -*Acenaphthene** (which appears under ethyl alcohol) refers to the system acenaphthene-ethyl alcohol, the data for which will be found in the Index under acenaphthene. Following these cross references are all the other systems containing ethyl alcohol, with references to the place where data for these systems may be found in the Tables.

Contents: The items included in the Index are:

1. All chemical compounds and systems given in the Tables, with their properties, except in the following cases: Refractive index of organic compounds (VII: 34–62); optical rotatory power of organic compounds (VII: 356–488); absorption spectra of organic compounds and dyes (V: 320–358; VII: 173–211); electrical conductivity of weak electrolytes in aqueous solution (VI: 259–304); data on 3,359 inorganic compounds and 6,175 organic compounds (I: 106–338). The compounds listed in these sections appear in the Index only if other properties are given in the Tables. These compounds are omitted because the tables in which they appear are so arranged as to enable the user readily to determine whether or not a given compound is listed and also because it was felt that the inclusion of thousands of names of complex organic compounds was not warranted in view of the tremendous increase in size and consequent cost of the Index.
2. All industrially important compounds and materials with their properties. Many of these are listed under their trade names.
3. All minerals, rocks and miscellaneous materials, with their properties.
4. The names of various effects, equations, formulas, etc.
5. General properties and characteristics of chemical compounds and materials, such as boiling point, compressibility, melting point, refractive index, etc.

Acknowledgments: Special acknowledgment is made to the following for their assistance in indexing special sections of the Tables or for general suggestions regarding the form and contents of the Index: H. K. Benson, E. J. Crane, N. E. Dorsey, P. H. Emmett, H. E. Howe, C. A. Kraus, W. W. Nicholas, E. W. Washburn and H. T. Wensel. A large number of the experts connected with the Tables also cooperated by expressing their opinions on several questions submitted to them in the form of a questionnaire. The clerical help of Mrs. D. St. James Sweitzer, of the Research Information Service, has been of great assistance.

CLARENCE J. WEST.

WASHINGTON, D. C.,
March, 1933.

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Volume VII

INTERNATIONAL CRITICAL TABLES

NATIONAL AND LOCAL SYSTEMS OF WEIGHTS AND MEASURES

CHARLES-ÉDOUARD GUILLAUME AND CHARLES VOLET

Plan.—Section A: International Metric System; list of countries in which its use was compulsory on January 1, 1925; list of those in which its use was either legally optional or partially compulsory on same date.

Section B: Other modern systems; the more important units at present in use or in use before adoption of metric system.

Section C: Weights and measures of antiquity.

Style and Abbreviations.—Only the singular number of the names of the units are used; ten meters will appear as 10 meter. Units of area and of volume will be written in the form centimeter^2 (=cm^2) and centimeter^3 (=cm^3), respectively.

ca.	Value given is only approximate.
ch.	Units have changed from time to time.
cm^2	Square centimeter = centimètre carré = Quadratzentimeter = centimetro quadrato.
current	Units, other than metric, which are now in use; some of the units included in this class are practically obsolete. (*See* Local.)
local	Units of local or native origin or derivation which are in use, but which are embraced neither by the metric system nor by that of the central government. Applies mainly to colonial possessions. (*See* Current.)
m^3	Cubic meter = mètre cube = Kubikmeter = metro cubico.
m.c.	International metric system compulsory since . . .
m.o.	International metric system legally optional since . .
older	Units used before adoption of international metric system.
older =	The older units were those of . . .
provincial	Units vary from one province or city to another.
since . . . = . . .	Since . . . the units have been the same as those of . . .
v.	*Vide* = see.
var.	Units are variable, not rigidly defined.

A. INTERNATIONAL METRIC SYSTEM

The decimal metric system, established in France by the Loi du 7 Avril, 1795, and represented by standards deposited in the Archives de France, became international on May 20, 1875, by the action of the Convention Internationale du Mètre. The new standards, of platinum-iridium, constructed at that time and serving as the basis of the international system, were copied from those of the Archives.

On January 1, 1925, the metric system was compulsory in:

Algeria
Allemagne
Argentina
Austria
Autriche
Belgium
Bolivia
Brazil
Bulgaria
Chile
Colombia
Congo, Belgian
Costa Rica
Cuba
Czechoslovakia
Denmark
Deutschland
Ecuador
Equateur
Espagne
Filippíne
Finland
France
Germany
Gioppóne
Greece
Guam
Guatemala
Haiti
Holland
Honduras
Hungary
Iceland
Italy & colonies
Japan
Kolumbien
Kongo, Belgisch
Kuba
Luxemburg
Malta
Mauritius
Mexico
Netherlands & colonies
Nicaragua
Norway
Olanda
Österreich
Panama
Pay-Bas & colonies
Philippine Islands
Peru
Poland
Porto Rico
Portugal and colonies
Rumania
Russia
Salvador
Schweden
Schweiz
Serbie-Croatie-Slovénie
Seychelles Islands
Siam
Spain
Suède
Suisse
Svézia
Svizzera
Sweden
Switzerland
Tchécoslovaquie
Tunis
Ungarn
Ungheria
Uruguay
Venezuela
Yugoslavia

On the same date, it was legally optional or partially compulsory in:

Canada
China
Egypt
Ethiopia
Great Britian
India, British
Ireland, Northern
Irish Free State
Paraguay
Turkey
United States of America

The fundamental units are: METER (m), which is the distance at 0°C between the axes of two lines ruled on the prototype deposited at the Bureau international des Poids et Mesures, Sèvres, France; KILOGRAM (kg), which is the mass of the prototype deposited at the same Bureau; and LITER (l), which is the volume of one kilogram of pure water at the temperature of its maximum density, under the pressure of one normal atmosphere.[1]

The primary units of the system are the *meter* (m), *micron* (μ) = 10^{-6} meter, *gram* (g) = 10^{-3} kilogram, *liter* (l), *are* (a) = area of a square with a side 10 meter long, and *stere* (s) = volume of a cube with an edge one meter long. The units of area [of volume], characterized by the adjective square [cubic], are *not* derived from a primary unit, but are each defined as the area [volume] of a square [cube] with side [edge] equal to the stated unit of length. The names of other secondary units are formed by attaching to the name of a primary unit certain prefixes of unvarying significance.

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[1] Normal atmosphere, *v.* p. 18.

Secondary units.

LENGTH m = meter		
μ	micron*	= 10^{-6} m
mm	millimeter	= 10^{-3} m
cm	centimeter	= 10^{-2} m
dm	decimeter	= 10^{-1} m
dkm	dekameter	= 10 m
hm	hectometer	= 10^{2} m
km	kilometer	= 10^{3} m
Mm	myriameter	= 10^{4} m
	megameter	= 10^{6} m

* mμ millimicron = 10^{-9} m   μμ micromicron = 10^{-12} m

MASS g = gram		
μg*	microgram	= 10^{-6} g
mg	milligram	= 10^{-3} g
cg	centigram	= 10^{-2} g
dg	decigram	= 10^{-1} g
dkg	dekagram	= 10 g
hg	hectogram	= 10^{2} g
kg	kilogram	= 10^{3} g
q	metric quintal = 10^{2} kg	= 10^{5} g
t	metric ton = 10^{3} kg	= 10^{6} g
c	metric carat	= 200 mg

* Symbol γ also used.

CAPACITY l = liter = 1.000 027 dm³		
μl*	microliter	= 10^{-6} l
ml	milliliter	= 10^{-3} l
cl	centiliter	= 10^{-2} l
dl	deciliter	= 10^{-1} l
dkl	dekaliter	= 10 l
hl	hectoliter	= 10^{2} l

* Symbol λ also used.

AREA m² = square meter		
mm²	square millimeter	= 10^{-6} m²
cm²	square centimeter	= 10^{-4} m²
dm²	square decimeter	= 10^{-2} m²
a	are	= 10^{2} m²
ha	hectare	= 10^{2} a
km²	square kilometer	= 10^{6} m²

VOLUME m³ = cubic meter		
mm³	cubic millimeter	= 10^{-9} m³
cm³	cubic centimeter	= 10^{-6} m³
dm³	cubic decimeter	= 10^{-3} m³
km³	cubic kilometer	= 10^{9} m³
ds	decistere = 0.1 s	= 10^{-1} m³
s	stere	= 1 m³
dks	dekastere = 10 s	= 10 m³

B. MODERN SYSTEMS

Abyssinia.—var.: current, *ca.*:

Length

1 pic = 0.686 m
1 farsang = 5.07 km
1 berri = $\frac{1}{3}$ farsang

Mass

1 rottolo = 311 g

Unit	Rottolo
1 drachm	= $\frac{1}{120}$
1 derime	
1 wakea	= $\frac{1}{12}$
1 mocha	= $\frac{1}{10}$

Capacity, dry

1 madega = 0.44 l
1 ardeb = 10 or 24 madega

Capacity, liquid

1 kuba = 1.016 l

Ägypten *v.* Egypt.

Äthiopien *v.* Ethiopia.

Algeria.—Since 1843 = France. Older:

Length

1 pic (dzera à torky) = 0.640 m
1 pic (dzera à rabry) = 0.480 m

Unit	Pic
1 termin	= $\frac{1}{8}$
1 rebia	= $\frac{1}{4}$
1 nus	= $\frac{1}{2}$

Mass

1 ukkia = 34.13 g
1 metical = *ca.* 4.7 g

Unit	Ukkia
1 rottolo à thary	= 16
1 rottolo à khadhary	= 18
1 rottolo à kebyr	= 24
1 cantar	= 100 rottolo

Capacity, dry

1 caffiso = 317.47 l
1 saah = 58 l
1 tarri = $\frac{1}{16}$ caffiso

Capacity, liquid

1 khoull = $16\frac{2}{3}$ l or 16 l

Allemagne *v.* Germany.

Anam.—var.: ch., current:*

Length

1 thuoc moc = 0.425 m
1 thuoc de ruong = 0.470 m
1 thuoc vai = 0.644 m

Unit	Thuoc
1 ly	= 0.001
1 phan	= 0.01
1 tat	= 0.1
1 tam	= 5
1 ngu	
1 truong	= 10
1 sao	= 15
1 chai vai	= 30
1 that	
1 mao	= 150
1 gon	= 300

Mass

1 dong = 3.775 g
1 picul = 60 kg

Unit	Dong
1 hao	= 0.001
1 li	= 0.01
1 fan	= 0.1
1 luong	= 10
1 neu	= 100
1 can	= 160
1 yen	= 1600
1 binh	= 8000
1 ta	= 16 000
1 quan	= 18 000

Area

1 ngu² = 4.5156 m²

Unit	Ngu²
1 thuoc	= 6
1 sao	= 90
1 mau	= 900
1 quo	= 1800

Capacity

1 hao or shita = 28.26 l
1 tao = 2 hao

Angola.—m.c. 1910.

Arabia.—Provincial, current:

Length

1 covid = 0.482 m
1 guz = 0.635 m
1 cassaba = 3.84 m
1 farsakh = 4.83 km

Unit	Farsakh
1 baryd	= 4
1 marhala	= 8

Mass

1 maund = 1350 g
1 ratl = *ca.* 460 g

Unit	Maund
1 coffilas	= $\frac{1}{400}$
1 vakias	= $\frac{1}{40}$
1 tukeas	
1 farzil	= 10
1 farecella	
1 bahar	= 150
1 bokard	

Capacity, dry

1 téman = 85 l

Unit	Téman
1 mecmeda	= $\frac{1}{40}$
1 kella	
1 mec dema	= $\frac{1}{80}$

Capacity, liquid

1 nusfiah = 0.79 l or = 0.95 l

Unit	Nusfiah
1 vakia	= $\frac{1}{16}$
1 cuddy	= 4
1 zudda	= 8

Argentine Republic.—m.c. 1887; m.o. 1863. Older,* provincial:

Length

1 vara = 0.8666 m

Unit	Vara
1 linéa	= $\frac{1}{432}$
1 pulgada	= $\frac{1}{36}$
1 pié	= $\frac{1}{3}$
1 braza	= 2
1 cuadra	= 150
1 legua	= 6000

Mass

1 libra† = 459.4 g

Unit	Libra
1 grano	= $\frac{1}{9216}$
1 adarme	= $\frac{1}{256}$
1 onza	= $\frac{1}{16}$

---

* By an ordinance of 1872, units were defined in terms of metric.

* National system derived from old Spanish. Units given are those of province of Buenos Aires.

† 1 libra de farmacia = $\frac{3}{4}$ libra = 344.5 g.

Unit Libra
1 arroba = 25
1 quintal = 100
1 tonelada = 2000

Area

1 vara² = 0.75 m²

Capacity, dry

1 fanega = 137.1977 l
Unit Fanega
1 cuartilla = $\frac{1}{4}$
1 tonelada = 7.5
1 lastre = 15

Capacity, liquid

1 frasco = 2.375 l
Unit Frasco
1 octava = $\frac{1}{16}$
1 cuarta = $\frac{1}{4}$
1 baril = 32
1 cuarter = 48
1 pipa = 192

Austria.—m.c. 1876; m.o. 1873. Older:

Length

1 Fuss* = 0.316 08 m
1 Ell = 0.7792 m
Unit Fuss
1 Punkt = $\frac{1}{1728}$
1 Linie = $\frac{1}{144}$
1 Zoll = $\frac{1}{12}$
1 Klafter = 6
1 Meile = 24 000

Mass, (1) ordinary

1 Pfund = 560.01 g
Unit Pfund
$\left.\begin{array}{l}\text{1 Pfennig}\\ \text{1 Denat}\end{array}\right\} = \frac{1}{512}$
1 Quentchen = $\frac{1}{128}$
1 Loth = $\frac{1}{32}$
1 Unze = $\frac{1}{16}$
1 Vierding = $\frac{1}{4}$
1 Mark = $\frac{1}{2}$
1 Stein = 20
1 Zentner = 100
1 Saum = 275
1 Karch = 400

Mass, (2) for drugs

1 Pfund apoth. = $\frac{3}{4}$ Pfund
= 420.01 g
Unit Pfund apoth.
1 Gran = $\frac{1}{5760}$
1 Scrupel = $\frac{1}{288}$
1 Drachme = $\frac{1}{96}$
1 Unze = $\frac{1}{12}$

Area

1 Joch = 1600 Klafter²
= 57.557 a
1 Metze = $\frac{1}{3}$ Joch

Capacity, dry

1 Metze = 61.489 l
Unit Metze
1 Probmetze = $\frac{1}{1024}$
1 Becher = $\frac{1}{128}$
1 Futtermassel = $\frac{1}{32}$
1 Muthmassel = $\frac{1}{16}$
1 Achtel = $\frac{1}{8}$
1 Viertel = $\frac{1}{4}$
1 Muth = 30

Capacity, liquid

1 Mass = 1.4151 l
Unit Mass
1 Pfiff = $\frac{1}{8}$
1 Seidel = $\frac{1}{4}$
1 Halbe = $\frac{1}{2}$
1 Viertel = 10
1 Eimer = 40
1 Fass = 400
1 Dreiling = 1200
1 Fuder = 1280

Balearic Islands.—*v.* Spain. Local:

Length

1 canna = 1.564 m
1 palmos = $\frac{1}{8}$ canna

Mass

1 rottolo = 408 g
Unit Rottolo
1 libra major = 3
1 corta = 9
1 quartano = 9
1 arroba = 26
1 misura = 36
1 cantaro barbaresco = 100
1 cantaro = 104
1 cargo = 312

Capacity, dry

1 quartera = 71.97 l
Unit Quartera
1 barcella = $\frac{1}{6}$
1 almude = $\frac{1}{36}$

Capacity, liquid

1 quartin = 27.14 l
Unit Quartin
1 quarte = $\frac{2}{13}$
1 quarta = $\frac{1}{26}$

Bavaria *v.* Germany.

Belgian Congo.—m.c. 1911.

Belgium.—m.c. 1820; at first with the names: aune = m, litron = l, livre = kg, once = hg, lood = dg, wigtje = g, Older:

Length

1 perche = 6.497 m
1 pied = $\frac{1}{20}$ perche

Mass

1 livre = 489.5 g
Unit Livre
1 loth = $\frac{1}{32}$
1 once = $\frac{1}{16}$
1 marc = $\frac{1}{2}$
1 stein = 8
1 quintal = 100
1 chariot = 165
1 balle = 200
1 schiffpfund = 300
1 charge = 400

Area

1 arpent = 400 perche²
= 130.6 a

Birmanie *v.* British India, Rangoon.

Bolivia.—m.c. 1893; m.o. 1871. Older = Spain.

Brazil.—m.c. 1862. Older:*

Length

1 pé = 0.33 m
Unit Pé
1 palmo = $\frac{2}{3}$
1 vara = $3\frac{1}{3}$
1 passo geometrico = 5
1 braca = $6\frac{2}{3}$
1 legoa = 20 000

Mass

1 libra = 459.05 g
Unit Libra
1 onza = $\frac{1}{16}$
1 marco = $\frac{1}{2}$
1 arroba† = 32
1 quintal = 128
1 tonelada = 1728

Area

1 tarefa = 30 to 40 a
1 alqueire = 242 or 484 a

Capacity

1 almude = 31.944 l
1 alqueire = 40 to 320 l
Unit Almude
1 canada = $\frac{1}{12}$
1 pipa = 15
1 tonel = 30

Britain, British *v.* Great Britain.

British India.—m.o. 1920. Current: British and local. Local,‡ provincial:

BOMBAY.

Length

1 guz = 0.6858 m
Unit Guz
1 tassoos = $\frac{1}{24}$

Unit Guz
$\left.\begin{array}{l}\text{1 hath}\\ \text{1 covid}\\ \text{1 cubit}\end{array}\right\} = \frac{2}{3}$

Mass

1 seer = 317.5147 g
Unit Seer
1 tank = $\frac{1}{72}$
$\left.\begin{array}{l}\text{1 pice}\\ \text{1 parah}\end{array}\right\} = \frac{1}{30} \text{ or } \frac{1}{15}$
1 maund = 40
1 candy = 800

Area

Unit Are
1 ground = 2.03
1 biggah = 24.68
1 kani = 30.75
1 cawnie = 54
1 chahar = 2962

Capacity

1 parah = 110.1 l
Unit Parah
1 tipree = $\frac{1}{128}$
1 seer = $\frac{1}{64}$
1 adoulie = $\frac{1}{16}$
1 candy = 8
1 garce = 80

CALCUTTA.

Length

1 guz* = 0.9144 m
Unit Guz
$\left.\begin{array}{l}\text{1 jaob}\\ \text{1 jow}\end{array}\right\} = \frac{1}{144}$
1 unglee = $\frac{1}{48}$
1 moot = $\frac{1}{12}$
1 span = $\frac{1}{4}$
$\left.\begin{array}{l}\text{1 covid}\\ \text{1 haut}\end{array}\right\} = \frac{1}{2}$
1 danda = 2
1 niranga = 10
1 coss = 2000

Mass

1 seer = 933.04 g
Unit Seer
1 ruttee = $\frac{1}{7680}$
1 masha = $\frac{1}{960}$
$\left.\begin{array}{l}\text{1 tolah}\\ \text{1 sicca}\end{array}\right\} = \frac{1}{80}$
1 chittack = $\frac{1}{16}$
1 pouah = $\frac{1}{4}$
1 raik = $\frac{5}{4}$
$\left.\begin{array}{l}\text{1 pally}\\ \text{1 dhurra}\end{array}\right\} = 5$
1 maund (bazar) = 40

Area

1 guz² = 0.836126 m²
Unit Guz²
1 chattack = 5
1 cottah = 80
1 biggah = 1600
1 tenab = 2500

---

* Vienna.

* Those of Portugal, with notable local differences.

† 1 arroba metrica = 15 kg.

‡ Local or national measures are now defined by their equivalents in British units.

* Old guz = 0.915 m.

British India.—*Cont'd.*

Capacity

1 pally = 5.0 to 5.5 l

Unit	Pally
1 chattack	= $\frac{1}{80}$
1 khoonke	= $\frac{1}{64}$
1 kunk	= $\frac{1}{16}$
1 raik	= $\frac{1}{4}$
1 soally	= 20
1 khahoon	= 320

Ceylon.

Length

1 covid = 0.464 m

Mass

1 candy 1 bahar	= 226.8 kg

Capacity

1 ammonam = 203.4 l

Unit	Ammonam
1 parrah	= $\frac{1}{8}$
1 seer	= $\frac{1}{288}$

Madras.

Length

1 covid = 0.472 m

Mass

1 seer = 283.495 g

1 cafh = 1.230 447 mg

Unit	Cafh
1 fanam	= 80
1 pagoda	= 2880

Unit	Seer
1 pagoda	= $\frac{1}{80}$
1 pollam 1 varahan	= $\frac{1}{8}$
1 powe	= $\frac{1}{4}$
1 vis	= 5
1 maund	= 40
1 candy	= 800

Area

1 cawnie = 53.41 a

1 maoney = $\frac{1}{24}$ cawnie

Capacity

1 puddy = 1.533 l

Unit	Puddy
1 olluck	= $\frac{1}{8}$
1 measure	= 1
1 marcal	= 8
1 parah	= 40
1 garce	= 3200

Rangoon.

Length

1 sandong = 0.5588 m

Unit	Sandong
1 palgat	= $\frac{1}{22}$
1 taim 1 cubit	= $\frac{9}{11}$
1 lan	= 4
1 bamboo 1 dha	= 7
1 oke thapal	= 140
1 dain	= 7000

Mass

1 tical = 16.32 g

Unit	Tical
1 ruay	= $\frac{1}{64}$
1 pai	= $\frac{1}{16}$
1 moo	= $\frac{1}{8}$
1 mat	= $\frac{1}{4}$
1 cattie	= $33\frac{1}{3}$
1 viss	= 100
1 candy	= 15 000

Capacity

1 byee = 0.505 l

Unit	Byee
1 lamany	= $\frac{1}{8}$
1 zalay	= $\frac{1}{4}$
1 zayoot	= 2
1 seit	= 4
1 kwai	= 8

Straits Settlements.

Mass

1 kati = 604.79 g

Unit	Kati
1 tahil	= $\frac{1}{16}$
1 pikul	= 100
1 bhara	= 300
1 koyan	= 4000

Capacity

1 gantang* = 4.545 96 l

Unit	Gantang
1 para	= 10
1 koyan	= 800

Bulgaria.—m.c. 1892.

Burma *v.* British India.

Cambodia *v.* Indo-China.

Canada.—m.o. 1871. Current = British,† French names are:

Length

1 pouce = 1 inch

1 chainon = 1 link

1 pied = 1 foot

1 verge = 1 yard

1 perche = 1 rod, pole

1 chaine = 1 chain‡

Mass

1 livre	= 1 pound av.
1 cent 1 quintal	= 1 hundred weight
1 tonneau	= 1 short ton

Area

1 arpent = 34.196 a

Capacity

1 pinte = 1 quart

1 chopine = 1 pint

1 boisseau = 8 gallons

1 minot = 39.025 l

Ceylon *v.* British India.

Chile.—m.c. 1848. Older were from Spanish; legal values:

Length

1 bara = 0.836 m

Unit	Bara
1 linea	= $\frac{1}{432}$
1 pulgada	= $\frac{1}{36}$
1 pié	= $\frac{1}{3}$
1 cuadra	= 150
1 legua	= 5400

Mass

1 libra = 460.093 g

Unit	Libra
1 granos	= $\frac{1}{9216}$
1 adarme	= $\frac{1}{256}$
1 castellano	= $\frac{1}{100}$
1 onza	= $\frac{1}{16}$
1 arroba	= 25
1 quintale	= 100

Area

1 bara^2 = 0.698 896 m^2

Capacity, dry

1 almude = 8.083 l

1 fanega = 12 almude

Capacity, liquid

1 cuartillo = 1.111 l

1 arroba = 32 cuartillo

China.—m.o. 1903 with the following names:

Length

kilometer = sin li

hectometer = sin yin

dekameter = sin tchang

meter = sin tchi

decimeter = sin tshwen

centimeter = sin fen

millimeter = sin li

Area

hectare = sin khing

are = sin meou

centare = sin li

Capacity

kiloliter = sin ping

hectoliter = sin chi

dekaliter = sin teou

liter = sin cheng

deciliter = sin ho

centiliter = sin cho

milliliter = sin tshwo

Great diversity in national system; since 1908, defined by metric equivalents. (The orthography here employed is arbitrary; there is diversity in provincial pronunciation.)

Length

1 tchi = 0.32 m

Unit	Tchi
1 hoé	= 10^{-6}
1 su	= 10^{-5}
1 hao	= 10^{-4}
1 lî	= 10^{-3}
1 fen	= 10^{-2}
1 tsouen	= 10^{-1}
1 pou	= 5
1 tchang	= 10
1 yin 1 yan	= 100
1 fen	= 120
1 kyo	= 300
1 li	= 1800
1 poû	= 18 000
1 thsan	= 144 000
1 tou	= 450 000

Mass

1 liang = 37.301 g

Unit	Liang
1 hao	= 0.0001
1 lii	= 0.001
1 fen	= 0.01
1 tsien	= 0.1
1 kin 1 tchin	= 16
1 kwan	= 480
1 tan	= 1600
1 shih	= 1920

Area

1 meou = 6000 tchi^2 = 614.4 m^2

Unit	Meou
1 hao	= $\frac{1}{1000}$
1 pou^2 1 kung	= $\frac{1}{240}$
1 lyi	= $\frac{1}{100}$
1 fen	= $\frac{1}{10}$
1 kish	= $\frac{1}{4}$
1 king	= 10
1 ching	= 100

Volume

1 tchi^3 = 32.768 dm^3

1 ma 1 fang	= 100 tchi^3

Capacity

1 cheng = 1.035 44 l

Unit	Cheng
1 quei	= 0.0001
1 ço	= 0.001
1 chao	= 0.01
1 yo	= 0.5
1 khô	= 0.1
1 to	= 10
1 hou	= 50
1 chei 1 sei	= 100
1 ping	= 500

Capacity, liquid

Liquids are measured by weight.

Chypre, Cipro *v.* Cyprus.

Cochin-China *v.* Indo-China.

Columbia.—m.c. 1854, but following, derived from metric system, are current:

---

* Gantang = British gallon.

† Old French measures have been used, but only minot and arpent are now in use.

‡ Gunther's.

Length

1 vara = 0.8 m
Unit Vara
1 pulgada = $\frac{1}{32}$
1 cuarta = $\frac{1}{4}$
1 cuadra = 100
1 legua = 6250

Mass

1 libra = 500 g
Unit Libra
1 onza = $\frac{1}{16}$
1 arroba = 25
1 quintal = 100
1 saco = 125
1 carga = 250
1 tonelada = 2000

Area

1 vara^2 = 0.64 m^2
1 fanegada = 10 000 vara^2

Cirénaïque *v.* Tripoli.

Congo, Belgian.—m.c. 1911.

Costa Rica, Guatemala, Honduras, Nicaragua, Salvador.—m.c. 1912 by a joint convention; in partial use at earlier dates. Older (modified Spanish, English, and local):

Length

1 vara = 0.8393 m (Costa Rica)
= 0.8359 m (Guatemala)
= 0.8128 m (Honduras)
Unit Vara
1 cuarta = $\frac{1}{4}$
1 tercia = $\frac{1}{3}$
1 mecate = 24

Mass

1 caja = 16 kg
1 fanega = 92 kg
1 carga = 161 kg

Area

1 manzana = 10 000 vara^2
= 6960.5 m^2 (Costa Rica)
= 6987.4 m^2 (Guatemala)
= 6987.4 m^2 (Nicaragua)
1 caballeria = 64 manzana

Capacity

1 botella = 0.63 to 0.67 l
1 cajuela = 16.6 l

Cuartillo is very variable.

Cuba.—m.c. 1858, but others (old Spanish, American, and local) are current:

Mass

1 tonelada = 1015.65 kg
1 tercio = 72.22 kg

Area

1 caballeria Cubana = 1342.02 a
1 cordele = $\frac{1}{324}$ caballeria

Capacity

1 bocoy = 136.27 l
1 barrile = $\frac{1}{6}$ bocoy

Cyprus.—British system. Accepted equivalents:

Length

1 pic = 2 foot
= 0.6096 m

Mass

1 oke = 2.8 pound av
= 1270.06 g
1 moosa* = 50 700 g
Unit Oke
1 drachme = $\frac{1}{400}$
1 rottolo = 0.44
1 stone = 5
1 kantar = 44
1 kantar (Aleppo) = 180
1 ton = 800

Area

1 donum = 1600 yard^2
= 13.378 a
1 scala = 1 donum

Capacity

1 oke = 1.278 55 l
1 cass = 4.73 l
1 kile† = 36.368 l
1 medimno = 75.05 l
1 kartos = 4 oke
1 kouza = 8 oke
1 gomari = 128 oke

Cyrenaïca *v.* Tripoli.

Czechoslovakia.—m.c. 1876.‡ Local:

Length

1 latro = 1.917 m

Bohemia.

1 stopa§ = 0.296 m
1 sah = 1.778 m
1 mile = 7.003 km

Prague.

1 loket = 0.593 m

Moravia.

1 stopa§ = 0.284 m
1 loket = 0.594 m

Silesia.

1 loket = 0.579 m
1 mile = 6.483 km

Area

Bohemia.

1 merice = 19.99 a
$\left.\begin{array}{l}\text{1 korec}\\ \text{1 strych}\\ \text{1 mira}\end{array}\right\}$ = 28.78 a
Unit Korec
1 jitro = 2
1 lan = 60

Capacity

1 merice* = 70.6 l
$\left.\begin{array}{l}\text{1 korec}\\ \text{1 strych}\end{array}\right\}$ = 93.592 l

Denmark.—m.c. 1912; m.o. 1910. Older:

Length

1 fod = 0.313 857 m
Unit Fod
1 linie = $\frac{1}{144}$
1 tomme = $\frac{1}{12}$
1 aln = 2
1 faon, favn = 6
1 ruthe = 10
1 miil = 24 000

Mass

1 pund = 500 g
Unit Pund
1 es = $\frac{1}{9152}$
1 ort = $\frac{1}{512}$
1 quintin = $\frac{1}{128}$
1 loth = $\frac{1}{32}$
1 unze = $\frac{1}{16}$
1 mark = $\frac{1}{2}$
1 bismerpund = 12
1 lispund = 16
$\left.\begin{array}{l}\text{1 wog}\\ \text{1 waag}\end{array}\right\}$ = 36
$\left.\begin{array}{l}\text{1 quintal}\\ \text{1 centner}\end{array}\right\}$ = 100
1 skippund = 320
1 skyplast = 5200
1 quint = 0.1
1 ort = 0.01
1 kvint = 0.001

Area

1 tondelande = 55.162 a
1 tonde = 283.69 a
Unit Tonde
1 penge = $\frac{1}{348}$
1 album = $\frac{1}{96}$
1 fjerdingar = $\frac{1}{32}$
1 skiepper = $\frac{1}{8}$
1 pflug = 32

Capacity, dry

1 korntonde = 139.12 l
Unit Korntonde
1 pott = $\frac{1}{144}$
1 achtel = $\frac{1}{64}$
1 viertel = $\frac{1}{32}$
$\left.\begin{array}{l}\text{1 skieppe}\\ \text{1 ottingkar}\end{array}\right\}$ = $\frac{1}{8}$
1 fjerdingkar = $\frac{1}{4}$
1 last = 22

Capacity, liquid

1 pott = 0.9661 l
Unit Pott
1 paegel = $\frac{1}{4}$
1 kande = 2
1 stubchen = 4
Unit Pott
1 viertel = 8
1 fod^3 = 32
1 anker* = 40
1 ohm* = 160
1 oxhoft* = 240
1 pipe* = 480
1 fuder* = 960

Deutschland *v.* Germany.

Dutch East Indies.—Same as Netherlands. Old Dutch and local measures are also used. Latter very variable; recently they have been legally defined by their metric equivalents. Current:

Length

1 depa = 1.70 m
Unit Depa
1 hasta = $\frac{1}{4}$
1 kilan = $\frac{1}{8}$

Mass. (1) *Ordinary*

$\left.\begin{array}{l}\text{1 pikol}\\ \text{1 pecul}\end{array}\right\}$ = 61.761 3025 kg
Unit Pikol
1 thail = $\frac{1}{1600}$
$\left.\begin{array}{l}\text{1 catti}\\ \text{1 kabi}\end{array}\right\}$ = $\frac{1}{100}$
1 kulack = 0.0725
1 amat = 2
1 small bahar = 3
1 large bahar = 4.5
1 timbang = 5
1 kojang (Batavia) = 1667.555 kg
1 kojang (Semarang) = 1729.316 kg
1 kojang (Soerabaya) = 1852.839 kg

Mass. (2) *For precious metals*

1 thail = 54.090 g
Unit Thail
1 wang = $\frac{1}{48}$
1 tali = $\frac{1}{16}$
1 soekoe = $\frac{1}{8}$
1 reaal = $\frac{1}{2}$

Mass. (3) *For opium*

1 thail = 38.601 g
Unit Thail
1 tji = 0.1
$\left.\begin{array}{l}\text{1 tjembang Mata}\\ \text{1 hoen}\end{array}\right\}$ = 0.001

Area

$\left.\begin{array}{l}\text{1 bahoe}\\ \text{1 bouw}\end{array}\right\}$ = 70.965 a
1 lieue^2† = 55.0632 km

Volume

1 kojang = 1.976 362 m^3
1 toembak = 6.684 m^3

Capacity, dry

1 kojang = 2011.2679 l
1 pikol = $\frac{1}{30}$ kojang

---

* Moosa = hundredweight.

† Kile = bushel.

‡ Old Vienna (*v.* Austria) and some local measures were still in use when the state was established.

§ Stopa = strevic.

* Moravian.

* Variable.

† Geographic.

Dutch East Indies.—*Cont'd.*

Capacity, liquid

(Legal equivalents)

Unit Liter
1 takar* = 25.770
1 kit* = 15.159
1 koelak* = 3.709
1 kan† = 1.5751
1 mutsje† = 0.1516
1 pintje* = 0.0758

Ecuador.—m.c. 1865, but the British and, more generally the old Spanish, measures are currently used.

Egypt.—m.o. 1873; m.c. in government use, 1891. Current:‡

Length

1 diraa baladi = 0.58 m
1 kassabah = 3.55 m
Unit Diraa
1 kirat = $\frac{1}{24}$
1 abdat = $\frac{1}{6}$
1 kadam = $\frac{1}{2}$
1 pic = 1
1 gasab = 4
1 mil hachmi = 1000
1 farsakh = 3000

Mass

1 oke = 1248 g
Unit Oke
1 kirat = $\frac{1}{6400}$
1 dirhem = $\frac{1}{400}$
1 miskal = $\frac{3}{800}$
1 okieh = 0.03
1 rotoli = 0.36
1 kantar = 36
1 helm = 200

Area

1 feddan = 42.008 a
Unit Feddan
1 sahme = $\frac{1}{576}$
1 kirat kamel = $\frac{1}{24}$
1 feddan masri = 1

Capacity

1 keddah = 2.0625 l
Unit Keddah
1 kirat = $\frac{1}{32}$
1 khanoubah = $\frac{1}{16}$
1 toumnah = $\frac{1}{8}$
1 robhah = $\frac{1}{4}$
1 nisf keddah = $\frac{1}{2}$
1 malouah = 2
$\left.\begin{array}{l}\text{1 rob}\\ \text{1 roubouh}\end{array}\right\} = 4$
1 keila = 8
1 ardeb = 96
1 daribah = 768

England *v.* Great Britain.

Equateur *v.* Ecuador.

Eritrea.—m.o. Local, provincial:

Length

1 cubi = 0.32 m
$\left.\begin{array}{l}\text{1 emmet}\\ \text{1 derah}\end{array}\right\} = 0.46$ m

Mass

1 rotolo = 448 g
1 okia = $\frac{1}{16}$ rotolo
1 gisla = 163 kg

Capacity

1 messé = 1.50 l
Unit Messé
1 cabaho = 4
1 tanica = 12
1 ghebeta = 16
1 entelam = 128

Espagne *v.* Spain.

Esthonia.—Russian and local. Current:

Length

1 archine (Russian) = 0.7112 m
1 elle (Livonian) = 0.6096 m
Unit Archine
1 elle (Kuunar) = 0.75
1 faden = 3

Mass

1 pfund = 430 g
Unit Pfund
1 quent = $\frac{1}{128}$
1 loth = $\frac{1}{32}$
1 liespfund = 20
1 centner = 120
1 tonne = 240
1 schiffspfund = 400

Area

Reval
1 lofstelle = 18.55 a
1 tonnland = 54.627 a
Livonian
1 lofstelle = 37.1 a
1 tonnland = 51.94 a

Capacity

1 hulmit = 11.48 l
Unit Hulmit
1 lof (Reval) = 3
1 lof (Livonian) = 6
1 tonne (Livonian) = 12

Etablissements des Détroits *v.* British India.

Etats-Unis *v.* United States.

Ethiopia.—var. Current:

Length

(Approximate only)

Unit cm
1 tat = 2.5
1 gat = 8
1 sinzer = 16
1 kend = 49

Mass

1 kasm = 3.90 g
1 neter = 336 g
1 farasula* = 13.478 kg
1 farasula† = 16.85 kg
1 farasula‡ = 17.972 kg
Unit Kasm
1 mutagalla = 2
1 alada = 4
1 wogiet = 8

Capacity

1 menelik = 1 l (approximate)

Filippine *v.* Philippine.

Finland.—m.c. 1892; m.o. 1887. Older (Russian and local):

Area

1 tunnland = 46.54 a

Capacity

1 tunna = 163.49 l
1 kannor = $\frac{1}{63}$ tunna
1 ottingar = 15.71 l
1 sextingkar = $\frac{1}{2}$ ottingar

France.—m.c. 1794. Other legal units:

Length

1 mille marin = 1852 m

Volume

1 tonneau de jauge = 2.83 m^3
1 tonneau de mer = 1.44 m^3

Old measures derived from the system of Charlemagne are:

Length

1 toise§ = 1.949 0365 m‖
1 toise§ = 1.949 090 m ¶
Unit Toise
1 ligne = $\frac{1}{864}$
1 pouce = $\frac{1}{72}$
1 pied = $\frac{1}{6}$
1 aune = 0.6064
1 lieue = 2280.3
1 mille marin = 950.13
1 lieue marine = 2850.4

Mass

1 livre** = 489.505 85 g
Unit Livre
1 grain = $\frac{1}{9216}$
1 scruple = $\frac{1}{384}$
$\left.\begin{array}{l}\text{1 gros}\\ \text{1 drachme}\end{array}\right\} = \frac{1}{128}$
1 once = $\frac{1}{16}$
1 marc †† = $\frac{1}{2}$
Unit Livre
1 quintal = 100
1 millier = 1000
Unit Livre (Ch)
1 sol = $\frac{1}{20}$
1 denier = $\frac{1}{240}$
1 obole = $\frac{1}{480}$
1 grain = $\frac{1}{5760}$

Area

1 $pied^2$ = 0.10552 m^2
Unit $Pied^2$
1 $toise^2$ = 36
1 perche de Paris = 324
1 perche des Eaux et Forêts = 484
1 arpent de Paris = 32 400
1 arpent des Eaux et Forêts = 48 400

Capacity, dry

1 boisseau = 1.862 78 l*
Unit Boisseau
1 litron = $\frac{1}{16}$
1 quart = $\frac{1}{4}$
1 minot = 3
1 mine = 6
1 setier = 12
1 muid = 144

Capacity, liquid

1 muid = 274.239 l†
1 muid = 268.241 l‡
1 pinte = 0.931 389 l§
Unit Pinte
1 roquille = $\frac{1}{32}$
1 posson = $\frac{1}{8}$
1 demi-setier = $\frac{1}{4}$
1 chopine = $\frac{1}{2}$
1 pot = 2
1 velte = 8
1 quarteau = 72
1 feuillette = 144
1 muid = 288

Fráncia, Isola di *v.* Mauritius.

Frankreich *v.* France.

Germany.—m.c. 1872. Since the beginning of the nineteenth century, the other units and their interrelations have been fairly definite, but before that there was great diversity. *Length:* fundamental unit was Fuss (foot), its value, depending upon the state, varied from 0.280 to 0.320 m. The one most extensively used was the Rheinlandischer Fuss (Rhenish foot) = 0.313 857 m. *Mass:* fundamental unit was Pfund

---

* For oil.

† For various products.

‡ In national system, units and their interrelations were very variable, but since 1891, have been defined by their metric equivalents.

* For ivory.

† For coffee.

‡ For rubber.

§ Toise de Perou at 16.25°C.

‖ Equivalent made legal in 1799.

¶ By measurement, in 1887, by J. R. Benoit.

** One livre de Charlemagne = 367.128 g.

††1 Marc de la Rochelle = 244.75 g
1 Marc de Limoges = 240.93 g
1 Marc de Tours = 237.87 g
1 Marc de Troyes et Paris = 260.05 g

* From 1 muid = 268.241 l by relation 144 boisseau = 1 muid (see Capacity, Liquid).

† Legal value.

‡ Derived from concrete standards.

§ From 1 muid = 268.241 l by relation 288 pinte = 1 muid.

(pound), its value generally varied little from 467 g; during transition period preceding 1872 the accepted equivalents were Pfund = 30 Loth = 300 Zeut = 3000 Korn; Centner = 100 Pfund. Older:

BAVARIA.

Length

1 Fuss = 0.291 86 m
1 Elle = 0.833 01 m
Unit Fuss
1 Linie = $\frac{1}{144}$
1 Zoll = $\frac{1}{12}$
1 Ruthe = 10
1 Chauseemeile = 25 406

Mass

1 Pfund = 560 g
Unit Pfund
1 Gran = $\frac{1}{7680}$
1 Pfennig = $\frac{1}{512}$
1 Quint = $\frac{1}{128}$
1 Loth = $\frac{1}{32}$
1 Unze = $\frac{1}{16}$
1 Zentner = 100

Area

1 Morgen
1 Tagwerk } = 34.072 a
1 Juchert
= 400 Ruthe²

Capacity, dry

1 Metzen = 37.0596 l
Unit Metzen
1 Dreissiger = $\frac{1}{32}$
1 Mässel = $\frac{1}{8}$
1 Scheffel = 6

Capacity, liquid

1 Masskanne = 1.069 03 l
Unit Masskanne
1 Zoll³ = $\frac{1}{43}$
1 Eimer = 60 or 64
1 Fass = 1600

PRUSSIA.

Length

1 Fuss = 0.313 857 m
Unit Fuss
1 Linie = $\frac{1}{144}$
1 Zoll = $\frac{1}{12}$
1 Ruthe = 12
1 Meile = 24 000
1 Elle = 25.5 Zoll

Mass

1 Pfund = 467.711 g
Unit Pfund
1 Quentchen = $\frac{1}{96}$
1 Loth = $\frac{1}{32}$
1 Stein = 22
1 Centner = 110
1 Schiffspfund = 330

Area

1 Morgen = 25.532 24 a
1 Morgen = 180 Ruthe²

Capacity, dry

1 Metze = 3.435 89 l
Unit Metze
1 Quart = $\frac{1}{3}$
1 Zoll³ = $\frac{1}{192}$
1 Scheffel = 16

Capacity, liquid

1 Quart = 64 Zoll³
1 Quart = 1.145 03 l
Unit Quart
1 Anker = 30
1 Eimer = 60
1 Ohm = 120
1 Oxhoft = 180
1 Fuder = 720

WÜRTTEMBERG.

Length

1 Fuss = 0.286 49 m
Unit Fuss
1 Linie = 0.01
1 Zoll = 0.1
1 Elle = 2.144
1 Ruthe = 10
1 Meile = 26 000

Mass

1 Pfund = 467.728 g
1 Apotheker-Pfund = 357.647 g
Unit Pfund
1 Quentlein = $\frac{1}{96}$
1 Loth = $\frac{1}{32}$
1 Mark = $\frac{1}{2}$
1 Zentner = 104

Area

1 Ruthe² = 8.207 66 m²
1 Morgen = 384 Ruthe²
1 Juchart } = 576 Ruthe²
1 Tagwerk

Capacity, dry

1 Simri = 942.125 Zoll³
= 22.1533 l
Unit Simri
1 Viertelein = $\frac{1}{128}$
1 Erklein = $\frac{1}{32}$
1 Vierling = $\frac{1}{4}$
1 Scheffel = 8

Capacity, liquid

1 Maass = 78.125 Zoll³
= 1.837 05 l
Unit Maass
1 Schoppe = $\frac{1}{4}$
1 Imi = 10
1 Eimer = 160
1 Fuder = 960

Gioppóne *v.* Japan.

Great Britain, Irish Free State, and Northern Ireland.—m.o. 1864. Since 1898, the national measures are convertible to metric by the legally sanctioned factors given below. National fundamental units defined thus: *Length:* The yard is distance at 62°F between axes of two lines traced on gold plugs set in a bronze bar preserved at the Standards Department of the Board of Trade. *Mass:* The pound avoirdupois is the mass of a certain platinum standard, similarly preserved. *Capacity:* The gallon is the volume of 10 pounds avoirdupois of pure water, as weighed in air against brass weights, the water and air being at the temperature of 62°F and the barometer at 30 inches. In official comparisons, the density of brass is taken as 8.143 g/cm³. Some of the units in the following tables are not in current use.

Length

1 yard* (yd.) = 0.914 3992 m
1 foot (ft.) = $\frac{1}{3}$ yd.
= 30.479 97 cm
1 inch (in.) = $\frac{1}{36}$ yd.
= 2.539 998 cm
Unit Inch
1 mil = 0.001
1 point = $\frac{1}{72}$
1 line = $\frac{1}{12}$
1 barleycorn = $\frac{1}{3}$
1 nail = 2.25
1 palm = 3
1 hand = 4
1 span } = 9
1 quarter
1 foot = 12
1 cubit = 18
1 pace = 30
1 yard = 36
1 ell = 45
Unit Foot
1 fathom = 6
1 pole
1 rod (rd.) } = 16.5
1 perch
1 rope = 20
1 chain† = 66
1 skein = 360
1 furlong = 660
1 cable length = 720
1 mile (statute) = 5280
1 mile (nautical) } = 6080
1 knot
1 league = 15 840

Mass

1 pound avoirdupois (lb. av.)
= 453.592 45 g
= 7 000 grain
1 grain (gr.) = 64.798 182 mg

(Three systems: avoirdupois, troy, apothecary.)

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* This is the present legal equivalent of the imperial yard; recent comparisons by the National Physical Laboratory show that the yard as defined by the Weights and Measures Act of 1878 = 0.914 3987 m.

† Gunther's chain, divided into 100 link.

Avoirdupois (av.)
(General use)

Unit Pound
1 dram (dm.) = $\frac{1}{256}$
1 ounce (oz.) = $\frac{1}{16}$
1 clove or customary stone = 8
1 stone (legal) = 14
1 quarter = 28
1 cental = 100
1 hundred-weight (cwt.) = 112
1 wey } = 252*
1 load
1 ton = 2240

Troy (t.)
(For precious metals)

Unit Grain
1 pennyweight (dwt.) = 24
1 ounce (oz.) = 480
1 pound (lb.) = 5760

Apothecary (ap.)
(For dispensing drugs)

Unit Grain
1 scruple (s.) = 20
1 drachm (dr.) = 60
1 ounce (oz.) = 480
1 pound (lb.) = 5760

Area

1 inch² (sq. in.)
= 6.451 5898 cm²
1 foot² (sq. ft.)
= 929.0289 cm²
1 yard² (sq. yd.)
= 0.836 1259 m²
1 acre (A.) = 4046.849 m²
Unit Foot²
1 inch² = $\frac{1}{144}$
1 yard² = $\frac{1}{9}$
Unit Yard²
1 pole² (sq. po.)
1 rod² } = 30.25
1 perch²
1 chain²† (ch.) = 484
1 rood = 1210
1 acre (A.) = 4840
Unit = Acre
1 mile² (sq. mi.)
= 640

Volume

1 yard³ (cu. yd.)
= 0.764 552 85 m³
1 foot³ (cu. ft.)
= 28 316.77 cm³
1 inch³ (cu. in.)
= 16.387 0253 cm³
Unit Foot³
1 inch³ = $\frac{1}{1728}$
1 yard³ = 27

* Variable.

† Gunther's chain.

Great Britain.—*Cont'd.*

Unit	Foot^3
1 register ton	= 100
1 rod	= 1000

Capacity, dry

1 gallon (gal.) = 4.545 9631 l
1 bushel (bu.) = 8 gallon
= 35.367 7048 l

Unit	Gallon
1 quartern	= $\frac{1}{2}$
1 peck	= 2
1 bucket	= 4
1 bushel	= 8
1 firkin	= 9
1 kilderkin	= 18
1 barrel	= 36
1 hogshead	= 63
1 puncheon	= 84
1 butt	= 126

Unit	Bushel
1 strike	= 2
1 sack 1 bag	= 3
1 coomb	= 4
1 quarter	= 8
1 seam	= 8
1 chaldron	= 32[*]
1 wey 1 load	= 40[*]
1 last	= 80[*]

Capacity, Liquid

1 gallon (gal.) = 4.545 9631 l

Unit	Gallon
1 gill 1 quartern 1 noggin	= $\frac{1}{32}$
1 pint	= $\frac{1}{8}$
1 quart	= $\frac{1}{4}$
1 pottle	= $\frac{1}{2}$

Greece.—m.c. 1922; m.o. 1836. Older:

Length

1 piki varies 0.640 to 0.670 m
1 pic = 1 piki
1 small piki of Constantinople = 0.648 m
1 large piki of Constantinople = 0.669 m
1 piki (masonry) = 0.750 m

Mass

1 dramme = 3.2 g
1 livre (Venetian) = 450 g
1 mna = 1.5 kg
1 mine (royal) = 1.5 kg
1 oka[†] = 1.280 kg
1 oka = 1.250 to 1.333 kg
1 stater = 56.32 kg
1 talanton = 150 kg

Area

1 stemma = 10 a

Capacity

1 oka = 1.333 to 1.340 l
1 baril = 74.236 l

Grossbritannien *v.* Great Britain.

Guam.—Metric is compulsory.

Guatemala *v.* Costa Rica.

Guinea.—m.c. 1910. Older = Portugal, England, and local:

Length

1 pik = 0.578 m
1 jacktan = 3.658 m

Mass

1 benda = 64.2 g
1 kantar = 977 kg
1 gammell = $\frac{1}{5}$ kantar

Unit	Benda
1 akey	= $\frac{1}{48}$
1 mediatabla	= $\frac{1}{32}$
1 aguirage	= $\frac{1}{16}$
1 quinto	= $\frac{3}{32}$
1 piso 1 uzan	= $\frac{1}{8}$
1 seron	= $\frac{3}{16}$
1 benda (offa)	= $\frac{1}{2}$

Haiti.—m.c. 1921. Older = British, old French, and Spanish; legal equivalents during transition period:

Length

1 toise = 1.9488 m
1 aune = 1.188 m

Area

1 carreau = 1292.3 m

Volume

1 baril = 0.1 m^3
1 corde = 3.84 m^3
1 toise = 8 m^3

Holland *v.* Netherlands.

Honduras *v.* Costa Rica.

Hungary.—m.c. 1876. Older = old Vienna:

Length

1 mertföld 1 meile	= 8.3536 km
1 marok 1 faust	= 0.105 36 m

Area

1 hold = 43.16 a
1 joch = 43.16 a
1 meile^2 = 6978 ha

Volume

1 eimer	= 54.30 l
1 halbe 1 itcze	= $\frac{1}{64}$ eimer
1 metzen 1 ako	= 62.53 l

Iceland.—m.c. 1907. Older (analogous to Danish) were defined by their metric equivalents.

Length

1 fet = 0.313 85 m
1 sjomila = 1855 m

Unit	Fet
1 lina	= $\frac{1}{144}$
1 þumlungur	= $\frac{1}{12}$
1 alin	= 2
1 faðmur	= 6
1 mila a landi	= 24 000

Mass

1 pund = 0.5 kg

Unit	Pund
1 mark	= 2
1 fisk	= 8
1 fierding	= 40
1 liespund	= 64
1 tunna smjörs	= 224
1 skippund 1 batt	= 320

Area

1 ferfaðmur = 3.546 m^2
1 fermila = 56.7383 km^2

Unit	Ferfaðmur
1 ferþumlungur	= $\frac{1}{5184}$
1 ferfet	= $\frac{1}{36}$
1 feralin	= $\frac{1}{9}$
1 tundagslatta	= 900
1 engjateigur	= 1600

Capacity

1 pottar = $\frac{1}{32}$ fet^3
= 0.9661 l

Unit	Pottar
1 kornskeppa	= 18
1 anker	= 39
1 almenn turma	= 120
1 öltunna	= 136
1 korntunna	= 144

India *v.* British India; *v.* Indo-China.

Indies, East *v.* British India; *v.* Dutch East Indies.

Indo-China, British *v.* British India.

Indo-China, French:

COCHIN CHINA.—m.c. 1911, with the names:

Length

1 môt thuoc = 1 m

Mass

1 môt cân tây = 1 kg
1 môt dông cân tây = 1 g
1 picul = 60 kg

Capacity

1 vuông môt bat tây = 1 l
1 vuông môt gia = 40 l

CAMBODIA.—m.c. 1914, with the names:

Length

1 muoi mètre = 1 m

Mass

1 pram rôi = 1 kg
1 muoi gramme = 1 g
1 hocsep = 60 kg

Capacity

1 muoi litre = 1 l
1 sêsep litre = 40 l

Irish Free State *v.* Great Britain.

Islande *v.* Iceland.

Italian colonies.—Metric compulsory.

Italy.—m.c. 1861; adopted in Milan as early as 1803, with the following names:

Length

metro = m
palmo = dm
dito = cm
atomo = mm

Mass

libbra nuova = kg
oncia = hg
grosso = dkg
denar = g
grano = dg

Capacity

soma = hl
mina = dkl
pinta = l
coppo = dl

Older, provincial:

Length

1 piede liprando = 0.513 77 m

Unit	Piede lip.
1 punto	= $\frac{1}{144}$
1 oncia	= $\frac{1}{12}$
1 canna	= 4
1 trabucco	= 6
1 miglio	= $4333\frac{1}{3}$

Mass

1 libbra = 307 to 398 g

Unit	Libbra
1 grano	= $\frac{1}{6912}$
1 denaro	= $\frac{1}{288}$
1 ottavo	= $\frac{1}{96}$
1 oncia	= $\frac{1}{12}$
1 rubbo	= 25
1 cantaro	= 150

Area

1 quadrao 1 giornata	= 38 a
1 tavola	= $\frac{1}{100}$ giornata

Capacity, dry

1 mine = varies 12 to 120 l

Capacity, liquid

1 barile da vino = 45.6 l
1 barile da olio = 33.4 l

---

[*] Variable.

[†] 0.85331 royal mine.

Japan.—m.o. 1893. Before 1891, great diversity; since 1891, fundamental units defined by metric equivalents.

Length

1 shaku* = $\frac{10}{33}$ m
= 0.303 0303 m
Unit Shaku
1 shi = 10^{-5}
1 mô = 10^{-4}
1 rin = 10^{-3}
1 bu = 10^{-2}
1 sun = 10^{-1}
1 yabiki = 2.5
1 hiro = 5
1 ken = 6
1 jô = 10
1 chô = 360
1 ri† = 12 960

Mass

1 kwan = $\frac{15}{4}$ kg
= 3.75 kg
Unit Kwan
1 shi = 10^{-7}
1 mô = 10^{-6}
1 rin = 10^{-5}
1 fun = 10^{-4}
1 candareen = 10^{-4}
1 mommé = 10^{-3}
1 niyo = 0.004
1 hyaku-mé = 0.10
1 kin = 0.16
1 ninsoku-ichi-nin = 7
1 kiyak-kin = 16
1 karus hiri-ichi-da = 18
1 komma-ichi-da = 40

Area

(Land Measure)

1 bu = $\frac{100}{30.25}$ m^2
= 3.305 785 12 m^2
Unit Bu
1 gô = 0.1
1 tsubo = 1
1 sé = 30
1 tan = 300
1 chô = 3000
1 ri^2 = 46 656

Capacity

1 shô = $\frac{2401}{1331}$ l
= 1.803 9068 l
= 64827 bu^3
Unit Shô
1 shaku = 10^{-2}
1 gô = 10^{-1}
1 to = 10
1 koku = 100

Kanada *v.* Canada.

Kolumbien *v.* Columbia.

Kongo *v.* Congo.

Kuba *v.* Cuba.

Latvia.—m.o. Russian and local measures since 1845. Old measures were those of Holland.

Length

1 elle = 0.537 m
1 quartier = $\frac{1}{4}$ elle
1 meile = 7 verste (Russian)
= 7.468 km

Mass

1 pfund = 419 g

For secondary units, *see* Esthonia.

Area

1 kapp = 1.4864 a
Unit Kapp
$\left.\begin{array}{l}\text{1 pourvete}\\\text{1 loofstelle}\end{array}\right\}$ = 25
1 tonnstelle = 35

Volume

1 faden = 4.077 s

Capacity

1 stoof = 1.2752 l
Unit Stoof
1 kanne = 2
1 kulmet = 9
1 anker = 30
$\left.\begin{array}{l}\text{1 poure}\\\text{1 loof}\end{array}\right\}$ = 54
1 tonne = 108

Lettonie *v.* Latvia.

Luxemburg.—m.c. 1820. Previously used a local unit: 1 malter = 191 l.

Malacca.—

Length

1 asta = 0.457 m
1 depa = 4 asta
1 jumba = 8 asta

Mass

1 catty = 0.61 kg
Unit Catty
1 miam = $\frac{1}{320}$
1 buncal = $\frac{1}{20}$
1 tampang = 1
1 bedur = 2
1 kip = 15
1 pecul = 100
1 bahar = 300

Area

1 jumba^2 = 13.38 m^2
1 orlong $\left\{\begin{array}{l}= 400 \text{ jumba}^2\\= 53.52 \text{ a}\end{array}\right.$

Capacity

1 chupa = *ca.* 1 l
1 gantang = 4 chupa

Malaysia *v.* British India; *v.* Dutch East Indies.

Malta.—m.c. 1914. Older, British and local (old Sicilian):

Length

1 foot = 0.2836 m
1 canna = 2.088 m
1 palmo = $\frac{1}{8}$ canna

Mass

1 rottolo = 1.75 lb. av.
= 0.793 79 kg
Unit Rottolo
1 parto = $\frac{1}{480}$
1 ounce = $\frac{1}{30}$
1 cantaro = 100

Capacity

1 caffiso = 20.457 l
1 baril = 43.162 l
1 salma = 290.944 l

Marokko *v.* Morocco.

Mauritius and Seychelles Islands.—m.c. Older = old French, British, and the following:

Capacity

1 cash = 227.11 l
1 velt = $\frac{1}{30}$ cash

Mexico.—m.c. 1896; m.o. 1857. Older (from Spanish, Castillian), legally defined, during *transition period, in terms* of metric equivalents:

Length

1 vara = 0.838 m
Unit Vara
1 linea = $\frac{1}{432}$
1 pulgada = $\frac{1}{36}$
1 pie = $\frac{1}{3}$
1 legua = 5000

Mass

1 libra = 460.246 34 g
Unit Libra
1 tomin = $\frac{1}{768}$
1 adarme = $\frac{1}{256}$
1 ochava = $\frac{1}{128}$
1 onza = $\frac{1}{16}$
1 arroba = 25
1 quintal = 100
1 tercio = 160

Area

1 fanega = 356.628 a
Unit Fanega
1 caballeria = 12
1 labor = 18
1 sitio = 492.28

Capacity, dry

1 cuartillo = 1.8918 l
Unit Cuartillo
1 almud = 4
1 fanega = 48
1 carga = 96

Capacity, liquid

1 cuartillo = 0.456 264 l
1 cuartillo for oil = 0.506 162 l
1 jarra = 18 cuartillos

Morocco.—m.o.; local, var.:

Length

$\left.\begin{array}{l}\text{1 cubit}\\\text{1 canna}\end{array}\right\}$ = 0.533 m
1 pic = 0.61 m
1 tonni = $\frac{1}{8}$ pic

Mass

$\left.\begin{array}{l}\text{1 rotal}\\\text{1 artal}\end{array}\right\}$ = 507.5 g
1 gerbe = 3 kg
1 kula = 22 rotal
1 kantar = 100 rotal

Capacity

$\left.\begin{array}{l}\text{1 sahh}\\\text{1 fanega}\end{array}\right\}$ = 56 l
$\left.\begin{array}{l}\text{1 mudd}\\\text{1 almude}\end{array}\right\}$ = 14 l

Mozambique *v.* Portuguese East Africa.

Netherlands.—m.c. 1820, with the names:

Length

streep = mm
duim = cm
palm = dm
elle = m
roede = dkm
mijle = km

Mass

korrel = dg
wigtje = g
lood = dkg
once = hg
pond = kg

Capacity, dry

maatje = dl
kop = l
schepel = dkl
mudde = hl
zak = hl
last = 30 hl

Capacity, liquid

vingerhoed = cl
maatje = dl
kan = l
dekaliter = dkl
vat = hl

Old national system is more or less current in some of the old colonies:

Length

(Amsterdam)

1 roeden = 3.679 77 m
1 elle = 0.687 813 m
1 voeten = 0.283 0594 m
1 duime = 25.733 mm
1 lyne = 2.144 mm

Mass

1 pond = 492.16772 g
1 pond* = 494.090 32 g

---

* The old shaku (kujirajaku) = 1.25 shaku is legal for fabrics.

† One ri marin (kai-ri) = nautical ri.

* Amsterdam.

Netherlands.—*Cont'd.*

1 pond (Apothecary)
= $\frac{3}{4}$ pond
= 369.126 g

Unit	Pond
1 mark	= $\frac{1}{2}$
1 unze	= $\frac{1}{16}$
1 drachme	= $\frac{1}{128}$
1 engel	= $\frac{1}{320}$
1 vierling	= $\frac{1}{1280}$
1 grein	= $\frac{1}{7680}$

Area

1 morgen = 81.244 346 a

Capacity, dry

1 schepel = 27.26 l

Unit	Schepel
1 kop	= $\frac{1}{32}$
1 vierd	= $\frac{1}{4}$
1 zak	= 3
1 mud	= 4
1 last	= 108

Capacity, liquid

1 mingelen = 1.200 to 1.237 l

Unit	Mingelen
1 vat	= 768
1 oxhooft	= 192
1 aam	= 128
1 anker	= 32
1 steekan	= 16
1 stoop	= 2
1 pint	= $\frac{1}{2}$
1 mutsje	= $\frac{1}{8}$

Nicaragua *v.* Costa Rica.

Niederlande *v.* Netherlands.

Northern Ireland *v.* Great Britain.

Norway.—m.c. 1882; m.o. 1879. Older differed very little from Danish; legal equivalents:

Length

1 fod = 0.3137 m

Mass

1 skaalpund = 0.4981 kg

Area

1 mal = 10 a

Capacity, dry

1 korntonde = 138.97 l

Capacity, liquid

1 pot = 0.9651 l

Oceania.—British measures.

Olanda *v.* Netherlands.

Österreich *v.* Austria.

Paési Bássi *v.* Netherlands.

Panama.—Metric compulsory.

Paraguay.—Metric almost exclusively used. m.o. 1899. Older = Spain; legal equivalents:

Length

1 vara (old) = 0.838 56 m
1 cuerda, 1 cordel = 83$\frac{1}{3}$ vara = 69.88 m
1 vara = 0.866 m

Unit	Vara
1 piede	= $\frac{1}{3}$
1 pouce	= $\frac{1}{36}$
1 ligne	= $\frac{1}{432}$
1 cuadra	= 100
1 lieue	= 5000

Mass

1 libra (old) = 460.08 g
1 libra = 459 g

Unit	Libra
1 once	= $\frac{1}{16}$
1 arrobe	= 25
1 quintal	= 100
1 tonne	= 2000

Area

1 liño (old) = 48.832 a
1 liño = 100 vara^2
1 liño = 75 m^2

Capacity, dry

1 fanega = 288 l
1 almude = $\frac{1}{12}$ fanega

Capacity, liquid

1 frasco = 3.029 l

Unit	Frasco
1 cuarta	= $\frac{1}{4}$
1 baril	= 32
1 pipe	= 192

Pays-Bas *v.* Netherlands.

Persia.—Metric is in process of adoption. By 1924 the following assimilation had occurred: 1 zar = 1 m, 1 dram = 1 g, 1 ralte = 1 l. National measures, provincial, var.; even today, in retail commerce, cereal grains are used as weights:

Length

1 guerze (common) = 0.63 to 0.97 m
= 1 monkelzer
1 zar = 1.04 m

Unit	Zar
1 gireh	= $\frac{1}{16}$
1 ouroub	= $\frac{1}{8}$
1 charac	= $\frac{1}{4}$
1 gez 1 guerze	= 1
1 farsakh 1 parasang	= 6000

Mass

1 miskal = 4.60 g

Unit	Miskal
1 una	= $\frac{1}{384}$
1 gandum 1 grain	= $\frac{1}{96}$
1 abbas	= $\frac{1}{25}$
1 nakhod 1 carat	= $\frac{1}{24}$
1 dung	= $\frac{1}{6}$
1 dartung	= 0.22
1 dirhem	= 2
1 sir	= 16
1 pinar	= 20
1 danar	= 40
1 abbassi	= 80
1 rottel	= 100
1 tcheirek	= 160
1 saddirham	= 320
1 batman (Tauris)	= 640
1 batman (Shirez)	= 1280
1 batman	= 600 to 1000
1 karvar	= 100 batman

Area

1 jerib = 1082 m^2 to 1153 m^2
= 1000 to 1066 zar^2

Capacity

1 chenica = 1.32 l

Unit	Chenica
1 sextario	= 0.25
1 capichas	= 2
1 sabbitha	= 5.5
1 colluthun	= 6.25
1 legana	= 30
1 artaba	= 50

Peru.—m.c. 1869. Older (from Spanish, Castillian):

Length

1 vara = 0.835 98 m

Mass

1 libra = 460.09 g

Unit	Libra
1 arroba	= 25
1 quintal	= 100
1 fanega	= 140

Area

1 topo = 27.06 a
1 fanegada = 64.596 a

Philippine Islands.—m.c. 1860. Older = Spain. Local:

Mass

1 catty = about 600 g

Unit	Catty
1 punto	= $\frac{1}{3}$
1 chinanta	= 10
1 lachsa	= 48
1 caban	= 97
1 pecul	= 100

Area

1 balita = 27.95 a

Unit	Balita
1 loan	= 0.1
1 quignon	= 10

Capacity

1 kaban = 99.90 l
1 chupa = 3.75 cm^3
1 ganta = $\frac{1}{25}$ kaban
1 apatan = $\frac{1}{4}$ chupa

Poland.—Metric in process of adoption; in some provinces it has been in use since 1872. Russian system legalized in 1849, without displacing national measurements. Since 1819 these have been defined by their metric equivalents. National:

Length

1 stopa = 0.288 m

Unit	Stopa
1 linja	= $\frac{1}{144}$
1 cal	= $\frac{1}{12}$
1 lokiec	= 2
1 sazen	= 6
1 pret	= 15

Old measures

1 pied (Warsaw) = 0.2978 m
1 pied (Cracow) = 0.3564 m
1 aune = 0.620 m

Mass

1 funt = 405.504 g

Unit	Funt
1 gran	= $\frac{1}{9216}$
1 skrupul	= $\frac{1}{384}$
1 drachma	= $\frac{1}{128}$
1 lut	= $\frac{1}{32}$
1 uncja	= $\frac{1}{16}$
1 kamian	= 25
1 centnar	= 100

Old measures

1 funt = 404 g
1 centner = 16 funt
1 stein = 3.2 funt

Area

1 pret^2 = 18.6624 m^2
1 morga = 300 pret^2
1 wloka = 9000 pret^2

Capacity

1 kwarta = 1 l

Unit	Kwarta
1 kwarterka	= $\frac{1}{4}$
1 garniec	= 4
1 cwierc	= 32
1 korzec	= 128

Porto Rico.—m.c. 1860. Older = Spain:

Area

1 cuerdo = 2250 vara^2
= 15.72 a

Portugal.—m.c. 1872; m.o. 1852. Older:*

Length

1 pe = 0.3285 m
1 estadio = 258 m
1 milha = 8 estadio
1 legoa = 24 estadio

---

* In some of the older colonies the old Portuguese system, more or less modified, is still in use.

Unit Pe
1 linha = $\frac{1}{144}$
1 pollegada = $\frac{1}{12}$
1 palmo = $\frac{2}{3}$
1 covada = 2
1 vara = $\frac{10}{3}$

Mass

1 libra* = 459 g
Unit Libra
1 grao = $\frac{1}{9216}$
1 escrupulo = $\frac{1}{384}$
1 outava = $\frac{1}{128}$
1 onca = $\frac{1}{16}$
1 marco }
1 meio } = $\frac{1}{2}$
1 arratel = 1
1 arroba = 32
1 quintal = 128

Area

1 vara^2 = 1.2 m^2
Unit Vara^2
1 ferrado = 605
1 geira = 4840

Capacity, dry

1 fanga = 54 l
Unit Fanga
1 outava = $\frac{1}{32}$
1 quarto = $\frac{1}{16}$
1 meio = $\frac{1}{8}$
1 alqueira = $\frac{1}{4}$
1 moio = 15

Capacity, liquid

1 almude = 16.5 l
Unit Almude
1 quartillo = $\frac{1}{48}$
1 meio = $\frac{1}{24}$
1 canada = $\frac{1}{12}$
1 alqueira = $\frac{1}{6}$
1 bota }
1 pipa } = 26
1 tonelada = 52

Portuguese Colonies.—Metric compulsory.

Portuguese East Africa (Mozambique).—m.c. 1910. Older, mainly of Portugal; one bahar is considered equivalent to 109 kg.

Prussia *v.* Germany.

Rumania.—m.c. 1884; m.o. 1866. In old Bessarabia, Russian measures replaced by metric in 1922. Older:

Length

1 halibiu = 0.701 m
1 endere = 0.662 m
1 stringene = 1.96 m

Mass

1 cantar = *ca.* 56 kg
1 oke = $\frac{1}{44}$ cantar

Capacity

1 dimerla = 24.6 l
Unit Dimerla
1 oke = $\frac{1}{16}$
1 mirze = 8
1 kilo = 16

Capacity, liquid

1 viacka = 14.15 l
1 oke = 0.1 viacka

Russia.—m.o. 1900. Definitions of fundamental national units: *Length:* Archine is distance at 17°C between the axes of two lines drawn on the platinum-iridium prototype marked "H 1894." *Mass:* Fount is mass of the platinum-iridium prototype marked "H 1894." *Capacity, liquid:* Vedro is volume of 30 founts of pure water at $16\frac{2}{3}$°C. *Capacity, dry:* Garnetz is $\frac{4}{15}$ vedro.

Length

1 archine = 0.711 200 m
1 totchka = 0.254 0000 mm
Unit Totchka
1 ligne = 10
1 paletz = 50
1 sotka = 84
1 duïme = 100
1 verchoc = 175
1 foute = 1200
1 archine = 2800
Unit Archine
1 sagène = 3
1 verste = 1500

Mass (1) *Ordinary*

1 fount = 409.51241 g
1 doli = 44.434 9403 mg
Unit Doli
1 sol }
1 zolotnik } = 96
1 lote = 288
1 once = 576
1 lana = 768
1 fount = 9216
Unit Fount
1 poud = 40
1 berkovets = 400
1 tonne marine = 2400

Mass (2) *For drugs*

Unit Doli
1 grain = 1.4
1 scrupule = 28
1 drachme = 84
1 once = 672
1 livre = 8064

Area

1 archine^2 = 0.505 8054 m^2
1 ligne^2 = 6.451 600 mm^2
Unit Ligne^2
1 duïme^2 = 100
1 verchoc^2 = 306.25
1 foute^2 = 14 400
1 archine^2 = 78 400
Unit Archine^2
1 sagène^2 = 9
1 déciatine = 21 600
1 verste^2 = 2 250 000

Volume

1 archine^3 = 0.359 7288 m^3
1 ligne^3 = 16.387 06 mm^3
Unit Ligne^3
1 duïme^3 = 1000
1 verchoc^3 = 5359.375
1 foute^3 = 1 728 000
1 archine^3 = 21 952 000
Unit Archine^3
1 sagène^3 = 27
1 tonne marine = 7.871 72
1 last marin = 15.743 44

Capacity, dry

1 garnetz = 3.279 842 l
1 tchast = 0.109 328 07 l
Unit Tchast
1 polougarnetz = 15
1 garnetz = 30
1 lof = 592
Unit Garnetz
1 tchetverik = 8
1 polouosmina = 16
1 osmina = 32
1 tchetvert = 64

Capacity, liquid

1 vedro = 12.299 41 l
1 tcharka = 0.122 9941 l
Unit Tcharka
1 chkalik = 0.5
1 bottle (vodka) = 5
1 bottle (wine) = 6.25
1 krouchka = 10
1 shtoff = 12.5
1 vedro = 100
Unit Vedro
1 stekar = 1.5
1 anker = 3
1 pipe = 36
1 fass }
1 botchka } = 40

Salvador *v.* Costa Rica.

Schottland *v.* Great Britain.

Schweden *v.* Sweden.

Schweiz *v.* Switzerland.

Scotland, Scozia *v.* Great Britain.

Serbie-Croatie-Slovénie *v.* Yugoslavia.

Seychelles Islands *v.* Mauritius.

Siam.—m.c. 1923; m.o. 1889. Older now defined by metric equivalents; those of transition period:

Length

1 wah = 2 m
Unit Wah
1 anukabiet = $\frac{1}{768}$
1 kabiet = $\frac{1}{384}$
1 niou = $\frac{1}{96}$
1 keup = $\frac{1}{8}$
1 sawk }
1 sock } = $\frac{1}{4}$
1 ken = $\frac{1}{2}$
1 sen = 20
1 roeneng = 2000
1 yote = 8000

Mass

1 tchang* = 1200 g
Unit Tchang
1 klom = $\frac{1}{10240}$
1 klam = $\frac{1}{5120}$
1 pai = $\frac{1}{2560}$
1 sompay }
1 grani } = $\frac{1}{1280}$
1 fuang = $\frac{1}{640}$
1 salung = $\frac{1}{320}$
1 baht = $\frac{1}{80}$
1 tamlung = $\frac{1}{20}$
1 doon = 20
1 hap = 50
1 bara = 400

Area

1 wah^2 = 4 m^2
1 ngan = 100 wah^2
1 rai = 400 wah^2

Capacity

1 tanan† = 1 l
Unit Tanan
1 niou = $\frac{1}{100}$
1 chai meu = $\frac{1}{32}$
1 kam meu = $\frac{1}{8}$
1 laang }
1 chang awn } = $\frac{1}{2}$
1 kanahn = 1
1 sat = 20
1 tang = 40
1 tamlaum = 400
1 seste = 800
1 ban = 1600
1 kwien }
1 koyan } = 2000 or 3200
1 cohi = 32 000

Siria *v.* Syria.

Somaliland.—m.o.; local, vary with material and province:

Length

1 top = 3.92 m
1 cubito = $\frac{1}{7}$ top

Mass

1 rottolo = 448 g

---

* For drugs 1 libra = $\frac{3}{4}$ libra = 344.25 g.

* Previously, 1 tchang = 600 to 1300 g.

† Previously, 1 tanan = 0.9 to 1.2 liter.

Somaliland.—*Cont'd.*

Unit	Rottolo
1 okia	= $\frac{1}{16}$
1 frasla	= 36
1 gisla	= 360

Area

1 darat = 80 a

Capacity, dry

1 chela = 1.359 l

Unit	Chela
1 tabla	= 15
1 gisla	= 120

Capacity, liquid

1 caba = 0.453 l

Soudan *v.* Sudan.

South Africa *v.* Union of South Africa

Spain.—m.c. 1860. Older,* var., provincial; Castillian:

Length

1 vara = 0.835 905 m

(Other vara comprised between 0.768 m and 0.912 m)

Unit	Vara
1 punto	= $\frac{1}{6912}$
1 linea	= $\frac{1}{576}$
1 diedo	= $\frac{1}{48}$
1 pulgada	= $\frac{1}{36}$
1 sesma	= $\frac{1}{6}$
1 palma	= $\frac{1}{4}$
1 pie	= $\frac{1}{3}$
1 codos	= $\frac{1}{2}$
1 passo	= $1\frac{2}{3}$
1 estado	= 2
1 estadal	= 4
1 milla †	= $1666\frac{2}{3}$
1 legua	= 5000 or 8000

Mass

1 libra = 460.093 g

(Other libra comprised between 350 g and 575 g)

Unit	Libra
1 grano	= $\frac{1}{9216}$
1 arienzo	= $\frac{1}{2304}$
1 tomin	= $\frac{1}{768}$
1 dinero	= $\frac{1}{384}$
1 adarme 1 dracma	= $\frac{1}{256}$
1 ochava 1 caracter	= $\frac{1}{128}$
1 escrupulo	= $\frac{3}{64}$
1 onza	= $\frac{1}{16}$
1 marco	= $\frac{1}{2}$
1 arroba	= 25
1 barril	= 50
1 quintal	= 100
1 quintalmacho	= 150
1 tonelada	= 2000

Area

1 vara^2 = 0.698 7372 m^2

Unit	Vara^2
1 cuartilla	= 25
1 calemin	= 768
1 aranzada	= 6400
1 fanega 1 fanegada	= 9216
1 yugada	= 460 800

Capacity, dry

1 fanega = 55.501 l

Unit	Fanega
1 ochavillo	= $\frac{1}{768}$
1 racion	= $\frac{1}{192}$
1 cuartillo	= $\frac{1}{48}$
1 medio	= $\frac{1}{24}$
1 calemin	= $\frac{1}{12}$
1 almude	= $\frac{1}{12}$
1 cuartilla	= $\frac{1}{4}$
1 cahiz	= 12

Capacity, liquid

(Arroba was defined as volume of 34 libra of river water. The arroba for oil was volume of 25 libra of oil)

1 arroba (wine) = 16.133 l

1 arroba (oil) = 12.563 l

Unit	Arroba
1 copas	= $\frac{1}{128}$
1 quarterone 1 panilla*	= $\frac{1}{100}$
1 libra 1 cuartillo	= $\frac{1}{32}$
1 azumbre	= $\frac{1}{8}$
1 cuartilla*	= $\frac{1}{4}$
1 cantara	= 1
1 moio	= 16
1 pipa	= 27
1 bota	= 30

Stati Uniti *v.* United States.

Straits Settlements *v.* British India.

Sud-Africaine, Union *v.* Union of South Africa.

Sudan.—Egyptian in use.

Suède *v.* Sweden.

Suisse *v.* Switzerland.

Svézia *v.* Sweden.

Svizzera *v.* Switzerland.

Sweden.—m.c. 1889; m.o. 1879. Older:

Length

1 fot = 0.296 90 m

Unit	Fot†
1 linie	= $\frac{1}{144}$
1 tum	= $\frac{1}{12}$
1 alm	= 2
1 famm	= 6
1 stang	= 16
1 ref	= 100 or 160
1 mil	= 18 000

Mass

1 skälpund = 425.076 g

Unit	Skälpund
1 as	= $\frac{1}{8848}$
1 quintin	= $\frac{1}{128}$
1 lod	= $\frac{1}{32}$
1 untz	= $\frac{1}{16}$
1 lispund	= 20
1 sten	= 32
1 centner	≐ 100 or 120
1 waag	= 165
1 skeppund	= 400
1 nyläst	= 12 000

Area

1 fot^2 = 0.088 149 61 m^2

1 kappland = 1.542 618 17 a
= 1750 fot^2

1 ref^2 = 8.814 961 a

1 tunland = 49.363 781 6 a
= 56 000 fot^2

Capacity, dry

1 kanna = 2.617 l

Unit	Kanna
1 ort	= $\frac{1}{32}$
1 junkfra	= $\frac{1}{32}$
1 quarter	= $\frac{1}{8}$
1 stop	= $\frac{1}{2}$
1 kappar	= $\frac{7}{4}$
1 fjerdingar	= 7
1 spanna	= 28
1 tunna	= 56
1 koltunna	= 63
1 kolläst	= 756

Capacity, liquid

1 kanna = 0.1 fot^3
= 2.617 162 l

Unit	Kanna
1 jungfrur 1 jungfer	= $\frac{1}{32}$
1 quarter	= $\frac{1}{8}$
1 stop	= $\frac{1}{2}$
1 ankar	= 15
1 eimer	= 30
1 am 1 ohm	= 60
1 oxhufud 1 oxhoft	= 90
1 pipe	= 180
1 fuder	= 360

Switzerland.—m.c. 1877; m.o. 1868. Older, var.; during transition were fixed as follows:

Length

1 pied, 1 fuss = 30 cm

Unit	Pied
1 ligne 1 linie	= $\frac{1}{144}$
1 pouce 1 zoll	= $\frac{1}{12}$
1 aune 1 elle	= 2
1 toise 1 ruthe	= 6
1 perche	= 16
1 lieue	= 16 000

Mass (1) Ordinary

1 livre = 500 g

Unit	Livre
1 loth	= $\frac{1}{32}$
1 once	= $\frac{1}{16}$

Mass (2) For medicine

1 livre = 375 g

Unit	Livre
1 grain	= $\frac{1}{5760}$
1 scruple	= $\frac{1}{288}$
1 drachme	= $\frac{1}{96}$
1 once	= $\frac{1}{12}$

Syria.—m.o.; current:

Length

1 pic = 0.582 m

Mass

1 rottolo = 1785 g

Unit	Rottolo
1 drachme 1 pesi	= $\frac{1}{600}$
1 metecali	= $\frac{1}{400}$
1 mitcal	= $\frac{1}{400}$
1 once	= $\frac{1}{60}$
1 zurbo	= 27.5
1 cola	= 35
1 cantar	= 100

Capacity

1 rotl = 3.2 l

Unit	Rotl
1 makuk	= 250
1 garava	= 450

Tchéco-Slovaquie *v.* Czechoslovakia.

Tonkin.—Same as Anam (*q.v.*)

Tripoli and Cyrenaïca.—m.o., current defined by metric equivalents:

Length

1 pik = 0.68 m
= 1 handaze

1 palmo = $\frac{1}{3}$ pik

1 draa = 0.46 m

Mass

1 rottolo = 512.8 g

1 oka = 2.5 rottolo
= 1282 g

1 metical = 4.76 g

Unit	Rottolo
1 kharouba	= $\frac{1}{2560}$
1 dram	= $\frac{1}{160}$
1 termino	= $\frac{1}{128}$
1 uckin	= $\frac{1}{16}$
1 mattaro	= 42
1 cantar	= 100

Area

1 pik^2 = 0.4624 m^2

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* Old national system, more or less modified, is still in use in the old Spanish colonies.

† Milla = 5000 pie.

* Oils.

† The fot is also divided into decimals.

Unit Pik^2
1 denum = 1600
1 jabia = 1800

Capacity, dry

1 orba = 7.6 l
Unit Orba
1 nufsorbah = $\frac{1}{2}$
1 temen = 4
1 ueba = 16

(Measured by weight)

1 oka = 1282 g
1 marta = 11 to 14 oka
1 kele = 2 marta

Capacity, liquid

1 barile = 64.8 l
1 bozze = $\frac{1}{24}$ barile

(Measured by weight)

1 oka = 1282 g
Unit Oka
1 gorraf = 9.75
1 giarra = 58.5

Tschechoslovak *v.* Czechoslovakia.

Tunis.—m.c. 1895. Current:

Length

1 pic arabe = 48.8 cm
1 pic turc = 63.7 cm
1 pic endazé = 67.3 cm

The pic used depends upon the object measured.

Mass

1 uckir = 31.495 g
Unit Uckir
1 rottolo attari = 16
1 rottolo sucki = 18
1 rottolo khaddari = 20
1 cantaro = 100

Capacity

1 cafisso = 496 l
1 millerole (Marseilles) = *ca.* 64 l
Unit Cafisso
1 saah = $\frac{1}{129}$
1 whiba = $\frac{1}{16}$

Turkestan.

Length

1 hasch = 0.7112 m
Unit Hasch
$\left.\begin{array}{l}\text{1 archine*}\\ \text{1 altschin}\end{array}\right\} = 1$

Mass

1 batman = 125 kg to 128 kg
Unit Batman
1 sir = $\frac{1}{8}$
1 tscharik = $\frac{1}{64}$
1 mimtscha = $\frac{1}{256}$

Turkey.—m.o.; current, var.:

Length

1 archine = 64 to 76 cm
1 archine (for architecture) = 75.77 cm
1 nul = 1 km
Unit Archine
1 nocktat = $\frac{1}{3456}$
1 hatt = $\frac{1}{288}$
1 parmack = $\frac{1}{24}$
1 ouromb = $\frac{1}{8}$
1 pic = 1

Mass

1 oka = 1283 g
Unit Oka
1 karat = $\frac{1}{6400}$
1 denke = $\frac{1}{1600}$
$\left.\begin{array}{l}\text{1 dirhem}\\ \text{1 drachme}\end{array}\right\} = \frac{1}{400}$
1 miskal = $\frac{3}{800}$
$\left.\begin{array}{l}\text{1 cequi}\\ \text{1 yusdrum}\end{array}\right\} = \frac{1}{4}$
1 rottel = 0.44
1 batman = 6
1 kantar = 44
1 tcheki = 176 to 195

Area

$\text{1 deunum} \left\{\begin{array}{l} = \text{1600 archine}^2\\ = \text{913 m}^2\end{array}\right.$
1 djeril = 100 a

Capacity

1 kile = 32 to 43 l
1 zira^3 = 0.435 m^3
Unit Kile
1 chinik = $\frac{1}{4}$
1 fortin = 4

Ungarn, Ungheria *v.* Hungary.

Union of South Africa.—Metric, British, and old Dutch:

Length

1 elle = 0.685 m

Mass

1 bundle = 3175 g

Area

1 morgen = 85.5 a

Capacity

1 gantang = 9.2 l
1 balli = 5 gantang
1 muid = 109.1 l
1 legger = 516 l
Unit Legger
1 kanne = $\frac{1}{388}$
1 ahm = $\frac{1}{4}$

United States of America.—m.o. 1866; m.c. for certain governmental purposes. Fundamental units of national system are defined in terms of metric units. For less common and obsolescent units, see Great Britain.

Length

1 yard (yd.) = $\frac{3600}{3937}$ m
= 0.914 401 83 m
1 foot (ft.) = $\frac{1}{3}$ yd.
= 30.480 061 cm
1 inch (in.) = $\frac{1}{36}$ yd.
= 2.540 005 08 cm
Unit Inch
1 mil = 0.001
1 hand = 4
1 span = 9
1 foot = 12
1 yard = 36
Unit Foot
1 fathom = 6
$\left.\begin{array}{l}\text{1 rod}\\ \text{1 pole}\\ \text{1 perch}\end{array}\right\} = 16.5$
1 chain* (Gunther's) = 66
1 chain* (engineer's) = 100
1 bolt = 120
1 furlong = 660
1 cable length = 720
1 mile (statute) = 5280
1 mile (nautical)† = 6080.20
1 league (statute) = 3 st. mile
1 league (nautical) = 3 n. mile

Mass

1 pound avoirdupois (lb. av.) = 453.592 4277 g
= 7000 grain (gr.)
1 grain = 64.798 918 24 mg

(Three systems: avoirdupois, troy, apothecary.)

Avoirdupois (av.)

(General use)

Unit Pound
1 dram (dr.) = $\frac{1}{256}$
1 ounce (oz.) = $\frac{1}{16}$
1 hundred-weight (cwt.) (long) = 112
1 ton (short) (sh. tn.) = 2000
1 ton (long) (l. tn.) = 2240

Troy (t.)

(For precious metals)

Unit Grain
1 pennyweight (dwt.) = 24
1 ounce (oz.) = 480
1 pound (lb.) = 5760

Apothecary (ap.)

(For dispensing drugs)

Unit Grain
1 scruple (s. or ℈) = 20
1 dram (dr. or ʒ) = 60
1 ounce (oz. or ℥) = 480
1 pound (lb.) = 5760

Area

1 inch^2 (sq. in.) = 6.451 6258 cm^2
1 foot^2 (sq. ft.) = 929.0341 cm^2
1 yard^2 (sq. yd.) = 0.836 130 71 m^2
1 acre (A.) = 4046.873 m^2
Unit Foot^2
1 inch^2 = $\frac{1}{144}$
1 yard^2 = 9
Unit Yard^2
$\left.\begin{array}{l}\text{1 rod}^2\text{ (sq. rd.)}\\ \text{1 perch}\end{array}\right\} = 30.25$
1 chain^2* = 484
1 rood = 1210
1 acre (A.) = 4840
Unit Acre
1 mile^2 (sq. mi.) = 640
1 township† = 23 040

Volume

1 yard^3 (cu. yd.) = 0.764 559 45 m^3
1 foot^3 (cu. ft.) = 28 317.0 cm^3
1 inch^3 (cu. in.) = 16.387 162 cm^3
Unit Foot^3
1 inch^3 = $\frac{1}{1728}$
1 board foot (bd. ft.) = $\frac{1}{12}$
1 yard^3 = 27
1 shipping ton = 40
1 register ton = 100
1 cord (cd.) = 128

Capacity, dry

1 bushel (bu.) = 2150.42 inch^3
= 35.238 329 l
Unit Bushel
1 pint (pt.) = $\frac{1}{64}$
1 quart (qt.) = $\frac{1}{32}$
1 peck (pk.) = $\frac{1}{4}$
1 barrel‡ (bbl.) = 3.281
1 chaldron§ = 36
1 firkin = 9 gallon

Capacity, liquid

$\text{1 gallon (gal.)} \left\{\begin{array}{l} = \text{231 inch}^3\\ = \text{3.785 332 l}\end{array}\right.$
1 minim (min. or ♏) = $\frac{1}{61440}$ gal.
= 0.061 6102 ml
Unit Minim
1 fluid dram (fl. dr.) = 60
1 fluid ounce (fl. oz.) = 480
1 gill (gi.) = 1920

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* Russian.

* 1 link = 0.01 chain.
† 1 nautical mile = 1853.249 m

* Gunther's chain.
† 36 mile^2.
‡ For dry commodities, except cranberries, barrel = 7056 inch^3; cranberry barrel = 5826 inch^3; lime barrel contains 180 lb. av. or 280 lb. av.; by custom, flour barrel = 196 lb. av.
§ Variable.

United States.—*Cont'd.*

Unit	Gallon
1 gill (gi.)	= $\frac{1}{32}$
1 pint (pt.)	= $\frac{1}{8}$
1 quart (qt.)	= $\frac{1}{4}$
1 barrel*	= 31.5
1 hogshead	= 63

Uruguay.—m.c. 1894; m.o. 1866. Older = Spain (Castillian), more or less modified.

Venezuela.—m.c. 1914; m.o. 1857. Older = Spain (Castillian), more or less modified, and the following of Granada:

Length

1 vara = 0.8 m
1 meile = 6280 vara

Mass

1 libra = 1 kg
1 bag = 62.5 kg

Vereinigte Staaten *v.* United States.

Württemberg *v.* Germany

Yugoslavia.—m.c. 1883. Older:

Length

1 linija = 21.95 mm
1 palaz = 36.34 mm
1 archine = 660 mm to 712 mm
1 khvat = 1.896 m
1 stopa = $\frac{1}{6}$ kvat

Mass

1 oka = 1280 g

Unit	Oka
1 dramm	= $\frac{1}{400}$
1 satlijk	= $\frac{1}{4}$
1 litra	= $\frac{1}{4}$
1 akov	= 40
1 tovar	= 100

Area

1 stopa^2 = 998.56 cm^2

Unit	m^2
1 dunum	= 700
1 motyka	= 800
1 raliza	= 2500
1 dan oranja	= 3597
1 lanaz	= 5760 = 1600 khvat^2

Capacity

(Liquids are measured by weight.)

C. SYSTEMS OF ANTIQUITY

Our knowledge of the measures of antiquity is derived from the texts and monuments which have persisted to modern times, and some actual standards which have come down to us. The latter enable us to establish quite exact equivalence between the measures which they represent and ours. But most frequently such equivalence is only very roughly known, or is actually unknown. In this section are given only the more important or the best studied of these systems. The values given must not be taken too literally. Indeed, especially in antiquity, systems do not succeed one another; they evolve. Several may coexist among a single people; it is generally impossible to fix the dates at which these systems were used. The ancients had no capacity measures, such as ours; they weighed liquids and grains in terms of standards forming a second system of weights.

Arabian System.

Length

1 foot = 0.320 m

Unit	Foot
1 assbaa (finger)	= $\frac{1}{16}$
1 cabda (palm)	= $\frac{1}{4}$
1 cubit (new)	= $1\frac{1}{2}$
1 cubit†	= 2
1 orgye (pace)	= 6
1 qasab	= 12
1 seir	= 600
1 ghalva	= 720
1 mille	= 6000
1 parasang	= 18 000
1 barid	= 72 000
1 veredus	
1 marhala	= 144 000

Mass

(So-called system of the Prophet)

1 rotl = 340 g

Unit	Rotl
1 dirhem	= $\frac{1}{120}$
1 nevat	= $\frac{1}{24}$
1 nasch	= $\frac{1}{6}$
1 oukia	= $\frac{1}{3}$
1 man	= 2
1 mine	
1 ocque	= 4
1 qanthar	= 100
1 kikkar	= 125

Area

1 feddan = 14 400 cubit^2†
= 59 a

Unit	Feddan
1 achir	= $\frac{1}{400}$
1 qasaba	
1 qamha	= $\frac{1}{96}$
1 habbah	= $\frac{1}{72}$
1 cafiz	= $\frac{1}{40}$
1 qirat	= $\frac{1}{24}$
1 daneq	= $\frac{1}{6}$
1 djarib	= $\frac{1}{4}$

Capacity

(Measured by weight)

1 cafiz = 32.64 kg

Unit	Cafiz
1 mudd	= $\frac{1}{48}$
1 kiladja	= $\frac{1}{24}$
1 caphite	
1 kist	
1 sâa	= $\frac{1}{12}$
1 makuk	= $\frac{1}{8}$
1 ferk	= $\frac{1}{4}$
1 woëbe	= $\frac{1}{2}$
1 khoull	
1 modius	= $1\frac{1}{4}$
1 artabe	= 2
1 amphora	
1 gariba	= 8
1 den	

Assyro-Chaldean-Persian System.

Length

1 foot = 0.320 m

Unit	Foot
1 finger	= $\frac{1}{16}$
1 palm	= $\frac{1}{4}$
1 zereth	= 1
1 cubit	= 2
1 pace	= 6
1 qasab	= 12
1 cane	
1 chebel	= 80
1 stadion	= 720
1 ghalva	
1 mille	= 5400
1 parasang	= 20 000
1 schoëme	= 21 600
1 stathmos	= 80 000
1 mansion	

Mass

1 talent = 32.6 kg
(Talent divided into 50, 60 or 100 mina)
1 drachma = 0.01 mina

Area

1 gar = 14.7 m^2
= 144 foot^2

Unit	Gar
1 dizaine	= 10
1 gan	= 100
1 gur	= 1000

Capacity

(Measured by weight)

1 amphora = 32.6 kg

Unit	Amphora
1 cados	= $\frac{1}{32}$
1 makuk	= $\frac{1}{8}$
1 woëbe	= $\frac{1}{2}$
1 modius	
1 small artaba	= $1\frac{1}{2}$
1 large artaba	= 2
1 large amphora	= 3
1 gariba	= 8

Egypt: System of the Pharaohs.

Length

1 pied = 0.349 m

Unit	Pied
1 doigt, finger	= $\frac{1}{16}$
1 theb	
1 palme	= $\frac{1}{4}$
1 choryos	
1 dichas	= $\frac{1}{2}$
1 spithame	= $\frac{3}{4}$
1 pied royal	= 1
1 zereth	
1 pigon	= $1\frac{1}{4}$
1 coudée royale	= $1\frac{1}{2}$
1 derah	
1 coudée longue	= 2
1 pas	= $2\frac{1}{3}$
1 xilon	= $4\frac{1}{2}$
1 orgye	= 6
1 canne	= $11\frac{2}{3}$
1 senus	= 150
1 stade	= 500 or 600
1 mille	= 5000
1 atour vulgaire	= 15 000
1 schoëme	= 18 000
1 parasange	= 20 000
1 atour royal	= 30 000

Mass

1 mine = 850 g

Unit	Mine
1 gerah	= $\frac{1}{1200}$
1 sicle	= $\frac{1}{60}$
1 kikkar	= 50
1 talent	

Area

1 pekeis = 27.405 m^2

Unit	Pekeis
1 coudée^2	= $\frac{1}{100}$
1 sû	= 6.25
1 dizaine	= 10
1 rema	= 50
1 aurure	= 100
1 aroure	
1 setta	= 1000

* Wine barrel.
† Hachemic.

Capacity

(Measured by weight)

1 khar = 34 kg

Unit	Khar
1 outen	= $\frac{1}{160}$
1 man 1 mine	= $\frac{1}{40}$
1 hecte	= $\frac{1}{16}$
1 apt	= $\frac{1}{4}$
1 keramion	= 1
1 metretes d'Héron	= $1\frac{1}{4}$
1 artabe des septante	= $1\frac{1}{2}$
1 artabe 1 letech	= $4\frac{7}{32}$

Greek System.

Length

1 pous* = 0.308 56 m

Unit	Pous
1 daktylos (finger)	= $\frac{1}{16}$
1 condylos	= $\frac{1}{8}$
1 palestra (palm)	= $\frac{1}{4}$
1 dichas	= $\frac{1}{2}$
1 spithame (span)	= $\frac{3}{4}$
1 cubit†	= $1\frac{1}{2}$
1 Grecian cubit	= 2
1 bema (pace)	= $2\frac{1}{2}$
1 orgyia	= 6
1 amma (corde)	= 60
1 plethron	= 100
1 stadion	= 600
1 mille	= 4500
1 kiloorgyia	= 6000

Mass

1 mina = 425 g

Unit	Mina
1 chalque	= $\frac{1}{4800}$
1 obol	= $\frac{1}{600}$
1 diobol	= $\frac{1}{300}$
1 drachma	= 0.01
1 tetradrachma	= 0.04
1 talent	= 60

Area

1 pous² = 0.095 209 m²

Unit	Pous²
1 dekapode²	= 100
1 plethron²	= 10 000

Capacity

(Measured by weight)

1 chenica = 816 g

Unit	Chenica
1 cyanthos	= $\frac{1}{24}$
1 oxybaphon	= $\frac{1}{16}$
1 cotyle	= $\frac{1}{4}$
1 sexte	= $\frac{1}{2}$
1 maris	= 2
1 choüs	= 3
1 hemiektos	= 4
1 hektos 1 modius	= 8
1 metretes	= 36
1 medimnos	= 48

Hebrew System.

Length

1 sacred cubit = 0.640 m

1 cubit* = 0.555 m

Unit	Cubit*
1 finger	= $\frac{1}{24}$
1 palm	= $\frac{1}{6}$
1 zereth	= $\frac{1}{2}$

Mass (Sacred system)

1 mina = 850 g

Unit	Mina
1 obol 1 gerah	= $\frac{1}{1200}$
1 rabah	= $\frac{1}{240}$
1 bekah	= $\frac{1}{120}$
1 shekel	= $\frac{1}{60}$
1 talent†	= 50

Mass (Talmudist or Rabbinical system)

1 mina = 354.2 g

Unit	Mina
1 pondiuscule	= $\frac{1}{1200}$
1 mehah 1 gerah 1 obol	= $\frac{1}{600}$
1 zuzah 1 drachma	= $\frac{1}{100}$
1 shekel 1 tetradrachma	= $\frac{1}{25}$
1 talent	= 60

Capacity, dry

(Measured by weight)

1 ephah (old) = 29.376 kg

1 ephah (new) = 21.420 kg

Unit	Ephah
1 log	= $\frac{1}{72}$
1 cab	= $\frac{1}{18}$
1 gomor	= 0.1
1 sath 1 modius	= 0.3
1 cor	= 10

Capacity, liquid

(Measured by weight)

1 bath (old) = 29.376 kg

1 bath (new) = 21.420 kg

Unit	Bath
1 log	= $\frac{1}{72}$
1 hin	= $\frac{1}{6}$
1 cor	= 10

Hindu System.

Length

1 hasta = 0.457 m

Unit	Hasta
1 angula (finger)	= $\frac{1}{24}$
1 vitasti (span)	= $\frac{1}{2}$
1 cubit	= 1
1 dhanush 1 orgyla	= 4
1 crosa	= 8000
1 gavyuti	= 16 000
1 yodjana	= 32 000

Mass

1 retti, 1 ratica = 0.147 g

1 pala = 47 g

Unit	Retti
1 yava	= 0.1
1 masha	= 2, 5, 6, or 8
1 tank-sala	= 24
1 kona	= 48
1 tola	= 80
1 karsha	= 96
1 dharana	= 32 (silver) 3200 (gold)
1 pala	= 320

Unit	Pala
1 tuba	= 100
1 hara	= 200
1 bara	= 2000
1 achita	= 20 000

Capacity

(Measured by weight)

1 drona = 13.2 kg

Unit	Drona
1 pala 1 musti	= $\frac{1}{256}$
1 cudava	= $\frac{1}{32}$
1 prastha	= $\frac{1}{16}$
1 adhaka	= $\frac{1}{4}$
1 cumbha (small)	= 2
1 shari	= 16
1 cumbha	= 20
1 baha	= 200

Persian System *v.* Assyrio-Chaldean-Persian.

Roman System.

Length

1 pes (common or Drusian) (foot) = 0.3196 m

1 legal pes (1st) = 0.2962 m

1 legal pes (2nd) = 0.2967 m

Unit	Pes
1 digitus (finger)	= $\frac{1}{16}$
1 uncia (inch)	= $\frac{1}{12}$
1 cubitus (cubit)	= $1\frac{1}{2}$
1 passus (pace)	= 5
1 decempeda (perch)	= 10
1 actus (chain)	= 120
1 millarium (mile)	= 5000

Mass

1 podium = 326 g

Unit	Podium
1 scrupulus	= $\frac{1}{288}$
1 denier*	= $\frac{1}{96}$
1 denier†	= $\frac{1}{90}$
1 denarius	= $\frac{1}{84}$
1 solidus 1 sextula	= $\frac{1}{72}$
1 miliaresium	= $\frac{1}{60}$
1 sicilium	= $\frac{1}{48}$
1 duella	= $\frac{1}{36}$
1 semuncia	= $\frac{1}{24}$
1 ounce	= $\frac{1}{12}$
1 mina	= $1\frac{2}{3}$
1 centum-podium	= 100

Area

1 common pes² = 0.102 14 m²

1 legal pes² (1st) = 0.087 73 m²

1 legal pes² (2nd) = 0.088 03 m²

Unit	Pes²
1 decempeda²	= 100
1 actus (small)	= 400
1 clima	= 3600
1 versum	= 10 000
1 actus	= 14 400
1 jugerum	= 28 800
1 heredium	= 57 600
1 centuria	= 5 760 000
1 saltus	= 23 040 000

Capacity, dry

1 sextarius = 544 g

Unit	Sextarius
1 modius	= 16
1 quadrantal	= 48
1 pes³‡ (of water)	= 48

Capacity, liquid

(Measured by weight)

1 sextarius, 1 sextus = 544 g

Unit	Sextarius
1 cyathus	= $\frac{1}{12}$
1 acetabulum	= $\frac{1}{8}$
1 quartus	= $\frac{1}{4}$
1 hemina	= $\frac{1}{2}$
1 congius	= 6
1 urna	= 24
1 amphora	= 48
1 culeus 1 dolium	= 960

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* The Olympic foot of Egyptian origin.

† Lapidary.

* Talmudist.

† Of Moses.

* Silver.

† Neronian.

‡ Legal pes (2).

SYMBOLS, BASIC CONSTANTS, CONVERSION DATA, DIMENSIONS, DEFINITIONS

BASES OF DATA CONTAINED IN I. C. T.

When many experts are cooperating in the assembling of data, it is essential that the same values for the fundamental constants and for the necessary conversion factors shall be employed by all. Consequently, at the very beginning of the work, the Editors compiled a set of accepted, or I. C. T., values for such constants and factors; and the Experts were instructed to base all their data upon these values. In the few cases in which it was not feasible to follow these instructions, the data were to be accompanied by a statement of the actual basis upon which they rest.

In compiling this list, and in choosing the accepted values of such of the quantities as were independently chosen, the Editors secured and utilized the advice of the United States Bureau of Standards, the National Physical Laboratory of Great Britain, and the Société Française de Physique. Acknowledgments are also due to Dr. F. E. Fowle, of the Smithsonian Institution, for his valued assistance in preparing the initial table of fundamental constants, and to Professors T. W. Richards and G. P. Baxter for their recommendations concerning the table of atomic weights.

The list so prepared comprised (1) a table of atomic weights (p. 43), (2) a set of nine basic constants (p. 17) (the estimated uncertainties were added at a later date), (3) twenty-one derived constants (computed directly from the nine basic constants), five conventional constants, and two experimental constants (p. 18) and (4) certain conversion factors selected from Tables 1 to 79 (p. 20–32). Although the accepted values were close approximations to the best values at that time available, it was not claimed that they were such best values.

SYMBOLS AND ABBREVIATIONS

Except as the contrary is definitely stated, the following symbols and abbreviations will always be used in the sense here indicated. Other symbols will be defined in the sections in which they are used. For those quantities which are included in the list of symbols approved by the International Association of Chemical Societies (*4*, **119**: 502; 21), the symbols so approved have, in general, been used; in some cases, this has necessitated the use of the same symbol to represent two distinct quantities; the context will serve to indicate which interpretation is correct. For explanations of the several technical terms, consult Selected Technical Terms, p. 34.

Å	Ångstrom unit
A.	Acre
A_n	Normal atmosphere
A_{45}	Atmosphere, 45° latitude
A	Atomic weight. Maximum work of a thermodynamic system
a	Are
(a)	Based on Int. ohm and Int. ampere as defined by silver voltameter. (*See* Int. elec. units, p. 27)
abs.	Absolute
ap.	Apothecaries
Av.	Average
av.	Avoirdupois
a	Van der Waal's pressure constant. Capillary constant.
BTU	British Thermal Unit
bbl.	Barrel
bd.	Board
bu.	Bushel
b	Van der Waal's volume constant
C	Centigrade
CTU	Centigrade thermal unit
C	Concentration. Molecular heat
C_1, C_2	Radiation constants of black body. (*See* definition of black body.)
C_i	Intensity coefficient. (*See* definition of black body.)
C_p, C_v	Molecular heat at constant pressure, at constant volume
c	Velocity of light in vacuo
c	Carat. Centi-
ca	Candle
ca.	*circa* = about, approximately
cal	Calorie (gram)
cd.	Cord
cf.	*Confer* = compare
cgs	Centimeter-gram-second system of units
cgse	Cgs electrostatic system
cgsm	Cgs electromagnetic system
ch.	Chain
cm	Centimeter
cm^2	Square centimeter
cm^3	Cubic centimeter
c.p.	Candle power
cu.	Cubic
cu. ft.	Cubic foot
cwt.	Hundredweight
c	Specific heat = heat capacity of the substance
c_p, c_v	Specific heat at constant pressure, at constant volume
D	Density
d	Derivative. Deci-
da	Day
deg	Thermometric degree, absolute C unless contrary is indicated
dk	Deka-
dm^3	Cubic decimeter
dr.	Dram
dwt.	Pennyweight
d	Density. Diameter
d_c	Critical density
$d^{t_2}_{t_1}$	Specific gravity at temperature t_{12}, with reference to water at temperature t_1
E	Electromotive force
E_0	Mean translational energy of molecule of ideal gas at 0°C
e	Electronic charge
e	Base of natural system of logarithms = 2.71828+
e.g.	*Exempli gratia* = for example
em	Cgsm unit of quantity of electricity
emf	Electromotive force
equiv	Electrochemical equivalent
es	Cgse unit of quantity of electricity
etc.	*Et cetera* = and so forth
et seq.	*Et sequentes* = and the following
c_0	Ratio of E_0 to T_0
F	Faraday
F	Fahrenheit
fath.	Fathom
fir.	Firkin
fl.	Fluid
fps	Foot-pound-second system of units
fpse	Fps electrostatic system
fpsm	Fps electromagnetic system
ft.	Foot
$ft.^2$	Square foot
$ft.^3$	Cubic foot
fur.	Furlong
G	Gravitation constant
g	Gram
gal.	Gallon
gi.	Gill
gr.	Grain
g	Acceleration due to gravity
g_s	Standard gravity
HP	Horse-power
H	Atomic weight of hydrogen
h	Planck's constant of action
h	Hecto-
ha	Hectare
hhd.	Hogshead
h.p.	Horse-power
hr	Hour
h	Height
Int.	International
I. C. T.	International Critical Tables
I	Electric current
ibid.	*Ibidem* = in the same place
i.e.	*Id est* = that is
in.	Inch
$in.^3$	Cubic inch
J	Radiance
J_λ	Intensity of monochromatic radiance of wave-length λ
J_m	Value of J_λ for $\lambda = \lambda_m$
K	Karat. Kelvin, or absolute C, scale of temperature
K	Constant of chemical equilibrium
k	Kilo-
kg	Kilogram
km	Kilometer
km^2	Square kilometer
k	Velocity coefficient of chemical reaction
k_0	Boltzmann's gas constant
L	Latent heat per mole
l	Liter
l.	Long
lat.	Latitude
lb.	Pound
li.	Link
liq.	Liquid
long.	Longitude
l	Length. Latent heat per gram
M	Molecular weight
$M[\alpha]$	Molecular rotatory power
$M[\omega]$	Molecular magnetic rotatory power
m_0	Mass of electron at low velocity
m	Meter. Milli-
m^2	Square meter
max.	Maximum
mg	Milligram
mi.	Mile
min	Minute

min.	Minim, Minimum
ml	Milliliter
mmf	Magnetomotive force
$m\mu$	Millimicron. Millimicro-
m	Mass
m_H	Mass of a hydrogen atom
N	Numeric
N_0	Avogadro's number
N_∞	Rydberg's universal series constant
n	Refractive index
n_a, n_k	Transport number for anion, kation
n_0	Loschmidt's number
O	Atomic weight of oxygen
oz.	Ounce
P	Pressure
pk.	Peck
pt.	Pint
p	Pressure
p_c, p_r	Critical pressure, reduced pressure
Q	Quantity
q	Quintal
qt.	Quart
q.v.	*Quod vide* = which see
R	Réaumur
R	Gas constant per mole of ideal gas. Electrical resistance.
rd.	Rod
r	Radius
r_G	Specific refractivity (Gladstone and Dale)
r_L	Specific refraction (Lorentz and Lorenz)
r_1	Radius of first Bohr ring, hydrogen
S.E.	Siemens unit
S	Entropy
s	Stere
s.	Scruple
sec	Second (mean solar unless contrary is stated)
sh.	Short
sq.	Square
sq. ft.	Square foot

T_0	Ice point, absolute C
T	Temperature on absolute C scale
T_c	Critical temperature, absolute C
t	Metric ton
t.	Troy
tn.	Ton
t	Time. Temperature C (above ice point)
t_c	Critical temperature C (above ice point)
U. S.	United States of America
V	Volume
V_0	Volume per gram-mole of ideal gas at 0°C and A_n
v.	*Vide* = see
(v)	Based on Int. ohm and Int. volt as defined by standard cell. (*See* Int. elec. units, p. 27.)
v	Volume
v_c, v_r	Critical volume, reduced volume
W	Electrical resistance
wt.	Weight
w	Wien's displacement constant
yd.	Yard
yr	Year
Z	Atomic number
α	Degree of dissociation. Angle of optical rotation
$[\alpha]$	Specific rotatory power
β	Specific heat constant
γ	Surface tension. Ratio of c_p/c_v. Gamma (magnetic unit)
Δ	Diffusion coefficient
ϵ	Dielectric constant. Electrode potential
ϵ_h, ϵ_c	Electrode potential above that of normal hydrogen, of normal calomel, electrode
η	Viscosity
θ	Angle (plane). Temperature C above ice point

κ	Susceptibility (magnetic). Electrical (volume) conductivity
Λ	Equivalent conductivity (electrical)
λ	Wave-length. $\lambda 5890$ = spectral line of wave-length = 5890Å
λ_m	Wave-length of maximum monochromatic radiance of black-body at stated temperature
μ	Permeability (magnetic). Micron, Micro-, Molecular conductivity (electrical)
$\mu\mu$	Micromicron. Micromicro-
ν	Frequency
ν_∞	Rydberg's fundamental frequency
π	Ratio of circumference of a circle to its diameter
σ	Stefan's constant (radiation)
φ	Fluidity. Angle
ψ	Luminous flux
Ω	Ohm
$[\Omega]$	Relative molecular magnetic rotatory power with reference to water
ω	Solid angle
$[\omega]$	Specific magnetic rotatory power

♏	Minim
℥	Apothecaries' ounce
ʒ	Apothecaries' dram
℈	Apothecaries' scruple
°	Degree (arc or temperature)
′	Minute of arc (sexagesimal)
″	Second of arc (sexagesimal)
%	Percent = per hundred
‰	Per thousand = 0.1 %
[ ]	Dimensional expressions are inclosed in [ ]. In text, [ ] is used to inclose a second reading. (*E.g.*, Length [diameter] of the bar is 10 cm [1 cm] = length of bar is 10 cm, diameter of bar is 1 cm)
$<$	$A < B$ [$A > B$] denotes that A is less than [greater than] B
$\nless$	Negative of $<$; $A \nless B$ denotes that A is not less than B
$\leq$	Combination of $<$ and $=$; $A \leq B$ denotes that A is equal to or less than, B
$\neq$	Is not equal to
$\equiv$	Identically equal to; used in defining symbols, etc.
$\cong$	Approximately (or essentially) equal to
∞	Infinity

FUNDAMENTAL CONSTANTS

By an *accepted*, *conventional*, or *defined* value, is meant one which is to be regarded as exactly correct for purposes of computation.[1] Thus, errors from computational approximations are avoided and do not enter into consideration in any future revision of the computed result for a discovered difference between the true and the accepted value. When the computation involves several accepted values, it is especially important that each shall be regarded as exactly correct, for only then can the result be independently revised (without complete recalculation) for changes in the values of each. For this reason the logarithms of the several accepted values are given to the full precision of Vega's seven-place table. The degree of uncertainty in the value accepted is indicated by the number of significant figures retained in the value itself, not by the logarithm.

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[1] In every computation it is tacitly assumed that the values employed are exact. If but three digits are employed, it is assumed that all others are zero; if a computing machine is used, the assumption is carried out to the extreme limit of the machine; if logarithms are used, it is carried to the limit within which the logarithms are interpolated. To adopt an accepted or a conventional value, and to give as its logarithm an abbreviated value, is to introduce an ambiguity of a magnitude determined by the degree of abbreviation of the logarithm. But the sole object in adopting accepted or conventional values is to avoid ambiguity.

ACCEPTED BASIC CONSTANTS Units: cgs, °C, liter, A_n, absolute electric

	Quantity	Value	Uncertainty	Log_{10} (value)
c	Velocity of light	2.9986 × 10^{10} cm sec^{-1}	0.0003	10.476 9185
G	Gravitation constant	6.66 × 10^{-8} cm^3 g^{-1} sec^{-2}	0.01	$\overline{8}$.823 4742
e	Electronic charge	4.774 × 10^{-10} es	0.005	$\overline{10}$.678 8824
e	Electronic charge	*1.592 × 10^{-20} em	....	$\overline{20}$.201 9639
$\mathbf{e/m_0}$	Electronic ratio	5.305 × 10^{17} es g^{-1}	0.010	17.724 6854
$\mathbf{e/m_0}$	Electronic ratio	*1.769 × 10^7 emg^{-1}	....	7.247 7669
F	Faraday	9.6500 × 10^4 coulombs	0.0010	4.984 5273
F	Faraday	*2.893 65 × 10^{14} es	....	14.461 4458
$\mathbf{v_0}$	Volume 1 mole at 0°C, A_n	†22.4115 × 10^3 cm^3 mole^{-1}	0.002	4.350 4709
h	Planck's constant	6.554 × 10^{-27} erg sec	0.001	$\overline{27}$.816 5064
$\mathbf{T_0}$	Ice point, absolute	273.1 deg C	+0.15 to −0.05	2.436 3217
O	Atomic weight of oxygen	16.000 (by definition)	(definition)	1.204 1200

* This value is derived from the preceding one, which is the value actually accepted.

† Derived from volume at 0°C, A_{45} = 22.412 liters/g-mole on assumption $\log_{10}(A_n/A_{45}) = 0.000\ 0214$, liter = 1000.027 cm^3.

ACCEPTED CONSTANTS:—CONVENTIONAL AND NON-BASIC Units: cgs, °C, liter, A_n absolute electric, international angstrom

Quantity		Value	Log$_{10}$ (value)
	A. Derived Constants		
R	Gas constant	8.315×10^{7} erg deg^{-1} mole^{-1}	7.919 8658
R	Gas constant	0.082 06 liter atm deg^{-1} mole^{-1}	$\bar{2}.914$ 1375
R	Gas constant	1.9869 cal$_{15}$ deg^{-1} mole^{-1}	0.298 1703
N_0	Avogadro's number	6.061×10^{23} mole^{-1}	23.782 5634
n_0	Loschmidt's number	2.705×10^{19} cm^{-3} (at 0°C, A_n)	19.432 0925
k_0	Molecular gas constant	1.372×10^{-16} erg deg^{-1}	$\overline{16}.137$ 3024
E_0	Translational energy of molecules, 0°C	5.620×10^{-14} erg	$\overline{14}.749$ 7154
e_0	Ratio of E_0 to T_0	2.058×10^{-16} erg deg^{-1}	$\overline{16}.313$ 3937
m_H	Mass of hydrogen atom	1.663×10^{-24} g	$\overline{24}.220$ 7679
m_0	Electronic mass	8.999×10^{-28} g	$\overline{28}.954$ 1970
r_1	Radius 1st Bohr ring of hydrogen	0.5305×10^{-8} cm	$\bar{9}.724$ 6912
h/e	Photo-electric constant	1.373×10^{-17} erg sec es^{-1}	$\overline{17}.137$ 6240
h/e	Photo-electric constant	*4.117×10^{-15} volt sec	$\overline{15}.614$ 5425
hc/e	Photo-electric constant	4.117×10^{-7} erg cm es^{-1}	$\bar{7}.614$ 5425
hc/e	Photo-electric constant	1.2344×10^{4} volt Å	4.091 4610
β	Specific heat constant	4.778×10^{-11} sec deg	$\overline{11}.679$ 2040
σ	Stefan's constant	5.709×10^{-5} erg cm^{-2} sec^{-1} deg^{-4}	$\bar{5}.756$ 5416
C_1	Radiation constant, first	3.703×10^{-5} erg cm^{2} sec^{-1}	$\bar{5}.568$ 5233
C_2	Radiation constant, second	1.433 cm deg	0.156 1225
w	Wien's displacement constant	0.2885 cm deg	$\bar{1}.460$ 1933
C_j	Intensity coefficient	1.301×10^{-4} erg cm^{-3} sec^{-1} deg^{-5}	$\bar{4}.114$ 2762
v_∞	Rydberg frequency	3.2775×10^{15} sec^{-1}	15.515 5372
N_∞	Rydberg wave number	1.0930×10^{5} cm^{-1}	5.038 6187
	B. Conventional Constants		
A_n	Normal atmosphere	$1.0132\ 50 \times 10^{6}$ dyne cm^{-2}	6.005 7166
A_{45}	Atmosphere, latitude 45°	$1.0132\ 00 \times 10^{6}$ dyne cm^{-2}	6.005 6952
Å	Wave-length of red Cd line is	6438.4696 Å	4.808 7827
g_s	Standard gravity	980.665 cm sec^{-2}	2.991 5207
	Aberration constant	20.47″	1.311 1178
	C. Experimental Constants		
	Grating space in calcite	3.028 Å	0.481 1559
H	Atomic weight of hydrogen	1.0077	0.003 3313
	‡Liter	1000.027 cm^{3}	3.000 0117
	‡Gram calorie (20°C)	4.181 joule	0.621 2802
	‡Gram calorie (15°C)	4.185 joule	0.621 6955
	‡Gram calorie (mean)	4.186 joule	0.621 7992
	‡British Thermal Unit (39°F)	1060.4 joule	3.025 4697
	‡British Thermal Unit (mean)	1054.8 joule	3.023 1701
	‡British Thermal Unit (60°F)	1054.6 joule	3.023 0878
	‡International ohm	1.000 52 ohm	0.000 2259
	‡International ampere (v)§	0.999 90 ampere	0.999 9566
	‡International ampere (a)§	0.999 93 ampere	0.999 9696

* This value is derived from the preceding one, which is the value actually accepted.

‡ In the original list, this quantity was included solely in the list of conversion factors; its value, however, is an independently selected, *accepted* constant, and, consequently, is treated as exact in all computations.

§ (v) = Based on Int. ohm and Weston normal cell = 1.018300 Int. volts at 20°C; (a) = based on deposit of 1.11800 mg of silver per Int. ampere second.

CONVERSION FACTORS AND DIMENSIONAL FORMULAE

N. Ernest Dorsey

In the following tables are given the factors by which values expressed in other units must be multiplied in order to obtain their equivalents in units of the centimeter-gram-second (cgs) system. To convert in the reverse direction, divide by the factor given. The dimensional formula in the cgs, or any similarly constructed, system is given in the title of each table.

Conversion Factors.—With few exceptions,[1] the values given are based exclusively upon legal definitions, conventional constants, and the I. C. T. accepted values (p. 16). Consequently, they are computable to as extreme a precision as may be desired. They have been computed by means of Vega's seven-place logarithms, and it is hoped that their logarithms as given are correct to a unit in the last digit. Obviously, those factors which involve the accepted value of an experimentally determined constant will be in error by an amount determined by the error in the accepted value; but quantities converted by means of the logarithms given will retain their same relative precision, however great this may be, within the limit set by the seven-place table, and may at any time be as exactly corrected for a revision of the accepted value. This would not be true if an abbreviated logarithm were used, unless the exact value of the abbreviated logarithm itself were given. The latter would be equivalent merely to the adoption of another accepted value for the experimental constant involved;

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[1] The exceptions are (1) astronomical unit of distance, (2) parsec, (3) sidereal second, (4) certain units of luminous intensity, (5) international electrical units prior to 1911, and (6) the data for hydrometers.

and the new value so fixed would, in general, be expressible only by an indefinite number of digits. The former procedure is to be preferred.

Frequently, the same factor applies to more than one type of physical quantity; if the units of the several types have distinctive names, separate tables are given, otherwise, not. In general, the tables are arranged in the order of increasing complexity of the dimensional formulae. Some quantities for which conversion factors are seldom required, and a few dimensionless quantities have been grouped together in Table 78. The dimensional formulae of the more important electric and magnetic units, and the numerical relations connecting these units in the three systems most frequently used, are assembled in Table 77. To find the conversion factor for a given quantity, consult the index below.

Dimensions.—Two types of dimensional equations need to be considered, *viz.:* (1) Those in which the dimensions are expressed in terms of the quantities directly involved in the phenomenon under consideration, and (2) those in which the dimensions are expressed in terms of certain fundamental units.

As an illustration of the first we may consider the force of repulsion between two point charges (e, e') of electricity situated at a distance, r, apart in a medium of dielectric constant ϵ. If this force is denoted by f, then $f = ee'/\epsilon r^2$, and we may write $[e^2] = [f\epsilon l^2]$, $[\epsilon] = [e^2 f^{-1} l^{-2}]$, etc., where [ ] denotes that we are concerned with dimensions only; $[l]$ denotes the dimension of length, $[f]$ that of force, etc. These dimensional equations are true whatever be the system of units employed. As they involve quantities, such as force, which can be expressed in terms of other units that are usually considered more fundamental, such dimensional equations will be referred to as "unreduced," in order to distinguish them from those of the second class in which the dimensions are expressed solely in terms of a small number of fundamental units.

It is evident that the dimensions of a quantity in terms of fundamental units can be assigned only in relation to a specific system of units and to a specific method of derivation. For example, (1) if the unit of volume is defined as the volume occupied by a unit mass of water when at its greatest density under a pressure of one atmosphere, then the volume so defined will be independent of the units of length and time, and will vary directly as the unit of mass: we will have $[v] = [m]$. (2) If the unit of volume is defined as the volume occupied by a mass of water (when at its greatest density, etc.) which is equal to the mass of a specified block of platinum, then the volume so defined will not change as we change our units of length, of mass, and of time: that is $[v] = [v]$. In this case $[v]$ is an independent unit and must be so regarded in all dimensional equations. (3) If the unit of volume is defined as the volume of a cube of which the edge is equal to the unit of length then $[v] = [l^3]$. A unit may be defined in any desired unambiguous manner and, in general, the dimensions of the unit will vary from definition to definition.

Dimensional equations of the second type stand in marked contrast to those of the former, in being far less general and in implying the acceptance of a very exactly defined system of units. This, however, is the type of equation which is commonly in mind when dimensional equations are mentioned, and is probably the one which is the more generally useful; the unreduced dimensional expressions (the first type), however, are often simpler, convey more detailed information, and in many cases are to be preferred. For these reasons, unreduced dimensional expressions are to be found in explanations of technical terms (p. 34); they are followed by others, the final one in each case being the fully reduced dimensions on the centimeter, gram, second, degree centigrade absolute, electrostatic system. Wherever necessary, this system of units will be denoted by the symbol *cgse* in order to distinguish it from the corresponding electromagnetic system, which will be denoted by *cgsm*. In the conversion tables, dimensional formulae only of the cgse and of the cgsm systems are given. In the cgse system, the fundamental units and their symbols are those of length $[l]$ the centimeter, of mass $[m]$ the gram, of time $[t]$ the mean solar second, of temperature $[T]$ the absolute centigrade degree, and of dielectric constant $[\epsilon]$, that of a vacuum. The fundamental units in the cgsm system differ from those in the cgse system only by the replacement of dielectric constant by magnetic permeability $[\mu]$, the unit being the permeability of a vacuum.

It should be realized that dimensional expressions give no positive information regarding the ultimate nature of the quantity to which they refer; *e.g.*, energy and torque have the same dimensions, but differ vastly in their nature.

Symbols.—(U. S.) before a logarithm denotes that it is based upon the U. S. yard; for explanation of other symbols, see Symbols and Abbreviations, p. 16.

INDEX TO TABLES OF CONVERSION FACTORS

INDEX TO TABLES OF CONVERSION FACTORS.—*Continued*

CONVERSION FACTORS

1. Length [l] (*see also* p. 1)

Unit		Value	Log$_{10}$ (value)
1 angström unit	=	1.0000×10^{-8} cm	$\bar{8}$.000 0000
1 micron	=	1.0000×10^{-4} cm	$\bar{4}$.000 0000
1 mil	=	2.5400×10^{-3} cm	$\bar{3}$.404 8346
1 inch	=	2.5400 cm	(U. S.) 0.404 8346
1 foot	=	30.480 cm	(U. S.) 1.484 0158
1 yard (U. S.)	=	91.44018 cm	1.961 1371
1 yard (British)	=	91.43992 cm	1.961 1350
1 mile, statute	=	1.6093 km	(U. S.) 0.206 6497
1 light year	=	9.4627×10^{12} km	12.976 0131
1 astronomical unit	=	1.495×10^{8} km	8.174 6712
1 parsec	=	3.084×10^{13} km	13.489 09

2. Length^{-1}; Absorptivity; Coefficient of Absorption* [l^{-1}]

Unit		Value	Log$_{10}$ (value)
1 angström^{-1}	=	1.0000×10^{8} cm^{-1}	8.000 0000
1 micron^{-1}	=	1.0000×10^{4} cm^{-1}	4.000 0000
1 mil^{-1}	=	393.70 cm^{-1}	2.595 1654
1 inch^{-1}	=	0.39370 cm^{-1}	(U. S.) $\bar{1}$.595 1654
1 foot^{-1}	=	3.2808×10^{-2} cm^{-1}	(U. S.) $\bar{2}$.515 9842
1 mile^{-1}	=	0.62137 km^{-1}	$\bar{1}$.793 3503

* Coefficient of transmission (τ) is so defined that $-\log_e \tau$ = coefficient of absorption.

3. Mass [m]; Weight (*see also* p. 1)

Unit		Value	Log$_{10}$ (value)
1 grain	=	64.799 mg	1.811 5677
1 carat (metric)	=	200.000 mg	2.301 0300
1 ounce (avoirdupois)	=	28.350 g	1.452 5458
1 ounce (apothecary) or (troy)	=	31.103 g	1.492 8090
1 pound (avoirdupois)	=	453.59243 g	2.656 6658
1 pound (apothecary) or (troy)	=	373.2417 g	2.571 9902
1 ton, short (2000 pounds)	=	907.185 kg	2.957 6958
1 ton, long (2240 pounds)	=	1016.047 kg	3.006 9138
1 slug (g_s)	=	14.594 kg	1.164 1707
1 gram mole	=	M. W.† g	
1 molecule/M. W.†	=	1.6498×10^{-24} g	$\overline{24}$.217 4366
1 assay ton	=	29.1667 g	1.464 8868

† M. W. denotes the molecular weight of the substance.

4. Mass^{-1} [m^{-1}]

Unit		Value	Log$_{10}$ (value)
1 grain^{-1}	=	1.5432×10^{-2} mg^{-1}	$\bar{2}$.188 4323
1 ounce^{-1} (avoirdupois)	=	3.5274×10^{-2} g^{-1}	$\bar{2}$.547 4542
1 ounce^{-1} (troy)	=	3.2151×10^{-2} g^{-1}	$\bar{2}$.507 1910
1 pound^{-1} (avoirdupois)	=	2.2046×10^{-3} g^{-1}	$\bar{3}$.343 3342
1 ton^{-1} (2000 pounds)	=	11.0231×10^{-4} kg^{-1}	$\bar{3}$.042 3042
1 ton^{-1} (2240 pounds)	=	9.8421×10^{-4} kg^{-1}	$\bar{4}$.993 0862
1 (gram mole)$^{-1}$	=	†(M. W.)$^{-1}$ g^{-1}	

† M. W. denotes the molecular weight of the substance.

5. Time [t]

Unit		Value	Log$_{10}$ (value)
1 second, mean solar	=	1.00273791 sidereal sec	0.001 1874
1 second, sidereal	=	0.997270 sec (mean solar)	$\bar{1}$.998 8126
1 hour (tropical, mean solar)	=	3.6000×10^{3} sec (mean solar)	3.556 3025
1 day (tropical, mean solar)	=	8.6400×10^{4} sec (mean solar)	4.936 5137
1 day (sidereal)	=	8.6164×10^{4} sec (mean solar)	4.935 3263
1 year (tropical, mean solar)	=	31.5569×10^{6} sec (mean solar)	7.499 0946
1 year (tropical, mean solar)	=	365.2422 day (mean solar)	2.562 5809

CONVERSION FACTORS.—*Continued*

6. Time^{-1}; Frequency; "Velocity" of a Process $[t^{-1}]$

1 second^{-1} (sidereal)	=	1.002738 sec^{-1} (mean solar)	0.001 1874
1 minute^{-1} (mean solar)	=	1.66667×10^{-2} sec^{-1} (mean solar)	$\bar{2}$.221 8487
1 hour^{-1} (mean solar)	=	2.77778×10^{-4} sec^{-1} (mean solar)	$\bar{4}$.443 6975
1 day^{-1} (mean solar)	=	1.15741×10^{-5} sec^{-1} (mean solar)	$\bar{5}$.063 4863
1 year^{-1} (mean solar)	=	3.16888×10^{-8} sec^{-1} (mean solar)	$\bar{8}$.500 9054
1 year^{-1} (mean solar)	=	2.73791×10^{-3} day^{-1} (mean solar)	$\bar{3}$.437 4191
1 electron-volt, quantum^{-1}	=	2.4292×10^{14} sec^{-1} (mean solar)	14.385 4575
1 joule per mole, N_0^{-1} quantum^{-1}	=	2.5173×10^{9} sec^{-1} (mean solar)	9.400 9301
1 velocity of light, (angström unit)$^{-1}$	=	2.9986×10^{18} sec^{-1} (mean solar)	18.476 9185
1 velocity of light, millimicron^{-1}	=	2.9986×10^{17} sec^{-1} (mean solar)	17.476 9185
1 velocity of light, micron^{-1}	=	2.9986×10^{14} sec^{-1} (mean solar)	14.476 9185
1 velocity of light, millimeter^{-1}	=	2.9986×10^{11} sec^{-1} (mean solar)	11.476 9185
1 velocity of light, meter^{-1}	=	2.9986×10^{8} sec^{-1} (mean solar)	8.476 9185

7. Angle $[\theta]$

1 radian	=	57.29578 degree	1.758 1226
1 circumference	=	6.28319 radian	0.798 1799
1 quadrant	=	1.57080 radian	0.196 1199
1 degree	=	1.74533×10^{-2} radian	$\bar{2}$.241 8774
1 minute	=	2.90888×10^{-4} radian	$\bar{4}$.463 7261
1 second	=	4.84814×10^{-6} radian	$\bar{6}$.685 5749

8. Angle^{-1} $[\theta^{-1}]$

1 circumference^{-1}	=	0.159155 radian^{-1}	$\bar{1}$.201 8201
1 degree^{-1}	=	57.29578 radian^{-1}	1.758 1226
1 minute^{-1}	=	3.43775×10^{3} radian^{-1}	3.536 2739
1 second^{-1}	=	2.06265×10^{5} radian^{-1}	5.314 4251

9. Solid Angle $[\omega]$

Entire space	=	12.5664 steradian	1.099 2099
1 hemisphere	=	6.2832 steradian	0.798 1799
1 square degree	=	3.0462×10^{-4} steradian	$\bar{4}$.483 7548

10. Solid Angle^{-1} $[\omega^{-1}]$

Entire space^{-1}	=	7.9577×10^{-2} steradian^{-1}	$\bar{2}$.900 7901
1 hemisphere^{-1}	=	1.5916×10^{-1} steradian^{-1}	$\bar{1}$.201 8201
1 square degree^{-1}	=	3.2828×10^{3} steradian^{-1}	3.516 2452

11. Temperature $[T]$ (*See also* Thermometry, p. 52)

Fahrenheit.................................. x° F = $(\frac{5}{9})(x - 32)$°C
Réaumur.................................. x° R = $(\frac{5}{4})x$°C
Absolute (Centigrade)........................ x° K = $(x - T_0)$°C
Absolute (Fahrenheit)........................ x° Rankine = $(\frac{5}{9})(x - 491.58)$°C

12. Degree^{-1} (Thermometric); Expansivity; Curie's Constant (magnetic) $[T^{-1}]$

1 per degree F	=	1.8000 per degree C	0.255 2725
1 per degree R	=	0.8000 per degree C	$\bar{1}$.903 0900
1 per degree K	=	1.000 per degree C	0.000 0000

13. Luminous Flux $[\psi]$

By definition, the total luminous flux emitted by a point source of one spherical candle power is 4π *lumen.*

14. Dielectric Constant; Electrical Inductivity $[\epsilon]$; $[\mu^{-1}l^{-2}t^{2}]$

Specific inductive capacity is of zero dimensions. It is numerically equal to the dielectric constant expressed in cgse or in fpse units.

1 cgsm unit	=	8.9916×10^{20} cgse unit	20.953 8370
1 fpse unit	=	1.0000 cgse unit	0.000 0000
1 fpsm unit	=	1.0764×10^{-3} cgsm unit	$\bar{3}$.031 9684
1 fpsm unit	=	9.6784×10^{17} cgse unit	17.985 8054

15. Magnetic Permeability; Susceptibility $[\epsilon^{-1}l^{-2}t^{2}]$; $[\mu]$

1 cgse unit	=	8.9916×10^{20} cgsm unit	20.953 8370
1 fpsm unit	=	1.0000 cgsm unit	0.000 0000
1 fpse unit	=	1.0764×10^{-3} cgse unit	$\bar{3}$.031 9684
1 fpse unit	=	9.6784×10^{17} cgsm unit	17.985 8054

CONVERSION FACTORS.—*Continued*

16. Area [l^2]

1 circular millimeter	=	7.8540×10^{-3} cm^2	$\bar{3}.895\ 0899$
1 circular mil	=	5.0671×10^{-6} cm^2	(U. S.) $\bar{6}.704\ 7591$
1 square inch	=	6.4516 cm^2	(U. S.) 0.809 6692
1 square foot	=	9.2903×10^{2} cm^2	(U. S.) 2.968 0316
1 square yard	=	8.3613×10^{3} cm^2	(U. S.) 3.922 2742
1 square mile	=	2.5900 km^2	(U. S.) 0.413 2995
1 are	=	1.0000×10^{2} m^2	2.000 0000
1 hectare	=	1.0000×10^{4} m^2	4.000 0000
1 acre	=	4.0469×10^{3} m^2	3.607 1196

17. Area^{-1} [l^{-2}]

1 (circular millimeter)$^{-1}$	=	127.324 cm^{-2}	2.104 9101
1 millimeter^{-2}	=	100.0000 cm^{-2}	2.000 0000
1 meter^{-2}	=	0.0001 cm^{-2}	$\bar{4}.000\ 0000$
1 (circular mil)$^{-1}$	=	1.9735×10^{5} cm^{-2}	(U. S.) 5.295 2409
1 inch^{-2}	=	0.15500 cm^{-2}	(U. S.) $\bar{1}.190\ 3308$
1 foot^{-2}	=	1.0764×10^{-3} cm^{-2}	(U. S.) $\bar{3}.031\ 9684$
1 yard^{-2}	=	1.19599×10^{-4} cm^{-2}	(U. S.) $\bar{4}.077\ 7258$
1 mile^{-2}	=	0.38610 km^{-2}	(U. S.) $\bar{1}.586\ 7005$

18. Volume [l^3] or [v]

1 liter	=	1000.027 cm^3	3.000 0117
1 cubic inch	=	16.387 cm^3	(U. S.) 1.214 5038
1 cubic foot	=	2.8317×10^{4} cm^3	(U. S.) 4.452 0474
1 cubic yard	=	7.6456×10^{5} cm^3	(U. S.) 5.883 4112
1 gallon (U. S.)	=	3.7854×10^{3} cm^3	3.578 1157
1 gallon (British)	=	4.5461×10^{3} cm^3	3.657 6376
1 bushel (U. S.)	=	3.5239×10^{4} cm^3	4.547 0271
1 bushel (British)	=	3.6369×10^{4} cm^3	4.560 7276
1 quart, dry (U. S.)	=	1101.23 cm^3	3.041 8771
1 quart, liquid (U. S.)	=	946.358 cm^3	2.976 0557
1 quart (British)	=	1136.521 cm^3	3.055 5776
1 fluid ounce (U. S.)	=	29.5737 cm^3	1.470 9057
1 fluid ounce (British)	=	28.4130 cm^3	1.453 5176

19. Volume^{-1} [l^{-3}] or [v^{-1}]

1 liter^{-1}	=	9.9997×10^{-4} cm^{-3}	$\bar{4}.999\ 9883$
1 inch^{-3}	=	6.1023×10^{-2} cm^{-3}	(U. S.) $\bar{2}.785\ 4962$
1 foot^{-3}	=	3.5314×10^{-5} cm^{-3}	(U. S.) $\bar{5}.547\ 9526$
1 yard^{-3}	=	1.3079 m^{-3}	(U. S.) 0.116 5888
1 gallon^{-1} (U. S.)	=	2.6417×10^{-4} cm^{-3}	$\bar{4}.421\ 8843$
1 gallon^{-1} (British)	=	2.1997×10^{-4} cm^{-3}	$\bar{4}.342\ 3624$
1 quart^{-1}, dry (U. S.)	=	9.0808×10^{-4} cm^{-3}	$\bar{4}.958\ 1229$
1 quart^{-1}, liquid (U. S.)	=	1.0567×10^{-3} cm^{-3}	$\bar{3}.023\ 9443$
1 quart^{-1} (British)	=	8.7988×10^{-4} cm^{-3}	$\bar{4}.944\ 4224$
1 (fluid ounce)$^{-1}$ (U. S.)	=	3.3814×10^{-2} cm^{-3}	$\bar{2}.529\ 0943$
1 (fluid ounce)$^{-1}$ (British)	=	3.5195×10^{-2} cm^{-3}	$\bar{2}.546\ 4824$

20. Length Degree^{-1} [lT^{-1}]

1 inch per °F	=	4.5720 cm per °C	0.660 1071
1 foot per °F	=	54.864 cm per °C	1.739 2883
1 meter per °C	=	100.00 cm per °C	2.000 0000

21. Mass^{-1} Degree^{-1} [$m^{-1}T^{-1}$]

1 per gram °F	=	1.8000 per gram °C	0.255 2725
1 per pound °F	=	3.9683×10^{-3} per gram °C	$\bar{3}.598\ 6067$
1 per pound °C	=	2.2046×10^{-3} per gram °C	$\bar{3}.343\ 3342$

22. Area^{-1} Time^{-1} [$l^{-2}t^{-1}$]

1 foot^{-2} second^{-1}	=	3.8750 cm^{-2} hr^{-1}	(U. S.) 0.588 2709
1 foot^{-2} second^{-1}	=	1.0764×10^{-3} cm^{-2} sec^{-1}	(U. S.) $\bar{3}.031\ 9684$
1 mile^{-2} second^{-1}	=	1.2184×10^{-3} cm^{-2} yr^{-1}	(U. S.) $\bar{3}.085\ 7951$
1 meter^{-2} second^{-1}	=	3.600×10^{-1} cm^{-2} hr^{-1}	$\bar{1}.556\ 3025$

CONVERSION FACTORS.—*Continued*

23. Velocity [lt^{-1}]

1 foot per second	=	30.4801	cm sec^{-1}	(U. S.) 1.484 0158
1 foot per minute	=	0.5080	cm sec^{-1}	(U. S.) $\bar{1}$.705 8645
1 mile per hour	=	44.7041	cm sec^{-1}	(U. S.) 1.650 3472
1 mile per minute	=	2.6822×10^{3}	cm sec^{-1}	(U. S.) 3.428 4984
1 meter per minute	=	1.6667	cm sec^{-1}	0.221 8487
1 kilometer per hour	=	27.7778	cm sec^{-1}	1.443 6975
Velocity of light	=	2.9986×10^{10}	cm sec^{-1}	10.476 9185

24. Acceleration [lt^{-2}]

1 foot per second^{2}	=	30.480	cm sec^{-2}	(U. S.) 1.484 0158
1 mile per hour second	=	44.704	cm sec^{-2}	(U. S.) 1.650 3472
1 mile per hour minute	=	0.74507	cm sec^{-2}	(U. S.) $\bar{1}$.872 1959
1 meter per second^{2}	=	100.000	cm sec^{-2}	2.000 0000
1 kilometer per hour second	=	27.778	cm sec^{-2}	1.443 6975
Gravity, standard	=	980.665	cm sec^{-2}	2.991 5207
Gravity, standard	=	32.174	ft. sec^{-2}	(U. S.) 1.507 5049

25. Angular Velocity [θt^{-1}]

1 revolution per day	=	7.2722×10^{-5}	radian sec^{-1}	$\bar{5}$.861 6662
1 revolution per minute	=	1.0472×10^{-1}	radian sec^{-1}	$\bar{1}$.020 0286
1 revolution per second	=	6.2832	radian sec^{-1}	0.798 1799
1 degree per second	=	1.7453×10^{-2}	radian sec^{-1}	$\bar{2}$.241 8774

26. Angular Acceleration [θt^{-2}]

1 revolution per second^{2}	=	6.2832	radian sec^{-2}	0.798 1799
1 revolution per minute^{2}	=	1.7453×10^{-3}	radian sec^{-2}	$\bar{3}$.241 8773
1 revolution per minute second	=	0.10420	radian sec^{-2}	$\bar{1}$.020 0286

27. Twist; Rotatory Power [θl^{-1}]

1 degree per inch	=	6.8714×10^{-3}	radian cm^{-1}	(U. S.) $\bar{3}$.837 0428
1 degree per foot	=	5.7261×10^{-4}	radian cm^{-1}	(U. S.) $\bar{4}$.757 8616
1 degree per centimeter	=	1.7453×10^{-2}	radian cm^{-1}	$\bar{2}$.241 8774
1 minute per centimeter	=	2.9089×10^{-4}	radian cm^{-1}	$\bar{4}$.463 7261

28. Density; Volume Concentration; Solubility (Non-gases) [ml^{-3}] or [mv^{-1}] (*See also* Hydrometer Tables, p. 31)

1 gram per milliliter*	=	0.999973	g cm^{-3}	$\bar{1}$.999 9883
1 pound per inch^{3}	=	27.680	g cm^{-3}	(U. S.) 1.442 1621
1 pound per foot^{3}	=	0.016018	g cm^{-3}	(U. S.) $\bar{2}$.204 6183
1 pound per gallon (U. S.)	=	0.119826	g cm^{-3}	$\bar{1}$.078 5502
1 pound per gallon (British)	=	0.099776	g cm^{-3}	$\bar{2}$.999 0282
1 slug per foot^{3} (g_s)	=	0.5154	g cm^{-3}	(U. S.) $\bar{1}$.712 1233
Mercury† at 0°C	=	15.5951	g cm^{-3}	1.192 9882

* Numerically equal to specific gravity $t°/4°$. † Internationally accepted conventional value to be used in expressing pressures in terms of columns of mercury.

29. Mass Concentration [$m_1m_2^{-1}$]

(This quantity involves two distinct units of mass; when the two units are the same, the concentration is called the "titer," or is denoted as a per cent.)

1 gram per ton (2000 pound)	=	1.1023	mg per kilogram	0.042 3042
1 gram per ton (2240 pound)	=	0.9842	mg per kilogram	$\bar{1}$.993 0862
1 milligram per assay ton	=	*34.286	mg per kilogram	1.535 1132
1 ounce (av.) per ton (2000 lb.)	=	31.2500	mg per kilogram	1.494 8500
1 ounce (av.) per ton (2240 lb.)	=	27.9018	mg per kilogram	1.445 6320
1 pound (av.) per ton (2000 lb.)	=	500.000	mg per kilogram	2.698 9700
1 pound (av.) per ton (2240 lb.)	=	446.429	mg per kilogram	2.649 7520
1 gram per ton (metric)	=	1.0000	mg per kilogram	0.000 0000
1 karat†	=	41.667	mg per gram	1.619 7888

* Equals one troy ounce per 2000 lb. av. † 1 of gold to 24 of mixture.

30. Force [mlt^{-2}]

1 gram weight (g_s)	=	980.665	dyne	2.991 5207
1 poundal	=	1.3825×10^{4}	dyne	(U. S.) 4.140 6816
1 pound weight (g_s)	=	4.4482×10^{5}	dyne	5.648 1864
1 ton weight (2000 lb.) (g_s)	=	8.8964×10^{8}	dyne	8.949 2164
1 ton weight (2240 lb.) (g_s)	=	9.9640×10^{8}	dyne	8.998 4344

CONVERSION FACTORS.—*Continued*

31. Force^{-1} [$m^{-1}l^{-1}t^2$]

1 (gram weight)$^{-1}$ (g_s)	=	1.0917×10^{-3} dyne^{-1}	$\bar{3}$.008 4793
1 poundal^{-1}	=	7.2330×10^{-5} dyne^{-1}	$\bar{5}$.859 3184
1 (pound weight)$^{-1}$ (g_s)	=	2.2481×10^{-6} dyne^{-1}	$\bar{6}$.351 8136

32. Torque; Moment of a Force [ml^2t^{-2}]

1 pound-foot (g_s)	=	1.3558×10^{7} dyne cm	(U. S.) 7.132 2022
1 pound-inch (g_s)	=	1.1298×10^{6} dyne cm	(U. S.) 6.053 0210
1 kilogram-meter (g_s)	=	9.8066×10^{7} dyne cm	7.991 5207
1 poundal-foot	=	4.2140×10^{5} dyne cm	(U. S.) 5.624 6974

33. Stress; Pressure; Tension; Young's Modulus; Modulus of Rigidity; Modulus of Compression; Bulk Modulus; Coefficient of Skin Friction [$ml^{-1}t^{-2}$]

1 barye	=	1.0000 dyne cm^{-2}	0.000 0000
1 bar	=	*1.0000×10^{6} dyne cm^{-2}	6.000 0000
1 gram weight per cm^2 (g_s)	=	980.665 dyne cm^{-2}	2.991 5207
1 kilogram weight per m^2 (g_s)	=	98.0665 dyne cm^{-2}	1.991 5207
1 kilogram weight per mm^2 (g_s)	=	9.8066×10^{7} dyne cm^{-2}	7.991 5207
1 pound weight per in.^{2} (g_s)	=	6.8947×10^{4} dyne cm^{-2}	(U. S.) 4.838 5173
1 pound weight per ft.^{2} (g_s)	=	4.7880×10^{2} dyne cm^{-2}	(U. S.)2.680 1548
1 ton (2000 lb.) weight per in.^{2} (g_s)	=	1.3789×10^{8} dyne cm^{-2}	(U. S.) 8.139 5473
1 ton (2240 lb.) weight per in.^{2} (g_s)	=	1.5444×10^{8} dyne cm^{-2}	(U. S.) 8.188 7653
1 ton (2000 lb.) weight per ft.^{2} (g_s)	=	9.5760×10^{5} dyne cm^{-2}	(U. S.) 5.981 1848
1 ton (2240 lb.) weight per ft.^{2} (g_s)	=	10.7251×10^{5} dyne cm^{-2}	(U. S.) 6.030 4028
1 centimeter of water at 4°C (g_s)	=	9.80638×10^{2} dyne cm^{-2}	2.991 5090
1 inch of water at 4°C (g_s)	=	2.49082×10^{3} dyne cm^{-2}	(U. S.) 3.396 3436
1 centimeter of mercury at 0°C (g_s)	=	1.33322×10^{4} dyne cm^{-2}	4.124 9031
1 inch of mercury at 0°C (g_s)	=	3.38639×10^{4} dyne cm^{-2}	(U. S.) 4.529 7377
1 normal atmosphere (g_s)	=	1.01325×10^{6} dyne cm^{-2}	6.005 7166

* This value accords with the only internationally accepted use of this term; but "bar" has also been used to denote a pressure of one dyne per cm^2.

34. Stress^{-1}; Compressibility [$m^{-1}lt^2$]

1 centimeter^2 per gram weight (g_s)	=	1.0197×10^{-3} cm^2 dyne^{-1}	$\bar{3}$.008 4793
1 centimeter^2 per kilogram weight (g_s)	=	1.0197×10^{-6} cm^2 dyne^{-1}	$\bar{6}$.008 4793
1 millimeter^2 per kilogram weight (g_s)	=	1.0197×10^{-8} cm^2 dyne^{-1}	$\bar{8}$.008 4793
1 inch^2 per pound weight (g_s)	=	1.4504×10^{-5} cm^2 dyne^{-1}	.(U. S.) $\bar{5}$.161 4827
1 inch^2 per ton weight (2000 lb.) (g_s)	=	7.2519×10^{-9} cm^2 dyne^{-1}	(U. S.) $\bar{9}$.860 4527
1 inch^2 per ton weight (2240 lb.) (g_s)	=	6.4749×10^{-9} cm^2 dyne^{-1}	(U. S.) $\bar{9}$.811 2347
1 foot^2 per pound weight (g_s)	=	2.0886×10^{-3} cm^2 dyne^{-1}	(U. S.) $\bar{3}$.319 8452
1 (centimeter of water at 4°C)$^{-1}$ (g_s)	=	1.0197×10^{-3} cm^2 dyne^{-1}	$\bar{3}$.008 4910
1 (inch of water at 4°C)$^{-1}$ (g_s)	=	4.0147×10^{-4} cm^2 dyne^{-1}	(U. S.) $\bar{4}$.603 6564
1 (centimeter of mercury at 0°C)$^{-1}$ (g_s)	=	7.5006×10^{-5} cm^2 dyne^{-1}	$\bar{5}$.875 0969
1 (inch of mercury at 0°C)$^{-1}$ (g_s)	=	2.9530×10^{-5} cm^2 dyne^{-1}	(U. S.) $\bar{5}$.470 2623
1 (normal atmosphere)$^{-1}$ (g_s)	=	9.8692×10^{-7} cm^2 dyne^{-1}	$\bar{7}$.994 2834

35. Work; Energy; Heat [ml^2t^{-2}]

1 centimeter-dyne	=	1.0000 erg	0.000 0000
1 joule (absolute)	=	1.0000×10^{7} erg	7.000 0000
1 joule (International) (v)	=	1.00032 joule (abs.)	0.000 1390
1 meter-kilogram (g_s)	=	9.80665 joule (abs.)	0.991 5207
1 foot-pound (g_s)	=	1.35582 joule (abs.)	(U. S.) 0.132 2022
1 liter-atmosphere (normal) (g_s)	=	101.328 joule (abs.)	2.005 7283
1 liter-atmosphere (45° lat.)	=	*101.323 joule (abs.)	2.005 7067
1 cubic centimeter-atmosphere (normal) (g_s)	=	0.101325 joule (abs.)	$\bar{1}$.005 7166
1 horse-power hour (HP hr.) (g_s)	=	2.6845×10^{6} joule (abs.)	(U. S.) 6.428 8674
1 horse-power hour (electrical, U. S., British)	=	2.6856×10^{6} joule (abs.)	6.429 0413
1 cheval-vapeur heure (g_s)	=	2.6478×10^{6} joule (abs.)	6.422 8845
1 kilowatt-hour (abs.)	=	3.6000×10^{6} joule (abs.)	6.556 3025
1 International volt (v) faraday	=	9.6541×10^{4} joule (abs.)	4.984 7097
1 International volt (v) electronic charge	=	1.5927×10^{-19} joule (abs.)	$\overline{19}$.202 1463
1 gram calorie (20°C)	=	4.181 joule (abs.)	0.621 2802
1 gram calorie (15°C)	=	4.185 joule (abs.)	0.621 6955
1 gram calorie (mean)	=	4.186 joule (abs.)	0.621 7992
1 British Thermal Unit (39°F)	=	1060.4 joule (abs.)	3.025 4697
1 British Thermal Unit (mean)	=	1054.8 joule (abs.)	3.023 1701
1 British Thermal Unit (60°F)	=	1054.6 joule (abs.)	3.023 0878
1 Centigrade Thermal Unit (15°C)	=	1.8983×10^{3} joule (abs.)	3.278 3613

* g_{45} = 980.616 cm sec^{-2}.

CONVERSION FACTORS.—*Continued*

36. Power [ml^2t^{-3}]

1 watt (absolute)	=	1.0000×10^7 erg sec^{-1}	7.000 0000
1 watt (International) (v)	=	1.00032 watt (abs.)	0.000 1390
1 meter-kilogram per second (g_s)	=	9.80665 watt (abs.)	0.991 5207
1 foot-pound per second (g_s)	=	1.35582 watt (abs.)	(U. S.) 0.132 2022
1 horsepower, electrical (U. S., British)	=	*746.00 watt (abs.)	2.872 7388
1 horsepower, electrical (Continental Europe)	=	*736.00 watt (abs.)	2.866 0778
1 horsepower (HP) (g_s)	=	†745.70 watt (abs.)	2.872 5649
1 cheval-vapeur (g_s)	=	735.499 watt (abs.)	2.866 5820

* Defined in terms of the watt, commonly used in rating electrical machinery. † Defined as 550 ft. lb. per sec.

37. Action [ml^2t^{-1}]

1 Planck's quantum	=	6.554×10^{-27} erg sec	$\overline{27}.816\ 5064$
1 volt electronic-charge second	=	2.4292×10^{14} quanta	14.385 4575
1 volt faraday second	=	1.4724×10^{38} quanta	38.168 0209
1 joule second	=	1.5258×10^{33} quanta	33.183 4936
1 calorie (15°C) second	=	6.3854×10^{33} quanta	33.805 1891
1 joule second/N_0*	=	2.5173×10^{9} quanta	9.400 9302
1 calorie (15°C) second/N_0*	=	1.0535×10^{10} quanta	10.022 6257

* N_0 denotes Avogadro's number, the number of molecules per gram mole.

38. Fluidity [$m^{-1}lt$] (*See also* 39)

1 rhe	=	1.0000 poise^{-1}	0.000 0000

39. Viscosity [$ml^{-1}t^{-1}$]

1 poise	=	1.000 gram cm^{-1} sec^{-1}	0.000 0000
1 gram weight sec cm^{-2} (g_s)	=	980.665 poise	2.991 5207
1 pound weight sec inch^{-2} (g_s)	=	6.895×10^4 poise	(U. S.) 4.838 5173
1 pound weight sec foot^{-2} (g_s)	=	4.788×10^2 poise	(U. S.) 2.680 1548

40. Kinematic Viscosity [l^2t^{-1}]

1 poise centimeter^3 gram^{-1}	=	1.000 cm^2 sec^{-1}	0.000 0000
1 poise inch^3 gram^{-1}	=	16.387 cm^2 sec^{-1}	1.214 5038
1 inch^2 second^{-1}	=	6.451 cm^2 sec^{-1}	(U. S.) 0.809 6692
1 poise foot^3 pound^{-1}	=	62.43 cm^2 sec^{-1}	(U. S.) 1.795 3817

41. Diffusivity; Diffusion, Coefficient of [l^2t^{-1}]

All quantities of the thing diffusing are to be expressed in terms of the same units. Heat diffusivity is numerically equal to heat conductivity divided by the product of the density times the heat capacity (per unit of mass); all must be expressed in the same system of units.

1 liter centimeter^{-1} day^{-1}	=	1.1574×10^{-2} cm^2 sec^{-1}	$\bar{2}.063\ 4980$
1 centimeter^2 day^{-1}	=	1.1574×10^{-5} cm^2 sec^{-1}	$\bar{5}.063\ 4863$
1 inch^2 sec^{-1}	=	6.4516 cm^2 sec^{-1}	(U. S.) 0.809 6692

42. Surface Tension [mt^{-2}] (*See also* Capillary Constant, Table 43)

1 milligram weight per mm (g_s)	=	9.80665 dyne cm^{-1}	0.991 5207
1 milligram weight per inch (g_s)	=	0.38609 dyne cm^{-1}	(U. S.) $\bar{1}.586\ 6861$
1 erg per centimeter^2	=	1.00000 dyne cm^{-1}	0.000 0000
1 erg per millimeter^2	=	100.00000 dyne cm^{-1}	2.000 0000

43. (Capillary Constant)^2 [l^2]

The term "Capillary Constant" is used in two different senses; *viz.*, either to denote $a_1 = \sqrt{\gamma/\rho g}$, or to denote $a_2 = \sqrt{2\gamma/\rho g}$. English authors generally follow the former practice, and German authors the latter; neither use the subscript. γ denotes the surface tension, g the acceleration of gravity, and ρ the positive difference in the densities of the adjacent fluids.

1 inch^2	=	6.451 cm^2	0.809 6692
1 millimeter^2 (a_1^2) (g_s)	=	*9.807 dyne cm^{-1} per (g cm^{-3})	0.991 5207
1 millimeter^2 (a_2^2) (g_s)	=	*4.903 dyne cm^{-1} per (g cm^{-3})	0.690 4907
1 inch^2 (a_1^2) (g_s)	=	*6.327×10^3 dyne cm^{-1} per (g cm^{-3})	(U. S.) 3.801 1899
1 inch^2 (a_2^2) (g_s)	=	*3.163×10^3 dyne cm^{-1} per (g cm^{-3})	(U. S.) 3.500 1599

* To convert a^2, when referred to g_s, to surface tension in dynes per cm, multiply a^2 by the factor given in this table and by the difference in the densities (gram per cm^3) of the adjacent fluids; if a^2 is referred to g, multiply the resulting product by g/g_s.

44. Thermal Conductivity [$T^{-1}mlt^{-3}$]

The dimensions practically employed in expressing this property are (Heat Area^{-1} Time^{-1} per Degree Length^{-1}). Other conversion factors may be obtained by combining those of Tables 35 (Heat), 22 (Area^{-1} Time^{-1}) and 20 (Length Degree^{-1}).

1 calorie (15°) cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$	=	4.185 joules (abs.) cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$	0.621 6955
1 calorie (20°) cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$	=	4.181 joules (abs.) cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$	0.621 2802

CONVERSION FACTORS.—*Continued*

44. Thermal Conductivity $[T^{-1}mlt^{-3}]$.—*Continued*

1 British Thermal Unit (39°F) ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$	=	5.218 joules (abs.) cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$	0.717 5452
1 British Thermal Unit (mean) ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$	=	5.191 joules (abs.) cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$	0.715 2456
1 British Thermal Unit (60°F) ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$	=	5.190 joules (abs.) cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$	0.715 1633

45. Intensity of Radiation $[mt^{-3}]$ or $[ml^{-1}t^{-2}]$

The dimensions depend upon the point of view; when the receptor is considered, they are [Energy, Area^{-1}, Time^{-1}]; when the radiation itself is considered they are [Energy, Volume^{-1}]. Conversion from one to the other involves the velocity of propagation; if this is the velocity of light in vacuo, the factors are as given below; if the velocity is v cm sec^{-1}, the factors given must be multiplied by $v/(2.9986 \times 10^{10})$. For other units, combine these factors with those of Tables 19 (Volume^{-1}), 22 (Area^{-1} Time^{-1}), and 35 (Energy).

1 erg cm^{-3}	=	2.9986 × 10^{10} erg cm^{-2} sec^{-1}	10.476 9185
1 foot-pound ft.$^{-3}$ (g_s)	=	1.4357 × 10^{13} erg cm^{-2} sec^{-1}	(U. S.) 13.157 0733

46. Luminous Intensity of a Source in a Given Direction $[\psi\omega^{-1}]$

By definition of the lumen, a source of one spherical candle power emits $4\pi(= 12.566)$ lumens. (*See also* Photometric Standards, in another section (consult index).)

1 candle, International	=	1.0000	Int. lumen per steradian		0.000 0000
1 pentane candle	=	1.0	Int. candle	Approximate	
1 Hefner unit	=	0.9_0	Int. candle		
1 Carcel unit	=	9.6	Int. candle		
1 bougie decimale	=	1.0	Int. candle		
1 English sperm candle	=	1.0	Int. candle		

47. Illumination of a Surface $[\psi l^{-2}]$

1 lux	=	1.000	lumen meter^{-2}	0.000 0000
1 meter-candle	=	1.000	lumen meter^{-2}	0.000 0000
1 phot	=	1.000 × 10^{4}	lumen meter^{-2}	4.000 0000
1 foot-candle	=	10.764	lumen meter^{-2}	(U. S.) 1.031 9684
1 lumen foot^{-2}	=	10.764	lumen meter^{-2}	(U. S.) 1.031 9684

48. Surface Brightness $[\psi l^{-2}\omega^{-1}]$

1 lumen centimeter^{-2} steradian^{-1}	=	1.0000	lambert	0.000 0000
1 lumen foot^{-2} steradian^{-1}	=	1.0764	millilambert	(U. S.) 0.031 9684
1 candle centimeter^{-2}	=	3.1416 × 10^{3}	millilambert	3.497 1499
1 candle inch^{-2}	=	4.8695 × 10^{2}	millilambert	(U. S.) 2.687 4807

49. Electrical Quantity; Charge; Total Electric Displacement; Flux of Induction $[\epsilon^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-1}]$; $[\mu^{-\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}]$

1 absolute coulomb	=	1.00010	Int. coulomb (v)	0.000 0434
1 absolute coulomb	=	1.00007	Int. coulomb (a)	0.000 0304
1 International coulomb (v)	=	0.99990	abs. coulomb	$\bar{1}$.999 9566
1 International coulomb (a)	=	0.99993	abs. coulomb	$\bar{1}$.999 9696
1 cgsm unit	=	10.0000	abs. coulomb	1.000 0000
1 cgsm unit	=	*2.9986 × 10^{10}	cgse unit	10.476 9185
1 cgse unit	=	3.3349 × 10^{-10}	abs. coulomb	$\overline{10}$.523 0815
1 fpsm unit	=	1.1758 × 10^{2}	cgsm unit	2.070 3408
1 fpse unit	=	3.5839 × 10^{3}	cgse unit	3.554 3566
1 fpse unit	=	1.1952 × 10^{-6}	abs. coulomb	$\bar{6}$.077 4381
1 ampere-hour (abs.)	=	3.6000 × 10^{3}	abs. coulomb	3.556 3025
1 electronic charge	=	1.5921 × 10^{-19}	abs. coulomb	$\overline{19}$.201 9639
1 electronic charge	=	4.774 × 10^{-10}	cgse unit	$\overline{10}$.678 8824
1 faraday	=	9.6500 × 10^{4}	abs. coulomb	4.984 5273
1 faraday	=	9.6510 × 10^{4}	Int. coulomb (v)	4.984 5707
1 faraday	=	9.6507 × 10^{4}	Int. coulomb (a)	4.984 5577
1 faraday	=	2.89365 × 10^{14}	cgse unit	14.461 4458

* Value of **c**; experimental value = 2.9979 × 10^{10} (Rosa and Dorsey, *Bull. U. S. Bur. Standards*, **3**: 433; 07).

50. Electrical Quantity^{-1}; Charge^{-1}; Total Electric Displacement^{-1}; Flux of Induction^{-1} $[\epsilon^{-\frac{1}{2}}m^{-\frac{1}{2}}l^{-\frac{3}{2}}t]$; $[\mu^{\frac{1}{2}}m^{-\frac{1}{2}}l^{-\frac{1}{2}}]$

1 absolute coulomb^{-1}	=	0.99990	Int. coulomb^{-1} (v)	$\bar{1}$.999 9566
1 absolute coulomb^{-1}	=	0.99993	Int. coulomb^{-1} (a)	$\bar{1}$.999 9696
1 cgsm unit^{-1}	=	0.1000	abs. coulomb^{-1}	$\bar{1}$.000 0000
1 cgse unit^{-1}	=	2.9986 × 10^{9}	abs. coulomb^{-1}	9.476 9185
1 ampere-hour^{-1}	=	2.7778 × 10^{-4}	abs. coulomb^{-1}	$\bar{4}$.443 6975
1 faraday^{-1}	=	1.0363 × 10^{-5}	abs. coulomb^{-1}	$\bar{5}$.015 4727
1 electronic charge^{-1}	=	6.281 × 10^{18}	abs. coulomb^{-1}	18.798 0361

CONVERSION FACTORS.—*Continued*

51. Electrical Current $[\epsilon^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}]$; $[\mu^{-\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}]$

1 absolute ampere	=	1.00010	Int. ampere (v)	0.000 0434
1 absolute ampere	=	1.00007	Int. ampere (a)	0.000 0304
1 International ampere (v)	=	0.99990	abs. ampere	$\bar{1}$.999 9566
1 International ampere (a)	=	0.99993	abs. ampere	$\bar{1}$.999 9696
1 cgsm unit	=	10.0000	abs. ampere	1.000 0000
1 cgse unit	=	3.3349×10^{-10}	abs. ampere	$\overline{10}$.523 0815
1 faraday second^{-1}	=	9.6500×10^{4}	abs. ampere	4.984 5273
1 International ampere (U. S. before 1911)	=	0.99916	Int. ampere (v)	$\bar{1}$.999 6353
1 International ampere (England before 1906)	=	0.99870	Int. ampere (v)	$\bar{1}$.999 4358
1 International ampere (England 1906–8)	=	0.99894	Int. ampere (v)	$\bar{1}$.999 5399
1 International ampere (England 1909–10)	=	0.99990	Int. ampere (v)	$\bar{1}$.999 9566
1 International ampere (France before 1911)	=	0.9998	Int. ampere (v)	$\bar{1}$.999 9131
1 International ampere (Germany before 1911)	=	0.99968	Int. ampere (v)	$\bar{1}$.999 8610

52. Electrical Potential $[\epsilon^{-\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}]$; $[\mu^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}]$

1 absolute volt	=	0.99958	Int. volt (v)	$\bar{1}$.999 8176
1 absolute volt	=	0.99955	Int. volt (a)	$\bar{1}$.999 8046
1 International volt (v)	=	1.00042	abs. volt	0.000 1824
1 International volt (a)	=	1.00045	abs. volt	0.000 1954
1 cgsm unit	=	1.0000×10^{-8}	abs. volt	$\bar{8}$.000 0000
1 cgse unit	=	299.86	abs. volt	2.476 9185
1 International volt (U. S. before 1911)	=	0.99916	Int. volt (v)	$\bar{1}$.999 6353
1 International volt (England before 1906)	=	0.99870	Int. volt (v)	$\bar{1}$.999 4358
1 International volt (England 1906–8)	=	0.99894	Int. volt (v)	$\bar{1}$.999 5399
1 International volt (England 1909–10)	=	0.99990	Int. volt (v)	$\bar{1}$.999 9566
1 International volt (Germany and France, before 1911)	=	0.99968	Int. volt (v)	$\bar{1}$.999 8610

53. Electrical Field Strength; Potential Gradient; Dielectric Strength $[\epsilon^{-\frac{1}{2}}m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}]$; $[\mu^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-2}]$

1 cgsm centimeter^{-1}	=	1.0000×10^{-8}	abs. volt cm^{-1}	$\bar{8}$.000 0000
1 cgsm inch^{-1}	=	3.9370×10^{-9}	abs. volt cm^{-1}	(U. S.) $\bar{9}$.595 1654
1 cgse centimeter^{-1}	=	2.9986×10^{2}	abs. volt cm^{-1}	2.476 9185
1 cgse inch^{-1}	=	1.1805×10^{2}	abs. volt cm^{-1}	(U. S.) 2.072 0839
1 volt inch^{-1}	=	3.9370×10^{-1}	volt cm^{-1}	(U. S.) $\bar{1}$.595 1654

54. Electrical Resistance; Surface Resistivity $[\epsilon^{-1}l^{-1}t]$; $[\mu l t^{-1}]$

1 absolute ohm	=	0.99948	Int. ohm	$\bar{1}$.999 7741
1 International ohm	=	1.00052	abs. ohm	0.000 2259
1 cgsm unit	=	1.0000×10^{-9}	abs. ohm	$\bar{9}$.000 0000
1 cgse unit	=	8.9916×10^{11}	abs. ohm	11.953 8370
1 International ohm (France before 1911)	=	0.9999	Int. ohm	$\bar{1}$.999 9566
1 Board of Trade unit (England 1903)	=	0.99984	Int. ohm	$\bar{1}$.999 9306
1 B. A. unit	=	0.98660	Int. ohm	$\bar{1}$.994 1420
1 "Legal ohm" of 1884 (England)	=	0.99718	Int. ohm	$\bar{1}$.998 7727
1 Siemens unit	=	0.94073	Int. ohm	$\bar{1}$.973 4667

55. Electrical Inductance $[\epsilon^{-1}l^{-1}t^{2}]$; $[\mu l]$

1 absolute henry	=	0.99948	Int. henry	$\bar{1}$.999 7741
1 International henry	=	1.00052	abs. henry	0.000 2259
1 cgsm unit*	=	1.0000×10^{-9}	abs. henry	$\bar{9}$.000 0000
1 cgse unit	=	8.9916×10^{11}	abs. henry	11.953 8370

* Occasionally called a centimeter.

56. Electrical Capacity $[\epsilon l]$; $[\mu^{-1}l^{-1}t^{2}]$

1 absolute farad	=	1.00052	Int. farad	0.000 2259
1 International farad	=	0.99948	abs. farad	$\bar{1}$.999 7741
1 cgsm unit	=	1.0000×10^{9}	abs. farad	9.000 0000
1 cgse unit*	=	1.1121×10^{-12}	abs. farad	$\overline{12}$.046 1630
1 cgsm unit	=	8.9916×10^{20}	cgse unit	20.953 8370
1 absolute farad	=	8.9916×10^{11}	cgse unit	11.953 8370

* Frequently called a centimeter.

57. Electrical Volume Resistivity $[\epsilon^{-1}t]$; $[\mu l^{2}t^{-1}]$

1 absolute ohm-centimeter	=	0.99948	Int. ohm-cm	$\bar{1}$.999 7741
1 International ohm-centimeter	=	1.00052	abs. ohm-cm	0.000 2259
1 cgsm unit	=	9.9948×10^{-10}	Int. ohm-cm	$\overline{10}$.999 7741
1 cgse unit	=	8.9869×10^{11}	Int. ohm-cm	11.953 6111

CONVERSION FACTORS.—*Continued*

57. Electrical Volume Resistivity $[\epsilon^{-1}t]$; $[\mu l^2 t^{-1}]$.—*Continued*

1 microhm-centimeter	=	1.0000×10^{-6}	ohm-cm		$\bar{6}.000\ 0000$
1 microhm-inch	=	2.5400	microhm-cm	(U. S.)	0.404 8346
1 ohm-inch	=	2.5400×10^{6}	microhm-cm	(U. S.)	6.404 8346
1 ohm (meter, millimeter²)	=	100.0000	microhm-cm		2.000 0000
1 ohm (meter, millimeter)	=	78.540	microhm-cm		1.895 0899
1 ohm (mil, foot)	=	1.6624×10^{-1}	microhm-cm	(U. S.)	$\bar{1}.220\ 7433$
International Annealed Copper Standard (20°C)	=	1.7241	microhm-cm		0.236 5720

58. Volume Conductivity $[\epsilon t^{-1}]$; $[\mu^{-1}l^{-2}t]$

1 absolute *ohm⁻¹-centimeter⁻¹	=	1.00052	Int.* ohm⁻¹ cm⁻¹		0.000 2259
1 International ohm⁻¹-centimeter⁻¹	=	0.99948	abs. ohm⁻¹ cm⁻¹		$\bar{1}.999\ 7741$
1 cgsm unit	=	1.00052×10^{9}	Int. ohm⁻¹ cm⁻¹		9.000 2259
1 cgse unit	=	1.11273×10^{-12}	Int. ohm⁻¹ cm⁻¹		$\overline{12}.046\ 3889$
1 microhm⁻¹-centimeter⁻¹	=	1.0000×10^{6}	ohm⁻¹ cm⁻¹		6.000 0000
1 microhm⁻¹-inch⁻¹	=	3.9370×10^{-1}	microhm⁻¹ cm⁻¹	(U. S.)	$\bar{1}.595\ 1654$
1 ohm⁻¹-inch⁻¹	=	3.9370×10^{-7}	microhm⁻¹ cm⁻¹	(U. S.)	$\bar{7}.595\ 1654$
1 ohm⁻¹ (meter, millimeter²)⁻¹	=	1.000×10^{-2}	microhm⁻¹ cm⁻¹		$\bar{2}.000\ 0000$
1 ohm⁻¹ (meter, millimeter)⁻¹	=	1.2732×10^{-2}	microhm⁻¹ cm⁻¹		$\bar{2}.104\ 9101$
1 ohm⁻¹ (mil, foot)⁻¹	=	6.0153	microhm⁻¹ cm⁻¹	(U. S.)	0.779 2567
International Annealed Copper Standard (20°C)	=	0.5800	microhm⁻¹ cm⁻¹		$\bar{1}.763\ 4280$
100% conductivity (20°C)	=	0.5800	microhm⁻¹ cm⁻¹		$\bar{1}.763\ 4280$

* "Mho" is occasionally used instead of ohm⁻¹.

59. Electrical Mass Resistivity $[\epsilon^{-1}ml^{-3}t]$; $[\mu ml^{-1}t^{-1}]$

1 absolute ohm (meter, gram)	=	0.99948.	Int. ohm (meter, gram)		$\bar{1}.999\ 7741$
1 International ohm (meter, gram)	=	1.00052	abs. ohm (meter, gram)		0.000 2259
1 cgsm unit	=	9.9948×10^{-6}	Int. ohm (meter, gram)		$\bar{6}.999\ 7741$
1 cgse unit	=	8.9869×10^{15}	Int. ohm (meter, gram)		15.953 6111
1 ohm (mile, pound)	=	1.7513×10^{-4}	ohm (meter, gram)	(U. S.)	$\bar{4}.243\ 3663$
1 ohm (centimeter, gram)	=	1.0000×10^{4}	ohm (meter, gram)		4.000 0000
1 ohm (centimeter, gram)	=	*D**	ohm-cm		
†International Annealed Copper Standard at 20°C	=	0.15328	ohm (meter, gram)		$\bar{1}.185\ 4738$

* *D* represents the density in grams per centimeter³. † Density = 8.89 grams per centimeter³. *See* Table 61.

60. Electrical Mass Conductivity $[\epsilon m^{-1}l^3t^{-1}]$; $[\mu^{-1}m^{-1}lt]$

1 absolute ohm⁻¹ (meter, gram)	=	1.00052	Int. ohm⁻¹ (meter, gram)	0.000 2259
1 International ohm⁻¹ (meter, gram)	=	0.99948	abs. ohm⁻¹ (meter, gram)	$\bar{1}.999\ 7741$
1 cgsm unit⁻¹	=	1.00052×10^{5}	Int. ohm⁻¹ (meter, gram)	5.000 2259
1 cgse unit⁻¹	=	1.1127×10^{-16}	Int. ohm⁻¹ (meter, gram)	$\overline{16}.046\ 3889$
1 ohm⁻¹ (mile, pound)	=	5.7100×10^{-3}	ohm⁻¹ (meter, gram)	$\bar{3}.756\ 6337$
1 ohm⁻¹ (centimeter, gram)	=	1.0000×10^{-4}	ohm⁻¹ (meter, gram)	$\bar{4}.000\ 0000$
1 ohm⁻¹ (centimeter, gram)	=	*D^{-1} (ohm-centimeter)⁻¹		

* D^{-1} = reciprocal of the density in grams per centimeter³.

61. Constants of Annealed Copper as Accepted at Various Times

Data taken from U. S. Bur. Standards Circular No. 31

Temperature °C	England (Eng. Stds. Com. 1904)	Germany (Old "Normal Kupfer" density = 8.91)	Germany (Old "Normal Kupfer" assuming density 8.89)	Lindeck, Matthiessen, assuming density 8.89	A. I. E. E. before 1907 (Matthiessen value)	A. I. E. E. 1907 to 1910	Bureau Standards and A. I. E. E. 1911	Inter. Annealed Copper Standard 1913
Resistivity in ohms (meter, grams)								
0	0.14136_2	0.13959_0	0.13927_7	0.14157_1	**0.14172_9**	**0.14172_8**	0.14106_8	0.14133_2
15	0.15043_7	**0.14850_2**	**0.14816_4**	**0.14997_4**	0.15014_1	0.15065_8	0.15003_4	0.15029_0
15.6	**0.1508**							
20	0.15346_3	0.15147_0	0.15113_0	0.15285_1	0.15302_2	0.15363_4	**0.15302_2**	**0.15328**
25	0.15648_8	0.15444_0	0.15409_8	0.15576_5	0.15593_8	0.15661_0	0.15601_0	0.15626_2
Temperature coefficient of resistance (mass constant)								
0	**0.00428**	0.00425_5	0.00425_5	$\frac{1}{R_t} = \frac{1}{R_o}(1 - 3.8701t \times 10^{-3} + 9.009t^2 \times 10^{-6})$		**0.0042**	0.00427_7	0.00426_5
15	0.00402_2	**0.004**	**0.004**			0.00395_1	0.00401_9	0.00400_9
20	0.00394_3	0.00392_2	0.00392_2			0.00387_5	**0.00394**	**0.00393**
25	0.00386_6	0.00384_6	0.00384_6			0.00380_1	0.00386_4	0.00385_4
Density								
	8.89 15.6°	8.91	(8.89)	(8.89)	8.89	8.89	8.89 20°	8.89 20°

CONVERSION FACTORS.—*Continued*

62. Ionic Mobility $[\epsilon^{\frac{1}{2}}m^{-\frac{1}{2}}l^{\frac{3}{2}}]$; $[\mu^{-\frac{1}{2}}m^{-\frac{1}{2}}l^{\frac{1}{2}}t]$

1 centimeter^2 second^{-1} per cgse unit of potential	=	3.3349×10^{-3}	cm^2 sec^{-1} volt^{-1} (abs.)	$\bar{3}$.523 0815
1 inch^2 second^{-1} per cgse unit of potential	=	2.1515×10^{-2}	cm^2 sec^{-1} volt^{-1} (abs.)	(U. S.) $\bar{2}$.332 7507
1 inch^2 second^{-1} volt^{-1} (absolute)	=	6.4516	cm^2 sec^{-1} volt^{-1} (abs.)	(U. S.) 0.809 6692

63. Thermoelectric Power $[\epsilon^{-\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}T^{-1}]$; $[\mu^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}T^{-1}]$

1 cgsm unit of potential per °C	=	1.0000×10^{-2}	microvolt per °C (abs.)	$\bar{2}$.000 0000
1 cgsm unit of potential per °F	=	1.8000×10^{-2}	microvolt per °C (abs.)	$\bar{2}$.255 2725
1 cgse unit of potential per °C	=	2.9986×10^{8}	microvolt per °C (abs.)	8.476 9185
1 cgse unit of potential per °F	=	5.3975×10^{8}	microvolt per °C (abs.)	8.732 1910
1 microvolt per °F	=	1.8000	microvolt per °C	0.255 2725

64. Peltier Coefficient $[\epsilon^{-\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}]$; $[\mu^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}]$

1 joule per ampere-hour (absolute)	=	2.7778×10^{-3}	joule em^{-1}	$\bar{3}$.443 6975
1 joule per ampere-hour (absolute)	=	9.2636×10^{-14}	joule es^{-1}	$\overline{14}$.966 7790
1 joule per coulomb	=	10.000	joule em^{-1}	1.000 0000
1 joule per faraday	=	1.0363×10^{-4}	joule em^{-1}	$\bar{4}$.015 4727
1 joule per electron	=	6.2811×10^{19}	joule em^{-1}	19.798 0361
1 calorie (15°C) per ampere-hour	=	1.1625×10^{-2}	joule em^{-1}	$\bar{2}$.065 3930
1 calorie (15°C) per coulomb	=	41.850	joule em^{-1}	1.621 6955
1 millivolt	=	1.0000×10^{-2}	joule em^{-1}	$\bar{2}$.000 0000

65. Thomson Effect, Coefficient of; Specific Heat of Electricity $[\epsilon^{-\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}T^{-1}]$; $[\mu^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}T^{-1}]$

1 joule coulomb^{-1} per °F	=	1.8000	joule coulomb^{-1} per °C	0.255 2725
1 joule es^{-1} per °F	=	5.3975×10^{9}	joule coulomb^{-1} per °C	9.732 1910
1 joule em^{-1} per °F	=	0.1800	joule coulomb^{-1} per °C	$\bar{1}$.255 2725
1 joule es^{-1} per °C	=	2.9986×10^{9}	joule coulomb^{-1} per °C	9.476 9185
1 joule faraday^{-1} per °C	=	1.0363×10^{-5}	joule coulomb^{-1} per °C	$\bar{5}$.015 4727
1 joule electron^{-1} per °C	=	6.2811×10^{18}	joule coulomb^{-1} per °C	18.798 0361
1 volt per °C	=	1.0000	joule coulomb^{-1} per °C	0.000 0000

66. Piezoelectric Constant $[\epsilon^{\frac{1}{2}}m^{-\frac{1}{2}}l^{\frac{1}{2}}t]$; $[\mu^{-\frac{1}{2}}m^{-\frac{1}{2}}l^{-\frac{1}{2}}t^{2}]$

1 em per kilogram weight (g_s)	=	3.0577×10^{4}	es per dyne	4.485 3978
1 em per pound weight (g_s)	=	6.7411×10^{4}	es per dyne	4.828 7321
1 es per kilogram weight (g_s)	=	1.0197×10^{-6}	es per dyne	$\bar{6}$.008 4793
1 es per pound weight (g_s)	=	2.2481×10^{-6}	es per dyne	$\bar{6}$.351 8136
1 coulomb per kilogram weight (g_s)	=	3.0577×10^{3}	es per dyne	3.485 3978
1 faraday per kilogram weight (g_s)	=	2.9507×10^{8}	es per dyne	8.469 9251
1 electron per kilogram weight (g_s)	=	4.868×10^{-16}	es per dyne	$\overline{16}$.687 3617

67. Magnetic Field Intensity; Magnetic Potential Gradient; Magnetizing Force $[\epsilon^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-2}]$; $[\mu^{-\frac{1}{2}}m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}]$

1 gauss, absolute	=	1.00010	Int. gauss (v)	0.000 0434
1 gauss, absolute	=	1.00007	Int. gauss (a)	0.000 0304
1 International gauss (v)	=	0.99990	abs. gauss	$\bar{1}$.999 9566
1 International gauss (a)	=	0.99993	abs. gauss	$\bar{1}$.999 9696
1 cgsm unit	=	1.0000	abs. gauss	0.000 0000
1 cgse unit	=	3.3349×10^{-11}	abs. gauss	$\overline{11}$.523 0815
1 gilbert per centimeter	=	1.0000	gauss	0.000 0000
1 ampere-turn per centimeter	=	1.2566	gauss	0.099 2099
1 ampere-turn per inch	=	0.49474	gauss	(U. S.) $\bar{1}$.694 3753
1 gamma, γ	=	1.0000×10^{-5}	gauss	$\bar{5}$.000 0000

68. (Magnetic Field Intensity)$^{-1}$; Coefficient of Leduc Effect $[\epsilon^{-\frac{1}{2}}m^{-\frac{1}{2}}l^{-\frac{1}{2}}t^{2}]$; $[\mu^{\frac{1}{2}}m^{-\frac{1}{2}}l^{\frac{1}{2}}t]$

1 gauss^{-1} (absolute)	=	0.99990	Int. gauss^{-1} (v)	$\bar{1}$.999 9566
1 International gauss^{-1} (v)	=	1.00010	gauss^{-1} (abs.)	0.000 0434
1 cgsm unit^{-1}	=	1.0000	gauss^{-1} (abs.)	0.000 0000
1 cgse unit^{-1}	=	2.9986×10^{10}	gauss^{-1} (abs.)	10.476 9185
1 centimeter per gilbert	=	1.0000	gauss^{-1}	0.000 0000
1 centimeter per ampere-turn	=	7.9577×10^{-1}	gauss^{-1}	$\bar{1}$.900 7901
1 inch per ampere-turn	=	2.0213	gauss^{-1}	0.305 6246

CONVERSION FACTORS.—*Continued*

69. Magnetomotive Force; Magnetic Potential $[\epsilon^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-2}]$; $[\mu^{-\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}t^{-1}]$

1 gilbert, absolute	=	1.00010	Int. gilbert (v)	0.000 0434
1 gilbert, absolute	=	1.00007	Int. gilbert (a)	0.000 0304
1 International gilbert (v)	=	0.99990	abs. gilbert	$\bar{1}$.999 9566
1 International gilbert (a)	=	0.99993	abs. gilbert	$\bar{1}$.999 9696
1 cgsm unit	=	1.00000	abs. gilbert	0.000 0000
1 cgse unit	=	3.3349 × 10^{-11}	abs. gilbert	$\overline{11}$.523 0815
1 ampere-turn	=	1.2566	gilbert	0.099 2099

70. Magnetic Induction; Intensity of Magnetization $[\epsilon^{-\frac{1}{2}}m^{\frac{1}{2}}l^{-\frac{3}{2}}]$; $[\mu^{\frac{1}{2}}m^{\frac{1}{2}}l^{-\frac{1}{2}}t^{-1}]$

Units of Magnetization are not named

1 maxwell per centimeter², absolute	=	0.99958	Int. maxwell per cm² (v)	$\bar{1}$.999 8176
1 maxwell per centimeter², absolute	=	0.99955	Int. maxwell per cm² (a)	$\bar{1}$.999 8046
1 International maxwell per centimeter² (v)	=	1.00042	abs. maxwell per cm²	0.000 1824
1 International maxwell per centimeter² (a)	=	1.00045	abs. maxwell per cm²	0.000 1954
1 maxwell per inch²	=	0.15500	maxwell per cm²	(U. S.) $\bar{1}$.190 3308
1 cgsm unit	=	1.00000	abs. maxwell per cm²	0.000 0000
1 cgse unit	=	2.9986 × 10^{10}	abs. maxwell per cm²	10.476 9185
1 line per centimeter²	=	1.00000	maxwell per cm²	0.000 0000
1 line per inch²	=	0.15500	maxwell per cm²	(U. S.) $\bar{1}$.190 3308

71. Flux of Magnetic Induction; Magnetic Flux; Pole Strength; Quantity of Magnetism $[\epsilon^{-\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}]$; $[\mu^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-1}]$

Units of Pole Strength and Quantity of Magnetism are not named

1 maxwell, absolute	=	0.99958	Int. maxwell (v)	$\bar{1}$.999 8176
1 maxwell, absolute	=	0.99955	Int. maxwell (a)	$\bar{1}$.999 8046
1 International maxwell (v)	=	1.00042	abs. maxwell	0.000 1824
1 International maxwell (a)	=	1.00045	abs. maxwell	0.000 1954
1 cgsm unit	=	1.0000	abs. maxwell	0.000 0000
1 cgse unit	=	2.9986 × 10^{10}	abs. maxwell	10.476 9185
1 line	=	1.0000	abs. maxwell	0.000 0000
1 volt-second	=	1.0000 × 10^{8}	maxwell	8.000 0000

72. Magnetic Reluctance $[\epsilon l t^{-2}]$; $[\mu^{-1}l^{-1}]$

1 oersted, absolute	=	1.00052	Int. oersted	0.000 2259
1 International oersted	=	0.99948	abs. oersted	$\bar{1}$.999 7741
1 cgsm unit	=	1.0000	abs. oersted	0.000 0000
1 cgse unit	=	1.1122 × 10^{-21}	abs. oersted	$\overline{21}$.046 1630

73. Hall Effect, Coefficient of $[\epsilon^{-\frac{3}{2}}m^{-\frac{1}{2}}l^{-\frac{1}{2}}t^{3}]$; $[\mu^{\frac{3}{2}}m^{-\frac{1}{2}}l^{\frac{5}{2}}]$

1 volt centimeter per ampere gauss (absolute)	=	1.0000 × 10^{9}	cgsm unit	9.000 0000
1 volt inch per ampere gauss (absolute)	=	2.5400 × 10^{9}	cgsm unit	(U. S.) 9.404 8346
1 cgse unit	=	2.6962 × 10^{31}	cgsm unit	31.430 7555

74. Ettinghausen Effect, Coefficient of $[\epsilon^{-1}m^{-1}l^{-1}t^{4}T]$; $[\mu m^{-1}lt^{2}T]$

1°C centimeter per ampere gauss (absolute)	=	10.000	°C cm per cgsm unit	1.000 0000
1°F inch per ampere gauss (absolute)	=	45.720	°C cm per cgsm unit	1.660 1071
1°C centimeter per cgse unit	=	8.9916 × 10^{20}	°C cm per cgsm unit	20.953 8370

75. Nernst Effect, Coefficient of $[\epsilon^{-1}tT^{-1}]$; $[\mu l^{2}t^{-1}T^{-1}]$

1 volt per gauss °C (absolute)	=	1.0000 × 10^{8}	cgsm unit per °C	8.000 0000
1 volt per gauss °F (absolute)	=	1.8000 × 10^{8}	cgsm unit per °C	8.255 2725
1 cgse unit per °C	=	8.9916 × 10^{20}	cgsm unit per °C	20.953 8370

76. Verdet's Constant $[\epsilon^{-\frac{1}{2}}m^{-\frac{1}{2}}l^{-\frac{3}{2}}t^{2}\theta]$; $[\mu^{\frac{1}{2}}m^{-\frac{1}{2}}l^{-\frac{1}{2}}t\theta]$

1 minute per gilbert	=	1.0000	minute per cgsm unit	0.000 0000
1 minute per ampere-turn	=	1.2566	minute per cgsm unit	0.099 2099
1 radian per gilbert	=	3.4377 × 10^{3}	minute per cgsm unit	3.536 2739

77. Fundamental Electric and Magnetic Units

Name of quantity	1 *Cgsm unit equals		Dimensions		
	Cgse units	Practical units (abs.)	Cgse system	Cgsm system	‡Practical system
Electric:					
Capacity	c^2	10^9 farad	ϵl	$\mu^{-1}l^{-1}t^{2}$	$IE^{-1}t$
Charge, quantity	c	10 coulomb	$\epsilon^{\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{3}{2}}t^{-1}$	$\mu^{-\frac{1}{2}}m^{\frac{1}{2}}l^{\frac{1}{2}}$	It

CONVERSION FACTORS.—*Continued*

77. Fundamental Electric and Magnetic Units.—(*Continued*)

Conductivity (mass)	c²	10⁹ ohm⁻¹ (cm, g)	$\epsilon m^{-1}l^{3}t^{-1}$	$\mu^{-1}m^{-1}lt$	$R^{-1}m^{-1}l^{2}$
Conductivity (surface)	c²	10⁹ ohm⁻¹	ϵlt^{-1}	$\mu^{-1}l^{-1}t$	R^{-1}
Conductivity (volume)	c²	10⁹ ohm⁻¹ cm⁻¹	ϵt^{-1}	$\mu^{-1}l^{-2}t$	$R^{-1}l^{-1}$
Current	c	10 ampere	$\epsilon^{\frac12}m^{\frac12}l^{\frac32}t^{-2}$	$\mu^{-\frac12}m^{\frac12}l^{\frac12}t^{-1}$	I
Dielectric constant	c²	†10⁹ ohm⁻¹ per (cm sec⁻¹)	ϵ	$\mu^{-1}l^{-2}t^{2}$	†$IE^{-1}l^{-1}t$
Displacement (local)	c	10 coulomb per cm²	$\epsilon^{\frac12}m^{\frac12}l^{-\frac12}t^{-1}$	$\mu^{-\frac12}m^{\frac12}l^{-\frac32}$	$Il^{-2}t$
Displacement (integral)	c	10 coulomb	$\epsilon^{\frac12}m^{\frac12}l^{\frac32}t^{-1}$	$\mu^{-\frac12}m^{\frac12}l^{\frac12}$	It
Electromotive force	c⁻¹	10⁻⁸ volt	$\epsilon^{-\frac12}m^{\frac12}l^{\frac12}t^{-1}$	$\mu^{\frac12}m^{\frac12}l^{\frac32}t^{-2}$	E
Field strength	c⁻¹	10⁻⁸ volt cm⁻¹	$\epsilon^{-\frac12}m^{\frac12}l^{-\frac12}t^{-1}$	$\mu^{\frac12}m^{\frac12}l^{\frac12}t^{-2}$	El^{-1}
Inductance	c⁻²	10⁻⁹ henry	$\epsilon^{-1}l^{-1}t^{2}$	μl	Rt
Inductivity	c²	† 10⁹ ohm⁻¹ per (cm sec⁻¹)	ϵ	$\mu^{-1}l^{-2}t^{2}$	†$IE^{-1}l^{-1}t$
Ionic mobility	c	10⁸ cm sec⁻¹ per (volt cm⁻¹)	$\epsilon^{\frac12}m^{-\frac12}l^{\frac32}$	$\mu^{-\frac12}m^{-\frac12}l^{\frac12}t$	$E^{-1}l^{2}t^{-1}$
Polarization capacity	c²	10⁹ farad cm⁻²	ϵl^{-1}	$\mu^{-1}l^{-3}t^{2}$	$IE^{-1}l^{-2}t$
Potential	c⁻¹	10⁻⁸ volt	$\epsilon^{-\frac12}m^{\frac12}l^{\frac12}t^{-1}$	$\mu^{\frac12}m^{\frac12}l^{\frac32}t^{-2}$	E
Resistance	c⁻²	10⁻⁹ ohm	$\epsilon^{-1}l^{-1}t$	μlt^{-1}	R
Resistivity (mass)	c⁻²	10⁻⁹ ohm (cm, g)	$\epsilon^{-1}ml^{-3}t$	$\mu ml^{-1}t^{-1}$	Rml^{-2}
Resistivity (surface)	c⁻²	10⁻⁹ ohm	$\epsilon^{-1}l^{-1}t$	μlt^{-1}	R
Resistivity (volume)	c⁻²	10⁻⁹ ohm-cm	$\epsilon^{-1}t$	$\mu l^{2}t^{-1}$	Rl
Specific heat of electricity (Thomson)	c⁻¹	10⁻⁸ volt deg⁻¹	$\epsilon^{-\frac12}m^{\frac12}l^{\frac12}t^{-1}T^{-1}$	$\mu^{\frac12}m^{\frac12}l^{\frac32}t^{-2}T^{-1}$	ET^{-1}
Specific inductive capacity	1	1	zero	zero	zero
Magnetic:					
Field intensity	c	1 gauss	$\epsilon^{\frac12}m^{\frac12}l^{\frac12}t^{-2}$	$\mu^{-\frac12}m^{\frac12}l^{-\frac12}t^{-1}$	Il^{-1}
Flux of induction (integral)	c⁻¹	1 maxwell	$\epsilon^{-\frac12}m^{\frac12}l^{\frac12}$	$\mu^{\frac12}m^{\frac12}l^{\frac32}t^{-1}$	Et
Induction (local)	c⁻¹	1 maxwell cm⁻²	$\epsilon^{-\frac12}m^{\frac12}l^{-\frac32}$	$\mu^{\frac12}m^{\frac12}l^{-\frac12}t^{-1}$	$El^{-2}t$
Intensity of magnetization (volume)	c⁻¹	1	$\epsilon^{-\frac12}m^{\frac12}l^{-\frac32}$	$\mu^{\frac12}m^{\frac12}l^{-\frac12}t^{-1}$	$El^{-2}t$
Magnetic flux (integral)	c⁻¹	1 maxwell	$\epsilon^{-\frac12}m^{\frac12}l^{\frac12}$	$\mu^{\frac12}m^{\frac12}l^{\frac32}t^{-1}$	Et
Magnetizing force	c	1 gauss	$\epsilon^{\frac12}m^{\frac12}l^{\frac12}t^{-2}$	$\mu^{-\frac12}m^{\frac12}l^{-\frac12}t^{-1}$	Il^{-1}
Magnetomotive force	c	1 gilbert	$\epsilon^{\frac12}m^{\frac12}l^{\frac32}t^{-2}$	$\mu^{-\frac12}m^{\frac12}l^{\frac12}t^{-1}$	I
Permeability	c⁻²	1 maxwell cm⁻² per gauss	$\epsilon^{-1}l^{-2}t^{2}$	μ	$I^{-1}El^{-1}t$
Pole strength	c⁻¹	1	$\epsilon^{-\frac12}m^{\frac12}l^{\frac12}$	$\mu^{\frac12}m^{\frac12}l^{\frac32}t^{-1}$	Et
Potential	c	1 gilbert	$\epsilon^{\frac12}m^{\frac12}l^{\frac32}t^{-2}$	$\mu^{-\frac12}m^{\frac12}l^{\frac12}t^{-1}$	I
Quantity	c⁻¹	1	$\epsilon^{-\frac12}m^{\frac12}l^{\frac12}$	$\mu^{\frac12}m^{\frac12}l^{\frac32}t^{-1}$	Et
Reluctance	c²	1 oersted	ϵlt^{-2}	$\mu^{-1}l^{-1}$	$IE^{-1}t^{-1}$
Susceptibility	c⁻²	¼π maxwell cm⁻² per gauss	$\epsilon^{-1}l^{-2}t^{2}$	μ	$I^{-1}El^{-1}t$

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* For the purposes of International Critical Tables, c has been taken as 2.9986 × 10¹⁰ cm per sec, $\log_{10}$ c = 10.476 9185, $\log_{10}$ c⁻¹ = $\overline{11}.523\ 0815$. This is the accepted value for the velocity of light in vacuo. The best directly determined value of the ratio of the two electrical units of quantity gives c = 2.9979 × 10¹⁰ cm per sec. (Rosa and Dorsey, *Bull. U. S. Bur. Standards*, **3**: 433; 07.)

† In practice this unit is not used; the quantity given in essentially every instance is the dimensionless "specific inductive capacity," which is numerically equal to the dielectric constant expressed in cgse units.

‡ In this column are given the dimensions in terms of the practical electrical units, as these generally enter into the actual determinations of the several quantities. As three basic electrical units are employed, alternative expressions are possible. T = thermometric degree, E = potential, I = current, R = resistance.

78. Indicated Conversion Factors

a = area, C = electrical capacity, T = thermometric degree, d = density, E = electrical potential, e = electric charge, F = electrical field intensity, h = heat, m = mass, Q = quantity of magnetism, R = electrical resistance, t = time, v = volume, ϵ = dielectric constant, η = viscosity, θ = plane angle.

Name of quantity	Dimensions	Tables
Electricity		
Electric displacement	ϵF	14, 53
Polarization capacity	Ca^{-1}	56, 17
Pyroelectric constant	$ea^{-1}T^{-1}$	49, 17, 12
Specific inductive capacity	zero	
Surface density of charge	ea^{-1}	49, 17
Thermoelectric power	ET^{-1}	52, 12
Volume density of charge	ev^{-1}	49, 19
Heat, capacity	$hm^{-1}T^{-1}$	35, 21
Latent	hm^{-1}	35, 4
Reaction	hm^{-1}	35, 4
Superficial latent	ha^{-1}	35, 17
Transformation	hm^{-1}	35, 4
Radiation, index of absorption	zero	
Intensity of	$ha^{-1}t^{-1}$	35, 22
Kerr's constant (magneto-optic)	$\theta Q^{-1}a$	7, 71, 16
Reflectivity	zero	
Refraction, index of	zero	
Solubility, gases in liquids	zero	
Viscosity, kinematic	ηd^{-1}	39, 28

79. Hydrometer Scales

Unless the hydrometer is used in the liquid and at the temperature for which it is graduated, corrections must be applied for the changed capillary depression and for the expansion (or contraction) of the instrument. (The following table does not include all scales which have been used.)

T = temperature at which the instrument is to be used; r = reading of instrument; the specific gravity is with reference to water at temperature T unless another temperature is indicated in the last column.

79. Hydrometer Scales.—*Continued*

Hydrometer	T	Specific gravity		Remarks
		Dense	Light	
A. P. I. = American Petroleum Institute.	60°F = 15.56°C		$\frac{141.5}{131.5 + r}$	Petroleum
Balling	17.5°C	$\frac{200}{200 - r}$	$\frac{200}{200 + r}$	
Bates	60°F = 15.56°C	$\frac{1000 + 2.78r}{1000}$		
Baumé	10°R = 12.5°C	$\frac{145.88}{145.88 - r}$	$\frac{145.88}{135.88 + r}$	
Baumé	15°C	$\frac{146.3}{146.3 - r}$	$\frac{146.3}{136.3 + r}$	
Baumé	17.5°C	$\frac{146.78}{146.78 - r}$	$\frac{146.78}{136.78 + r}$	
Baumé	15°C	$\frac{144.3}{144.3 - r}$		"Rational"
Baumé	15°C	$\frac{144.3}{144.3 - r}$		"Rational" (water at 4°C)
Baumé-Lunge	12.5°C	$\frac{144.32}{144.32 - r}$	$\frac{144.32}{144.32 + r}$	"Rational"
Baumé	15°C	$\frac{144.32}{144.32 - r}$	$\frac{144.32}{144.32 + r}$	French (water at 4°C)
Baumé	60°F = 15.56°C	$\frac{145}{145 - r}$	$\frac{140}{130 + r}$	American
Beck	12.5°C	$\frac{170}{170 - r}$	$\frac{170}{170 + r}$	
Brix	12.5°R = 15.625°C	$\frac{400}{400 - r}$	$\frac{400}{400 + r}$	
Cartier	12.5°C	$\frac{136.8}{126.1 - r}$	$\frac{136.8}{126.1 + r}$	
Fischer	12.5°R = 15.625°C	$\frac{400}{400 - r}$	$\frac{400}{400 + r}$	
Fleischer		$\frac{1000 + 10r}{1000}$		
Gay-Lussac		$\frac{100}{100 - r}$	$\frac{100}{100 + r}$	
Gerlach, or "new"	17.5°C	$\frac{146.78}{146.78 - r}$		
Holland, or "old"	12.5°C	$\frac{144}{144 - r}$		
Stoppani	12.5°R = 15.625°C	$\frac{166}{166 - r}$		
Twaddell	60°F = 15.56°C	$\frac{1000 + 5r}{1000}$		British (water at 4°C)

TECHNICAL EFFLUX VISCOMETERS: INTERPRETATION AND INTERCONVERSION OF READINGS

Winslow H. Herschel

Since changes are made from time to time in the standardization or method of operation of these instruments, and many old instruments are still in use, it is believed that in general the determination of kinematic viscosity from the readings of the instruments, and direct interconversions between instruments, when used at the same temperature, may be made by the use of Fig. 1, with as great precision (about 5%) as the data will warrant. It is assumed that the instruments are used in the normal manner. For the Saybolt instruments, a higher precision is occasionally justified, and may be obtained by the use of Table 2.

If the instruments are used at different temperatures, appropriate temperature corrections must be applied. For lubricating oils, the viscosity at one temperature may be estimated from that at another by the approximate empirical rule, applicable between 100° and 212°F (37.8° and 100°C), that the logarithmic viscosity-temperature graphs are straight and meet at a point, temperatures being expressed in degrees Fahrenheit. (For other temperatures see (1, 7, 8)). The location of the point of intersection for several classes of oils is given in Table 1.

Table 1.—Coordinates of Points of Intersection of Logarithmic Graphs(5)

η_0 = viscosity in poises; t_0 = temperature in °F

Class of oils	$\log_{10} \eta_0$	η_0	$\log_{10} t_0$	t_0
Paraffin base	$\bar{3}.58$	0.0038	2.77	589
Naphthene base	$\bar{3}.88$	.0076	2.57	371
Mixed base	$\bar{3}.43$	.0027	2.78	605
Fatty oils	$\bar{3}.75$	.0056	2.82	661

In estimating the viscometer reading at a given temperature for a certain type of instrument, from an observed reading at another temperature with another type of instrument, the following steps may be taken.

1. Determine the kinematic viscosity corresponding to the observed reading by means of Fig. 1.
2. Multiply by the density (g/cm³) so as to obtain the absolute viscosity (η) in poises; find the logarithm of the absolute viscosity and the logarithm of the temperature (t) of test (°F).
3. Plot the observed η, t and the η_o, t_o of the point of intersection, as given in Table 1, on logarithmic paper. Or plot the corresponding logarithms on equispaced coordinate paper. In either case, these two points locate a straight graph upon which the viscosity at the desired temperature will be found.
4. Divide the absolute viscosity at the desired temperature by the density at that temperature to get the kinematic viscosity. From this, determine, by means of Fig. 1, the corresponding time of flow on the desired viscometer.

It will be noted that the density under (2) and (4) must be the density at the temperature under consideration, and not the density at 60°F (15.6°C), which is generally the standard for such density determinations.

If an instrument is used in an irregular manner, appropriate corrections must be applied (2, 3, 6, 9).

Table 2.—Saybolt Universal and Saybolt Furol Viscometers

Units: Time (t), sec; kinematic viscosity = (η/d), poise/(g per cm³).

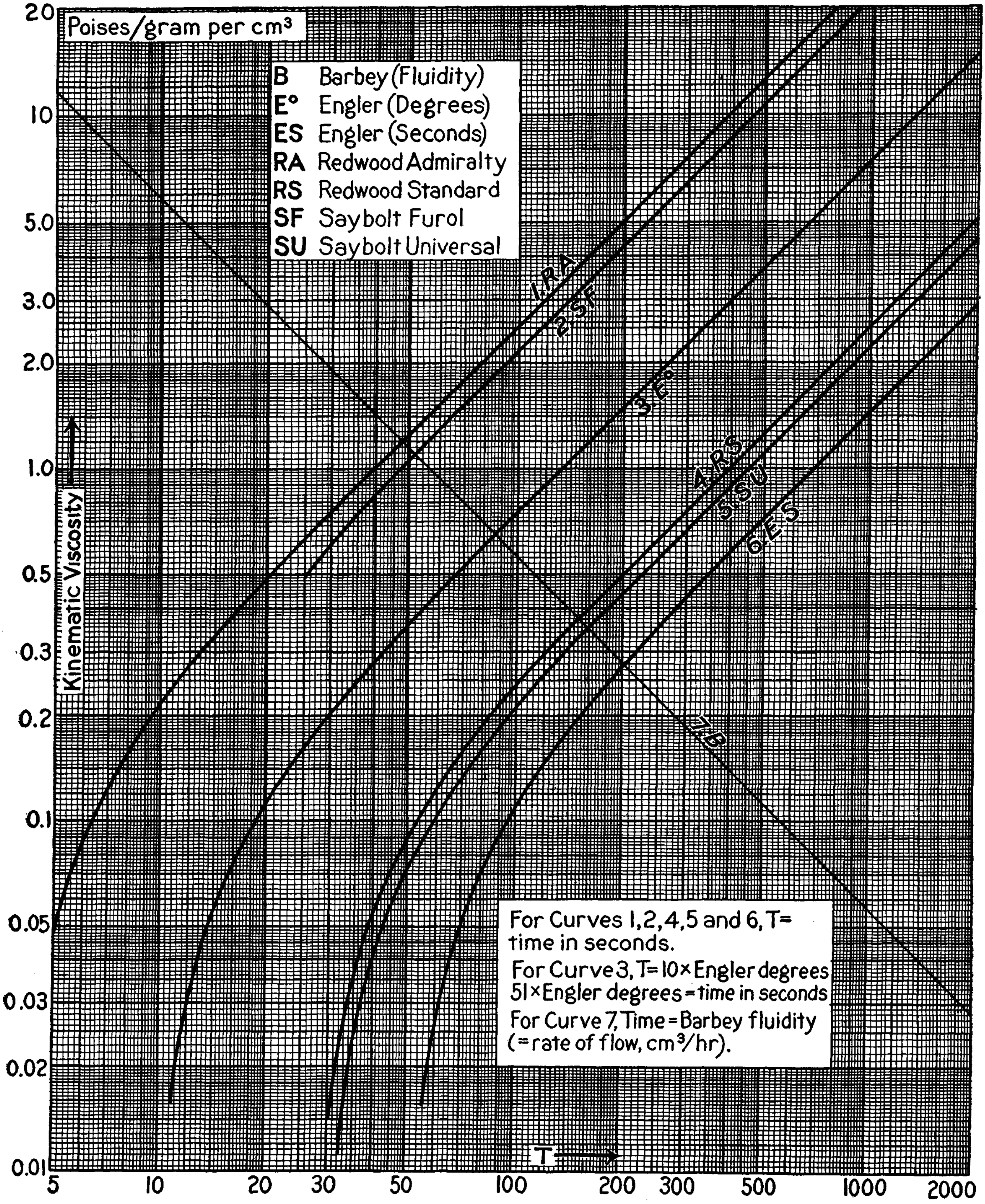
Saybolt Universal		Saybolt Furol	
t	η/d	t	η/d
32	0.0115	25	0.486
40	0.0417	26	0.512
50	0.0740	27	0.537
60	0.103	28	0.562
70	0.130	29	0.586
80	0.156	30	0.610
90	0.181	35	0.730
100	0.206	40	0.846
125	0.266	45	0.960
150	0.324	50	1.072
175	0.381	60	1.292
200	0.437	70	1.507
225	0.492	80	1.724
250	0.548	90	1.939
275	0.603	100	2.155
300	0.658		

For higher viscosities the kinematic viscosity is equal to 0.00220t for the Saybolt Universal, or to 0.0216t for the Saybolt Furol.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Fortsch and Wilson, *45*, **16**: 789; 24. (2) Ganz, *252*, **6**: 218; 99. (3) Herschel, *32*, No. **100**; 17. (4) Herschel, *244*, **10**: 31; 22. (5) Herschel, *45*, **14**: 715; 22. (6) Holde, Examination of hydrocarbon oils, 1917. (7) Lane and Dean, *45*, **16**: 905; 24. (8) MacCoull, *253*, **7**: No. 6; 21. (9) Ubbelohde, Tabellen zum Englerschen Viskosimeter, 1907.



For Curves 1,2,4,5 and 6, T= time in seconds.
For Curve 3, T= 10× Engler degrees
51× Engler degrees = time in seconds
For Curve 7, Time = Barbey fluidity (= rate of flow, cm³/hr).

FIG. 1.—Conversion diagram for viscosimeters at a common temperature (4).

SELECTED TECHNICAL TERMS

N. Ernest Dorsey

In this section are given the definitions of numerous units, and very brief explanations of such technical terms as occur in many sections of the I. C. T. or are for other reasons more suitably considered here than elsewhere. Other terms will be explained where they occur in the body of the work. Symbolical explanations will be given wherever they appear to be satisfactory. In many cases, dimensional formulae (see p. 18) are given; these are enclosed in [ ]. Symbols are enclosed in ( ). The sequence will be: Name, symbol or symbols, dimensional formula, definition or explanation; but the symbol or formula, or both may be omitted. For the explanation of the symbols employed in the formulae and explanations, see p. 16.

Aberration, Constant of.—[θ]. tan $(V\text{-}v)/\mathbf{c}$. V, v = maximum and minimum velocity of earth in its orbit, $\mathbf{c}$ = velocity of light in vacuo.

Absolute.—(abs.). 1. An adjective, descriptive of a system of units which is based upon the smallest possible number of independent units. In this connection, every specification of a definite substance or of a vacuum is to be regarded as the introduction of an independent unit. 2. **Absolute zero.** The temperature at which the pressure of a fixed mass of an ideal gas, maintained at a constant volume, becomes zero. 3. **Absolute temperature.** The temperature reckoned from the absolute zero.

Absorption.—When the absorption of radiation by a substance is such that $J = J_o e^{-kl}$, J, J_o = intensity, l = length of path, k is the **coefficient of absorption.** k/d = coefficient of **mass absorption.** Writing $k = (4\pi k'n)/\lambda$, n = index of refraction, λ = wave length in vacuo, k' = **index of absorption.** (Some call $k'n$ the index.)

Absorptivity.—Ratio of radiant energy absorbed to that absorbed, under same conditions, by a black body.

Action, Planck's constant of.—*See* Planck.

Ampere.—Unit of electric current. **Abs. ampere** = 0.1 cgs unit. **Int. ampere** is that unvarying electric current which, when passed through a solution of silver nitrate in water, in accordance with certain specifications, deposits silver at the rate of 0.00111800 gram per second.

Ampere-turn.—Unit of mmf. Difference in magnetic potential between the faces of a coil of one turn carrying one ampere.

Ångstrom unit.—(Å). [l]. 10^{-10} meters. **International Ångstrom** defined as such a length that wave-length of red cadmium line in air at 15°C, A_n, is exactly 6438.4696 Int. Å; it = 10^{-10} m within experimental error.

Anomalistic.—Anom. year [month] = time between successive passages of earth [moon] through perihelion [perigee].

Aphelion.—Point of planet's orbit farthest from sun.

Apogee.—Point of moon's orbit farthest from earth.

Aries, First point of.—Designation of position of vernal equinox (*see* Celestial sphere); not at present in constellation Aries.

Assay ton.—[m]. 29⅙ grams; as many mg as there are troy ounces in short ton.

Astronomical unit of length.—Mean distance (*q.v.*) earth to sun; 149.50×10^6 km.

Astronomical unit of mass.—Mass of sun.

Astronomical unit of time.—Mean solar day.

Atmosphere.—[force area^{-1}], [m/lt^2]. 1. **Normal atmosphere** (A_n) defined as pressure exerted by vertical column of liquid 76 cm long, density 13.5951 grams per cm³, acceleration of gravity being 980.665 cm sec^{-2}. 2. **Atmosphere at 45°** (A_{45}) differs from A_n only in use of acceleration of gravity at sea level and lat. 45° instead of 980.655 cm sec^{-2}. 3. **British atmosphere** is based on 30 inches instead of 76 cm.

Avogadro's number.—(N_0). [m^{-1}]. Number of molecules in a mole.

Bar.—[force/area], [m/lt^2]. Internationally accepted unit of pressure; = 10^6 dyne/cm². Has also been used to denote one dyne/cm² (*cf.* Barye).

Barye.—[force/area], [m/lt^2]. The cgs unit of pressure, one dyne/cm². (In accordance with recommendation of special committee of International Congress of Physicists, Paris, 1900, and with the usage of the International Bureau of Weights and Measures.) (*cf.* Bar).

B. A. unit.—A unit of electrical resistance based on certain coils prepared in 1863–1864 by British Association for Advancement of Science.

Black Body.—One which absorbs all radiant energy incident upon it. Its radiance of wave-length λ is $J_\lambda\,d\lambda$; the **intensity,** $J_\lambda = C_1\lambda^{-5}[e^{C_2/\lambda T} - 1]^{-1}$, T = absolute temperature, C_1, C_2 are **radiation constants. Total radiance** (J) is $\int J_\lambda\,d\lambda$ taken over all wave-lengths. $J = \sigma T^4$, σ = **Stefan,** or **Stefan-Boltzmann** constant of total radiation. For each T there is a wave-length (λ_m) for which $J_\lambda (= J_m)$ is a maximum; $J_m = C_j T^5$, C_j = **intensity coefficient**; $\lambda_m = w/T$, w = **Wien's displacement constant.**

Board of Trade unit.—1. A unit of **electrical resistance** based upon certain coils preserved by British Board of Trade. 2. (B.T.u.). Unit of **work.** Generally used in England as equivalent of one kilowatt-hour. (To be distinguished from British thermal unit (BTU).)

Boltzmann's molecular gas constant.—(k_o). [ml^2/t^2T]. Gas constant (*q.v.*) per molecule.

Bougie decimale.—[$\psi\omega^{-1}$]. An old unit of luminous intensity, 0.05 Violle unit.

Brightness.—[$\psi/l^2\omega$]. Luminous intensity per unit of apparent area of the luminous surface; if emission follows Lambert's law, brightness is independent of direction of line of sight, otherwise it is not; in latter case, line of sight is assumed to be normal to the surface unless the contrary is stated.

British Thermal Unit.—(BTU). [energy], [ml^2/t^2]. Heat per pound, per °F of rise, required to produce small rise in temperature of water under pressure A_n; varies with temperature, which must be stated. **"Mean" BTU** = 1⁄180 of heat required to raise one lb. of water from 32°F to 212°F, pressure A_n. (To be distinguished from Board of Trade unit (B.T.u.).)

Bulk modulus.—[stress], [m/lt^2]. Hydrostatic pressure divided by resulting decrease in volume per unit volume. Also called **volume elasticity, cubical elasticity, resistance to compression, modulus of compression** (*cf.* compressibility).

Calorie.—[Heat], [ml^2/t^2]. 1. Heat per unit of mass, per °C of rise, required to produce small rise in temperature of water under pressure A_n; varies with temperature, which must be stated. If unit of mass is gram, it is called small calorie, gram calorie, or calorie; symbol is cal. If unit of mass is kilogram, it is called large calorie, kilogram calorie, or Calorie; symbol, Cal. (2) **Mean calorie** = 1⁄100 of heat required to raise unit mass of water from 0°C to 100°C, pressure A_n.

Candle.—(ca). [$\psi\omega^{-1}$]. Basic photometric unit of luminous-intensity. A value determined by international agreement, and maintained at certain national laboratories by means of incandescent electric lamps is known as the "International candle."

Candle per square centimeter.—[$\psi/l^2\omega$]. Brightness of surface which, in direction considered, has a luminous intensity of one candle per cm^2 of apparent area; π lamberts. Similarly: Candle per sq. in., etc.

Candlepower.—(c.p.). Luminous intensity in terms of candles.

Capacity, heat.—1. Of a substance, is heat per unit of mass, per degree of rise, required to produce a very small rise in temperature, also called **specific heat,** and **thermal capacity.** 2. Of a body, is heat, per degree of rise, required to heat the body.

Capacity, electrical.—Of body A with reference to body B is $Q/(V_A - V_B)$, all other bodies in the field being insulated and uncharged; Q = charge on A; V_A, V_B = potential of A, B.

Capacity, polarization.—Of one electrode with reference to another is its electrical capacity per unit of area.

Capillary constant.—(a). [l]. 1. **British usage:** $a_1^2 = \gamma/(d_1 - d_2)g$; γ = surface tension, g = acceleration of gravity, $(d_1 - d_2)$ = positive difference in the densities of the fluids separated by the surface. 2. **German usage:** $a_2^2 = 2\gamma/(d_1 - d_2)g$. (The subscripts to the a are usually omitted.)

Carat fine.—*See* Karat.

Càrcel unit.—A superseded unit of luminous intensity; approximately = 9.6 Int. candles.

Celestial sphere.—Sphere, concentric with earth, serving to locate angular positions of celestial bodies; its intersection with plane of earth's orbit [equator] is called **ecliptic [celestial equator]**; intersections of ecliptic and equator are called **equinoxes**; motion of equinoxes with reference to stars is called **precession of equinoxes,** it is resultant of an oscillatory and a nearly uniform motion, a fictitious equinox possessing only the latter motion is called **mean equinox.** The mean equinox through which sun passes in spring of northern terrestrial hemisphere is called mean vernal equinox, and is point from which **celestial longitude** (along the ecliptic) and **mean right ascension** (R. A.) (along the equator) are measured—positive to the east. Intersections of the sphere and the axis of rotation of earth are called **celestial poles**; that of the sphere and its diameter perpendicular to plane of ecliptic called **poles of the ecliptic.** Declinations are measured from equator along great circles passing through the poles—positive towards north; **celestial latitudes,** from ecliptic along great circles passing through poles of ecliptic—positive towards north. The pole of the sphere has a motion compounded of a nearly uniform progressive motion and a rotation about a point having the former motion; that point is called **mean pole,** its motion is the **precession of the pole,** the rotation of the true pole about the mean pole is called the nutation of the pole; mean (angular) distance between mean pole and true pole is called **constant of nutation.**

Centi-.—Prefix denoting $\frac{1}{100}$.

Centigrade.—(C). Thermometric system in which freezing point of water is called 0° and its boiling point is called 100°; pressure = A_n.

Centigrade thermal unit.—(CTU). [energy], [ml^2/t^2]. Differs from British Thermal Unit only in the substitution of Centigrade for Fahrenheit scale.

Centimeter.—(cm). 1. The cgs unit of **length,** 0.01 meter. 2. Often used to denote cgse unit of **electrical capacity.** 3. Occasionally used to denote cgsm unit of **electrical inductance.**

Centimeter-dyne.—[work], [ml^2/t^2]. One erg.

Centimeter of water [of mercury, etc.] at t°.—[force/area], [m/lt^2]. Denotes pressure exerted by a vertical column of water [of mercury, etc.] one cm long, temperature t°, at a place where acceleration of gravity is g_s ($=980.665$ cm/sec²).

Cheval-vapeur.—[work/time], [ml^2/t^3]. 1. Primary definition, 75 meter-kilograms per second. Also called **force de cheval, continental horsepower, Pferdekraft.** 2. For electrical purposes, generally regarded as exactly 736 watts; may be called **continental electrical horsepower.**

Circular inch.—(cir. in.). [l^2]. Area of a circle one inch in diameter. Similarly for **circular mil** (cir. mil), **circular millimeter** (cir. mm), etc.

Compressibility.—[lt^2/m]. Reciprocal of bulk modulus.

Compression, modulus of.—[m/lt^2]. *See* Bulk modulus.

Concentration.—1. The amount per unit of volume; may be called **volume concentration.** If amount is measured by mass, the symbol is C. 2. The mass of the material per unit of mass of the mixture containing it; may be called **mass concentration.** If both masses are expressed in terms of the same unit, this concentration is generally called the **titer** of the mixture.

Conductance.—Reciprocal of resistance.

Conductance, Specific.—*See* Conductivity, electrical.

Conductivity, Electrical.—Reciprocal of electrical resistivity (*q.v.*). 1. (κ) **Volume conductivity** = reciprocal of volume resistivity; specific conductance. 2. **Mass conductivity** = κ/d; d = density. 3. **Equivalent conductivity** (Λ) is κ/c; c = equivalents of solute per unit volume of solution. 4. **Molecular conductivity** (μ) is κ/m; m = moles of solute per unit volume of solution.

Conductivity, Thermal.—[(heat/area-time)/(T/l)]; [ml/Tt^3]. $\mathrm{d}Q/\mathrm{d}t = -k\,\mathrm{d}x\mathrm{d}y\dfrac{\mathrm{d}\theta}{\mathrm{d}z}$; k = thermal conductivity, $\mathrm{d}Q$ = amount of heat through $\mathrm{d}x\mathrm{d}y$, in direction $\mathrm{d}z$, in time $\mathrm{d}t$, $\mathrm{d}\theta$ = increase in temperature in distance $\mathrm{d}z$.

Coulomb.—The quantity of electricity transferred in one second by a current of one ampere.

Critical.—1. Any point, line, or region serving to locate a well marked **transition** may be described as critical. 2. As regards **condensation** of vapors, the temperature corresponding to the isotherm above which liquefaction is impossible is called the **critical temperature**; the vapor pressure at which the two phases are in equilibrium at the critical temperature is the **critical pressure**; volume of unit mass at the critical pressure and temperature is the **critical volume.** These three values are called the **critical constants.**

Cubic.—(cu.), (^{3}). Used in conjunction with name of unit of length to form name of a related unit of volume; *e.g.*, cubic meter (cu. m) (m^3) is name of a unit of volume equivalent to volume of a cube with edges one meter long.

Cubic centimeter atmosphere.—*See* Liter-atmosphere.

Curie.—Internationally defined as amount of radon (radium emanation) which can exist in equilibrium with one gram of radium.

Current.—(I). The current of x through a surface S is $I = \mathrm{d}x/\mathrm{d}t$, where $\mathrm{d}x$ is the amount of x which passes through S in time $\mathrm{d}t$. The density of the current through S at a given point is $\sigma_s = \mathrm{d}I/\mathrm{d}S$, where $\mathrm{d}I$ is the current at that point through an element of S of area $\mathrm{d}S$. The value of σ varies with the orientation of $\mathrm{d}S$, and for a certain orientation it is a maximum. The normal, in the direction of the flux, to the element so oriented is the **direction of the current**; and this maximum value of σ is called the **density,** or the **intensity,** of the current at that point.

Dalton.—[m]. A unit of mass, $\frac{1}{16}$ mass of atom of oxygen. Approximately $1.65_0 \times 10^{-24}$ grams.

Day.—(da). [t]. 1. **Solar day** = interval between successive transits of sun across same meridian. It is not of uniform length. 2. **Mean solar day** = average length of all the solar days in a tropical year. This is the basis of all our time measurements and is what is meant by day unless the contrary is definitely indicated. 3. **Sidereal day** = interval between successive transits of true vernal equinox. 4. The day defined by successive transits of **same fixed star** is not used in astronomical computations, and appears to have no name.

Deci-.—Prefix denoting $\frac{1}{10}$.

Declination.—1. Of **celestial objects.** *See* Celestial sphere. 2. **Magnetic declination** = angular deviation of horizontal component of earth's magnetic field from northerly measured geographic meridian; easterly deviations, positive.

Degree.—1. (°), (deg). Unit of difference in **temperature**; size depends upon thermometric scale employed. 2. (°). Unit of angle, $\frac{1}{360}$ of complete circumference. 3. (°). **Hydrometer degree** is an arbitrary unit of difference in specific gravity; its value depends upon type of hydrometer (*see* p. 31).

Deka-.—Prefix denoting 10.

Demal.—A concentration of one g-equivalent per dm^3.

Density.—1. **Volume density** = $\mathrm{d}Q/\mathrm{d}v$, $\mathrm{d}Q$ = amount of the physical quantity considered which is contained in the element of volume $\mathrm{d}v$. 2. **Density of a substance,** (d), (D), is $\mathrm{d}m/\mathrm{d}v$, m = mass. When, on a particular scale of operation, the density varies from point to point, it may be that on a larger scale it will not; then the density on the larger scale may properly be called the **apparent density** (sometimes called **bulk density**) when operations on the smaller scale are being considered. 3. **Surface density** = $\mathrm{d}Q/\mathrm{d}s$, $\mathrm{d}s$ = element of area of surface over which $\mathrm{d}Q$ is distributed.

Dielectric constant.—(ϵ). $[t^2/\mu l^2]$, $[\epsilon]$. The force (f) of repulsion between two point charges (e, e') of electricity at a distance (r) apart in a uniform medium of great extent is $f = ee'/\epsilon r^2$; ϵ depends upon the nature of the medium, and is called its dielectric constant.

Diffusion, Coefficient of.—*See* Diffusivity.

Diffusivity.—1. (Δ). $\left[\frac{\text{quantity}}{\text{area time}} \Big/ \frac{\text{vol. concen.}}{\text{distance}}\right]$, $[l^2/t]$. $\mathrm{d}Q/\mathrm{d}t = -\Delta(\mathrm{d}c/\mathrm{d}x)\mathrm{d}y\mathrm{d}z$. $\mathrm{d}Q$ = amount of Q passing through area $\mathrm{d}y\mathrm{d}z$ in direction of x in time $\mathrm{d}t$, $\mathrm{d}c/\mathrm{d}x$ = rate of increase, in direction of x, of volume concentration of Q. Also called **coefficient of diffusion.** 2. **Heat diffusivity.** $\left[\frac{\text{heat}}{\text{area} \times \text{time}} \div \frac{\text{specific heat} \times \text{density} \times \text{temp.}}{\text{distance}}\right]$, $\left[\frac{\text{heat conductivity}}{\text{density} \times \text{specific heat}}\right]$, $[l^2/t]$. $\mathrm{d}Q/\mathrm{d}t = -\Delta_t cd(\mathrm{d}T/\mathrm{d}x)\mathrm{d}y\mathrm{d}z$, Δ_t = **heat diffusivity,** c = specific heat, d = density, T = temperature. $\Delta_t cd$ = **thermal conductivity.** Δ_t also called **temperature conductivity.**

Displacement constant, Wien's.—*See* Black body.

Displacement, Electric.—*See* Induction, electrostatic.

Draconic month.—*See* Nodical month.

Dyne.—$[ml/t^2]$. The cgs unit of force. The force which, when acting continuously upon a mass of one gram and not opposed by another, will impart to the mass a uniform acceleration of one cm per sec.[2]

Dyne-centimeter.—[force · length], $[ml^2/t^2]$. The torque of one dyne acting on a lever-arm of one cm.

Ecliptic.—*See* Celestial sphere.

Elastic modulus.—Ratio of stress to resulting elastic strain. There are as many types of moduli as there are types of strain. 2. Occasionally used to denote **Young's modulus.**

Elasticity.—1. **Cubical**; *see* Bulk modulus. 2. **Longitudinal**; *see* Young's modulus. 3. **Shear**; *see* Rigidity. 4. **Torsional**; *see* Rigidity. 5. **Modulus of**; *see* Elastic modulus.

Electric displacement, field strength, etc.—*See* corresponding nouns.

Electromagnetic unit of quantity of electricity.—*See* Quantity of electricity.

Electromotive force.—(E), (emf). *See* Potential.

Electron.—Negative electrons are very small negatively charged particles observed under many, very diverse conditions. All appear to be alike in every way, including amount of charge carried. They appear to be one of the basic elements of which atoms are made.

Electronic charge.—(e). A quantity of electricity, of either sign, which is numerically equal to the electric charge carried by an electron.

Electronic mass.—(m_o). The mass of a negative electron when moving with a velocity much less than that of light.

Electronic ratio.—$(\mathrm{e}/\mathrm{m}_o)$. Ratio of electronic charge to electronic mass.

Electrostatic unit of quantity of electricity.—*See* Quantity of electricity.

Elongation.—Distance of an oscillating, or of a revolving, body from a point of reference; *e.g.*, the distance of an electron from the nucleus about which it revolves.

Emissivity.—Ratio of radiance of the body to that of a black body at same temperature. If radiation of only one wave-length is considered, it is **monochromatic emissivity**; if all wave-lengths, it is **total emissivity.** The ratio of the radiances (or of the emissivities) of two non-black bodies is called **relative emissivity** of first with respect to second.

English sperm candle.—*See* Sperm candle.

Equation of time.—*See* Time.

Equator.—1. The intersection of surface of the **earth,** or other rotating spheroid, with the plane through its center perpendicular to its axis of rotation. 2. The intersection of the surface of a **spheroid** with a plane through its center and perpendicular to any diameter chosen as axis. 3. **Celestial equator.** *See* Celestial sphere.

Equinox.—*See* Celestial sphere.

Equivalent.—(equiv). Electrochemical equivalent (briefly equivalent) of an ion—actual or potential—is its formula weight divided by its valence.

Erg.—[force · distance], $[ml^2/t^2]$. Work done by a force of one dyne while acting through a distance of one centimeter in its own direction.

Erg-second.—[work · time], $[ml^2/t]$. The action produced by one dyne acting through one cm in one sec.

Expansion, coefficient of.—*See* Expansivity.

Expansivity.—$[T^{-1}]$. 1. **Volume expansivity** = $\mathrm{d}v/(v\mathrm{d}T)$. 2. **Linear expansivity** = $\mathrm{d}l/(l\mathrm{d}T)$. v, l, T = volume, length, temperature; $\mathrm{d}v[\mathrm{d}l]$ is change in $v[l]$ produced by change $\mathrm{d}T$ in temperature.

Fahrenheit.—(F). A thermometric system in which 32° denotes the freezing, and 212°, the boiling point of water under pressure of A_n.

Farad.—Capacity of electrical condenser which is charged to a potential difference of one volt by one coulomb.

Faraday.—(F). A subsidiary unit, the electrical charge carried in electrolysis by one gram-equivalent.

Field.—The field of a physical quantity is the region of space within which phenomena characteristic of the quantity exist. The strength, or intensity, of the field at any point is measured by the magnitude at that point of some chosen, characteristic phenomenon, and the complete designation of the field includes an indication of this phenomenon; *e.g.*, electrical field of force. As force is the phenomenon most frequently chosen, and in other cases the context indicates what is intended, the explicit designation of the chosen phenomenon is quite frequently omitted.

Field intensity.—The strength, or intensity, of a field of force at any point is $\mathrm{d}f/\mathrm{d}m$, where $\mathrm{d}f$ is the mechanical force experienced by $\mathrm{d}m$, a vanishingly small amount of m placed at that point. For an **electrical field,** m is positive electricity; for a **magnetic field** it is a north magnetic pole; for a **gravitational field** it is mass. Magnetic field strength is frequently called **magnetizing force.**

Fluidity.—(φ). Reciprocal of viscosity. Also called **coefficient of fluidity.**

Flux.—1. Flux (ψ) of **vector** (V) through surface S is $\psi = \int_S V_n \mathrm{d}S$; V_n = component of V normal to $\mathrm{d}S$, integral is to be taken over S. 2. Flux of a **quantity** Q through surface is $\psi = \mathrm{d}Q/\mathrm{d}t$,

dQ = amount of Q which passes through S in time dt. 3. From **point source.** If $V = I/r^2$, where r = distance from source and I is a constant independent of direction, I is called **intensity of the source,** and $\psi = I\omega$; ω = solid angle subtended, at the source, by S (*cf.* Intensity, luminous).

Flux, Luminous.—(ψ). Flux of radiant energy expressed in terms of its power to produce luminous sensation in the human eye.

Flux, Magnetic.—Flux of magnetic induction.

Foot-candle.—$[\psi/l^2]$. Unit of illumination, one lumen per square foot.

Foot-lambert.—$[\psi/l^2\omega]$. Unit of brightness; *see* Lambert.

Foot-pound.—$[ml^2/t^2]$. Work required to raise one pound a vertical distance of one foot, where $g = 980.665$ cm/sec^2 (*cf.* meter-kilogram).

Foot-poundal.—$[ml^2/t^2]$. Work done by force of one poundal (*q.v.*) acting through a distance of one foot.

Force.—$[ml/t^2]$. That which imparts acceleration to material bodies.

Force, Electromotive.—*See* Potential.

Force, Magnetizing.—*See* Field intensity.

Force, Magnetomotive.—*See* Potential.

Force de cheval.—*See* Cheval-vapeur.

Frequency.—(ν). $[N/t]$. Number per unit of time. In case of vibrations, waves, etc., the frequency is the number of complete vibrations, of complete waves, etc., per unit of time.

Gamma.—(γ). $[\sqrt{m/\mu l t^2}]$, $[\sqrt{ml\epsilon/t^4}]$. A unit of magnetic field intensity; 0.000 01 gauss.

Gas constant.—1. (R). [work/mass-degree], $[l^2/t^2T]$. The coefficient R in the ideal gas equation $pv = RTm$; p = pressure, v = volume of the mass m at absolute temperature T. 2. (R). [work/mole-degree]. **Gas constant per mole** obtained by expressing m in moles. 3. (k). [work/molecule-degree], $[ml^2/t^2T]$. **Boltzmann's molecular gas constant:** obtained by expressing m in terms of number of molecules.

Gas, Ideal.—One which strictly satisfies the equation ($pv = RTm$) and other relations deduced from the classical kinetic theory of gases on the assumption that the molecules are infinitely small and devoid of mutual attraction.

Gauss.—$[\sqrt{m/\mu l t^2}]$, $[\sqrt{ml\epsilon/t^4}]$. The cgsm unit of magnetic field intensity.

Gaussian gravitation constant.—The square root of the intensity of the gravitational field of force of the sun at a point whose distance from the sun is the astronomical unit of length (*cf.* Gravitation constant).

Geepound.—*See* Slug.

Gilbert.—$[\sqrt{ml/\mu t^2}]$, $[\sqrt{\epsilon m l^3/t^4}]$. Electromagnetic unit of magnetic potential, of magnetomotive force. Unless contrary is indicated, it is the cgsm unit. In precise work, the International gilbert, based upon the Int. elec. units, should be distinguished from the absolute, or cgsm, gilbert.

Grade.—$[\theta]$. Unit of plane angle, $\frac{1}{400}$ of complete circumference.

Gram atom.—*See* Mole.

Gram calorie.—*See* Calorie.

Gram equivalent.—*See* Mole.

Gram formula weight.—*See* Mole.

Gram weight.—*See* Weight.

Gravitation constant.—(G). $[l^3/mt^2]$. The coefficient G occurring in the equation $f = \mathrm{G}\,(mm')/r^2$; f = force of gravitational attraction between two point masses (m, m') in vacuo, r = distance between m and m' (*cf.* Gaussian gravitation constant).

Gravity, Acceleration of.—(g), (g_s). $[l/t^2]$. Unless the contrary is indicated, this expression refers specifically to the earth, and denotes the resultant acceleration downward experienced by a freely falling body placed at the point considered. It includes centrifugal effects arising from the rotation of the earth, as well as the effects of gravitational attraction (*cf.* Gravity, standard).

Gravity, Specific.—*See* Specific gravity.

Gravity, Standard.—(g_s). $[l/t^2]$. Standard gravity is the value adopted by the International Committee on Weights and Measures as the "accepted" value of the acceleration of gravity to which all measurements involving this quantity are to be referred. Thus a pressure of x cm of mercury at t°C is to be understood as denoting the pressure exerted by x cm of mercury at t°C at a place where the acceleration of gravity is g_s. The accepted value is $g_s = 980.665$ cm/sec^2 (= 32.174 ft./sec^2).

Heat.—1. By the **heat of a process** is meant the amount of heat evolved, per unit quantity of material involved, during the isothermal process, the process proceeding in the direction indicated. The quantity of material may be expressed in terms of mass, of moles, of equivalents, etc., as may seem desirable. 2. By the **latent heat** of a transformation is meant the amount of heat absorbed per unit quantity of material transformed, the transformation proceeding in the direction indicated. Latent heat of transformation of A to B = $-$(heat of transformation of A to B) = heat of transformation of B to A.

Heat diffusivity.—*See* Diffusivity.

Heat, Specific.—*See* Capacity, and Specific heat.

Hecto-.—Prefix denoting 100.

Hefner unit.—A superseded unit of luminous intensity; approximately = 0.9 Int. candles.

Henry.—$[\mu l]$, $[t^2/\epsilon l]$. Unit of electromagnetic inductance. Defined as that inductance for which an induced electromotive force of one volt is produced when the inducing current is changed at the uniform rate of one ampere per second.

Horsepower.—(h.p.). [work/time], $[ml^2/t^3]$. 1. (HP) **Primary definition** of the term is work done at the rate of 550 foot-pounds per second. 2. For electrical purposes it is regarded as exactly = 746 watts, which is frequently called the **electrical horsepower.** 3. **Continental horsepower.** *See* Cheval-vapeur.

Humidity.—1. **Absolute humidity** of a gas is the actual amount of water vapor per unit volume of the gas. Usually expressed in terms of the actual pressure of the water vapor present. 2. **Relative humidity** of a gas = ratio of the pressure of water vapor present to the pressure of water vapor which is in equilibrium with water at the same temperature. 3. **Dew-point** of a gas is the temperature at which the pressure of water vapor in equilibrium with water is equal to the actual pressure of the water vapor contained in the gas. If the temperature of the gas be varied while its absolute humidity remains unchanged, then the dew-point is that temperature at which the relative humidity is 100%. 4. If the bulb of a thermometer be encased in a fabric which is kept wet with water (**wet-bulb**), the thermometer will record a lower temperature than if the bulb were dry (**dry-bulb**). If the circulation over the wet bulb is sufficiently rapid, the difference in the temperatures depends solely upon the total pressure of the gas, its absolute humidity, and its temperature. Hence the humidity of the atmosphere, or of any other very large volume of gas, can be readily determined by the use of wet- and dry-bulb thermometers.

Hydrometer.—An instrument which, by the extent of its submergence, indicates the specific gravity of the liquid in which it floats. Frequently, its readings are expressed in degrees (°). Various systems of graduations are in use, *see* p. 31.

Hygrometric.—Pertaining to humidity of atmosphere.

Hypsometry.—The art of measuring the elevation above sea-level. More specifically, the use of the boiling-point of water for such measurements.

Ice point.—(T_0). Temperature at which water freezes when under the pressure of one normal atmosphere.

Ideal gas.—*See* Gas, ideal.

Illumination.—$[\psi/l^2]$. The illumination at a point of a surface is the surface density of the luminous flux incident at that point.

Inch of water [of mercury, etc.] at $t°$.—Analogous to cm of water (*q.v.*)

Index of absorption.—*See* Absorption.

Index of refraction.—*See* Refraction.

Inductance.—The electrical inductance of circuit A with reference to circuit B is ψ_A/I_B; ψ_A = flux of magnetic induction through A as a result of the current I_B in B. A and B may be the same circuit.

Induction.—1. That **modification** which is acquired by a medium when it becomes the seat of a field of force, and which is evidenced by the fact that its boundaries with other media exhibit distinctive properties which they do not possess in the absence of the field. 2. The distinctive **properties** mentioned in (1); as in magnetization by induction, induced electric charges, etc. 3. **Electrostatic induction.** $[\sqrt{m/\mu l^3}]$, $[\sqrt{\epsilon m/lt^2}]$. ϵF, ϵ = dielectric constant, F = intensity of electrostatic field of force. **Electric displacement** = $\epsilon F/4\pi$. 4. **Magnetic induction** (B). $[\sqrt{\mu m/lt^2}]$, $[\sqrt{m/\epsilon l^3}]$. $B = \mu H$, μ = magnetic permeability, H = intensity of magnetic field of force. 5. **Electromagnetic induction** is the phenomenon which is characterized by the appearance, in every circuit, of a cyclical emf which is proportional to the rate of change of the flux of magnetic induction through that circuit.

Intensity coefficient.—*See* Black body.

Intensity, Field.—*See* Field intensity.

Intensity, luminous.—1. Of a **point source** in a given direction = amount of luminous flux, per unit of solid angle, which the source emits in the direction considered. 2. Of a **point of an extended source** = brightness of that point of the source; also called intrinsic brightness. 3. Of an **extended source,** in a given direction, is its intensity at a point so distant in the stated direction that the source may be regarded as a point. For nearer points the **apparent intensity** will depend upon the distance, and is defined as the intensity of that point source which at the same distance will produce the same illumination (*cf.* flux).

Intensity of magnetization.—*See* Magnetization.

Intensity of radiation.—1. The intensity of the **radiation emitted** in a specified direction by a body is the amount of radiant energy emitted in that direction, per unit of time, per unit of area, and per unit of solid angle of emission. For spectral, or monochromatic, intensity, *See* Radiance. 2. Of **received radiation,** *See* Irradiation. 3. Of **radiation in transit.** The amount of radiant power per unit area which passes through an element of area which is normal to the direction of propagation; this equals the volume density of radiant energy at the point considered.

International electrical units.—A system of electrical and magnetic units based upon the ohm, the ampere, and secondarily upon the volt, all as realized by certain concrete standards which have been internationally agreed upon, and upon the cgs units for such other quantities as may be involved. The concrete standards have been so chosen as to make the international system nearly identical with the practical system; as now defined, the outstanding discrepancy in no case exceeds 52 parts in 100 000. In distinguishing between the two systems, the units of the practical system are described as absolute, those of the other, as international. The introduction of the volt as a secondary unit defined by a concrete standard (Weston normal cell = 1.018300 Int. volts at 20°C) introduces confusion when measurements of high precision are to be recorded. In these Tables, values based upon the Int. ohm and the Int. ampere (as defined by the silver voltameter) are denoted by (a). Those based on the Int. ohm and the Int. volt (as defined by the standard cell) are denoted by (v).

Irradiation.—The radiant power, per unit of area, incident upon a surface.

Joule.—$[ml^2/t^2]$. 1. **Absolute joule** = 10^7 ergs. 2. **International joule** = work expended per second by an Int. ampere in an Int. ohm.

Karat.—(K). Denotes the "fineness of gold" in terms of parts (by weight) of gold per 24 parts of the alloy. Twenty-four g of an n karat alloy contains n g of gold, the alloy is **"n carats fine."**

Kelvin.—(K). Name applied to the absolute centigrade scale of temperature.

Kilo-.—Prefix denoting 1000.

Kilogram calorie.—*See* Calorie.

Kilogram-meter.—A torque equivalent to that of one kilogram weight acting on a lever-arm one meter long.

Kilowatt-hour.—Work expended by one kilowatt in one hour. In Great Britain it is quite generally called **Board of Trade unit** (B.T.u.).

Kinematic viscosity.—$[l^2/t]$. Ratio of viscosity to density.

Lambert.—$[\psi/l^2\omega]$. The brightness of a surface which, radiating in accordance with Lambert's law, emits a total luminous flux of one lumen per cm². For such a surface, brightness is independent of direction of the line of sight and equals $1/\pi$ lumen, per steradian, per cm² = $1/\pi$ candles per cm². If the total emission is one lumen per sq. ft., the brightness is called one **foot-lambert.**

Lambert's law.— $I = I_o \cos\theta$; $I_o[I]$ = intensity of radiation emitted in direction normal [at angle θ with normal] to the surface. In many cases this law does not express the facts.

Latent heat.—(l, L). *See* Heat.

Latitude.—(lat.). 1. The angular distance of a point from the equator of a **spheroid,** measured along a great circle passing through the poles. 2. **Celestial latitude.** *See* Celestial sphere.

Legal ohm.—A unit of resistance; so designated by the International Conference of 1884, and defined as the resistance of a column of mercury 1 mm² in cross-section and 106 cm in length at the temperature of melting ice. It was never legalized.

Light-year.—Distance traveled by light in free space in one year.

Line.—Unit of flux of magnetic induction = one maxwell.

Liter-atmosphere.—The amount of external work done when a volume is increased by one liter against an external pressure of one atmosphere.

Longitude.—(long.). 1. The longitude of a point is the angle which its axial plane makes with a fiducial one. For the **earth,** angles measured from the fiducial plane towards the west are usually considered positive. 2. **Celestial** or **astronomical** longitude. *See* Celestial sphere.

Loschmidt's number.—(n_o). $[l^{-3}]$. Number of molecules per unit volume of an ideal gas at 0°C and pressure A_n.

Lumen.—$[\psi]$. Fundamental unit of luminous flux. A uniform point source of one candle emits 4π lumens.

Luminous flux.—*See* Flux, luminous.

Luminous intensity.—*See* Intensity, luminous.

Lunar month.—The time which elapses between successive new moons. Also called synodical month.

Lux.—A unit of illumination, one lumen per square meter.

Magnetic flux.—*See* Flux, magnetic.

Magnetic induction.—*See* Induction.

Magnetic moment.—*See* Moment.

Magnetization, Intensity of.—Magnetic moment per unit of volume (*cf.* moment).

Magnetomotive force.—(mmf). *See* Potential.

Magnitude.—The **magnitude, or apparent magnitude,** (m) of a star is primarily an indication of the amount of light the earth receives from it. The value to be assigned to the latter depends upon the characteristics of the perceptive apparatus: visual, photovisual, photographic, and radiometric magnitudes are to be distinguished. Certain stars near the north pole have been chosen as standards; the numerical magnitudes assigned to them are such as represent satisfactorily the range covered by early naked-eye estimates, and satisfy the equation $m = 2.5 (\log_{10} I_0 - \log_{10} I)$, I = intensity of light from a star of magnitude m, and I_0 = that from one of magnitude zero. For Vega, $m = 0.2$; a star of $m = 6$ is near the limit of naked-eye visibility. The **absolute magnitude** M is internationally defined as the apparent magnitude the star would have if its distance were 0.1 parsec; $M = m + 5 + 5 \log_{10} \pi$, π = parallax expressed in ″.

Mass, Engineers' unit of.—*See* Slug.

Maxwell.—The cgsm unit of flux of magnetic induction.

Mean distance.—In astronomical parlance, the mean distance of a planet from the sun denotes the mean of the greatest and the least distance from the sun to the path of the planet. Similarly in other cases.

Mean spherical candlepower.—Average candlepower of a source, in all directions.

Mega-.—Prefix = 1 000 000.

Megmho.—Conductance of one reciprocal microhm.

Meter-candle.—The illumination of an element of surface one meter distant from a uniform source of one candle situated upon the normal to the center of the element. One lux.

Meter-kilogram.—$[ml^2/t^2]$. Work required to raise one kilogram a vertical distance of one meter at a place where the acceleration of gravity is 980.665 cm/sec.^{2}

Mho.—An electrical conductance of one reciprocal ohm.

Micro-.—Prefix denoting $1/10^6$.

Microhm.—10^{-6} ohm.

Micromicro-.—Prefix denoting $1/10^{12}$.

Micron.—(μ). Unit of length = $1/10^6$ m = 0.001 mm.

Mil.—0.001 in. (*cf.* Circular inch).

Milli-.—Prefix = 0.001.

Millimicro-.—Prefix = 0.000 000 001.

Minute.—1. (min). **Time,** $\frac{1}{1440}$ of a day. 2. (′). Unit of **angle,** $\frac{1}{60}$ degree. 3. (\`). **Centesimal minute** = unit of angle = 0.01 grade.

Modulus.—1. *See* Elastic modulus. 2. For the several elastic moduli—bulk, compression, elasticity, rigidity, torsion, Young's—*see* distinguishing name.

Mohs.—An arbitrary scale of hardness based upon a selected list of 10 native minerals.

Mole.—A variable, derived unit of mass; its mass is numerically equal to the molecular weight of the substance measured. The expressions **gram-mole, kilogram-mole,** etc. are used to designate the basic unit of mass employed. Similarly derived units based upon the atomic weight, the formula weight, or the equivalent are called the **gram-atom, gram-formula weight** or **gram-equivalent** when the gram is the basic unit, and correspondingly in other cases.

Molecular.—For molecular properties, *see* appropriate properties.

Molecular volume.—Volume occupied by one mole. Molecular weight divided by density.

Molecular weight.—(M). The sum of the atomic weights of all the atoms contained in a molecule.

Moment.—1. Of force (F) about a point = Fl, l = perpendicular distance from the point to the line of F. 2. Of a **couple** = product of either force times perpendicular distance between them. 3. Of a **magnet** = moment of couple acting upon it when it is at right angles to a magnetic field of unit intensity. 4. Of **inertia** about an axis = sum of the products of each element of mass times the square of its distance from the axis.

Month.—1. Period of time determined by motion of **moon.** *See* lunar, synodical, tropical, sidereal, anomalistic, nodical, draconic. 2. **Solar month** = $\frac{1}{12}$ of tropical year. 3. **Calendar month** = conventional subdivision of year.

Myria-.—Prefix = 10 000.

Node.—1. A point of a **standing wave** where the displacement is independent of the time. 2. In **astronomy,** the points where an orbital, or other, plane cuts the ecliptic; the **rising node** is the one at which the passage across the plane of the ecliptic is from south to north.

Nodical month.—Time required by the moon to pass from one rising node to the next. Also called **draconic month.**

Noon.—*See* Time.

Normal.—1. The normal to a **surface** is a line drawn perpendicular to the surface at the point considered. 2. Any **line** perpendicular to another may be said to be normal to it. 3. A **concentration** of one gram-equivalent per liter.

Normal atmosphere.—(A_n). *See* Atmosphere.

Numeric.—(N). A pure number. A dimensionless quantity.

Nutation.—*See* Celestial sphere.

Oersted.—The cgsm unit of magnetic reluctance.

Ohm.—(Ω). A unit of electrical resistance. 1. **Absolute ohm** = 10^9 cgsm units. 2. **International ohm** is the resistance, at the temperature of melting ice, offered to an unvarying electric current by a column of mercury, of constant sectional area, having a mass of 14.4521 grams and a length, at the temperature mentioned, of 106.300 cm.

Ohm-centimeter.—Unit of electrical volume resistivity. The resistivity of a material of which a uniform bar one cm^2 in sectional area has a longitudinal resistance of one ohm per cm of length. Frequently called one **ohm per centimeter cube.**

Ohm (cm, gram).—Unit of electrical mass resistivity. The resistivity of a material of which a bar, having such a uniform section that its mass per linear cm is one gram, has a longitudinal resistance of one ohm per cm of length.

Ohm (meter, mm).—Unit of electrical volume resistivity. The resistivity of a material of which a circular cylinder one mm in diameter has a longitudinal resistance of one ohm per meter.

Ohm (meter, mm^2).—Unit of electrical volume resistivity. The resistivity of a material of which a circular cylinder one square mm in sectional area has a longitudinal resistance of one ohm per meter.

Ohm (mil, ft.).—Analogous to ohm (meter, mm). Cylinder one mil in diameter, resistance of one ohm per foot.

Ohm (mile, pound).—Analogous to ohm (cm, gram).

Ohm-inch.—Analogous to ohm-centimeter.

Parallax.—1. The **annual parallax** of a star is defined as the maximum angle subtended by one astronomical unit of length at the distance of the star from the sun. 2. The **equatorial horizontal parallax** of a member of the solar system is the maximum angle subtended by the equatorial radius of the earth at the distance of the earth from the member considered.

Parsec.—The distance of a star for which the annual parallax is one second of arc.

Pentane candle.—A superseded unit of luminous intensity = one Int. candle.

Percent.—(%). The number of units of the constituent in 100 units of the mixture containing it. If units of volume are used, the ratio is called **volume percent;** if units of mass, it is called **mass percent, weight percent,** or simply **percent.** (% must be distinguished from ‰ which is frequently used to denote per thousand.)

Perigee.—That point of the moon's orbit which is nearest to the earth (*cf.* apogee).

Perihelion.—That point of a planet's, or comet's, orbit which is nearest to the sun (*cf* aphelion).

Permeability.—(μ.) The force (f) of repulsion between two rigidly magnetized poles (m, m') at a distance r apart is $f = (mm')/(\mu r^2)$; μ depends upon the material in which the poles are immersed, and is called its permeability.

Pferdekraft.—*See* Cheval-vapeur.

Phot.—An illumination of one lumen per cm^2.

Photoelectric constant.—1. **h/e.** It is $1/\nu$ of the rise in potential required to impart to a negative electron the energy it has when emitted under the action of radiation of frequency ν. 2. **hc/e.** This is λ times the rise in potential mentioned in (1). λ = wave-length in vacuo.

Planck's constant of action.—(**h**). $[ml^2/t]$. A universal constant which fixes the amount of energy contained in the individual bundles, or quanta, of radiation emitted by a radiating body. Each such bundle contains an amount of energy $= \mathbf{h}\nu$, ν = vibration frequency of the radiation. **h** is also called **Planck's quantum.**

Poise.—$[m/lt]$. The cgs unit of viscosity. If the tangential force, per unit area, which one layer of a fluid exerts upon an adjacent one is one dyne when the space rate of variation of the tangential velocity from layer to layer is unity, the viscosity of the fluid is one poise.

Poisson's ratio.—If a bar of uniform section be subjected to a pure tensile stress, the ratio of its transverse contraction per unit of transverse thickness to its elongation per unit of length is called the Poisson's ratio of the material.

Pole strength.—*See* Quantity of magnetism.

Poncelet.—Unit of power = 100 meter-kilograms per second.

Potential.—The excess of the potential at the point A over that at B, with reference to any quantity m, is the mechanical work per unit of m which must be done in carrying a very small positive amount of m from B to A. The difference in electrical potential is called **electromotive force, emf, potential difference**; in magnetic potential, is called **magnetomotive force, mmf.**

Potential gradient.—The space rate of increase in the potential. If the direction in which the rate to be measured is not stated, that corresponding to the maximum gradient is to be understood.

Pound weight.—*See* Weight.

Poundal.—The unit of force in the fps system. It is the force which, if acting continuously upon a mass of one pound, will impart to it a uniform acceleration of one foot per $second^2$ (*cf.* Dyne).

Power.—1. The time **rate of doing work.** 2. If when the two junctions of a bimetallic circuit differ in temperature by a small amount (dt), there is an open circuit emf (dE) around the circuit, then $(dE)/(dt)$ is called the **thermoelectric power** of the circuit, corresponding to the average temperature of the two junctions. 3. The **ability** to do some specific thing; as in rotatory power.

Practical electric units.—A system of electrical units based upon 10^9 cm, 10^{-11} gram, sec, and the permeability of a vacuum, as fundamental units. The units of most interest are the ohm ($=10^9$ cgsm), ampere ($=0.1$ cgsm), and volt ($=10^8$ cgsm). Frequently described as absolute (*cf.* Int. elec. units).

Precession of the equinoxes.—*See* Celestial sphere.

Pressure.—(p), (P). $[m/lt^2]$. Normal force per unit of area. A **hydrostatic pressure** is a pressure which is the same in all directions. For critical pressures, *see* Critical.

Quadrant.—1. Unit of **angle** = 90°. 2. Formerly used occasionally to denote the **henry.**

Quantity of electricity.—1. (es). The **electrostatic unit** is that quantity which when concentrated to a point and placed at unit distance from an equal point charge will exert upon it a unit force, the surrounding medium being a vacuum. 2. (em). The **electromagnetic unit** is that quantity which is transferred per unit of time across any section of an infinitely long, straight, linear conductor when the current is such that the intensity of the resulting magnetic field at unit distance from the conductor is unity. 3. For **other units**—coulomb, electronic charge, faraday—*see* corresponding names.

Quantity of magnetism.—Also called **pole strength.** 1. The **electromagnetic unit** is that quantity which when concentrated to a point pole and placed at a unit distance from an equal point pole will exert upon it a unit force, the surrounding medium being a vacuum. 2. The **electrostatic unit** is that quantity which when concentrated to a point pole and placed at a unit distance from an infinitely long, straight, linear conductor would experience a unit force as a result of a current in the conductor such that one electrostatic unit of electricity per second is transferred across each section of the conductor. 3. The **Int. electric unit** is not named, it is the same as the cgsm unit.

Quantum.—1. Certain processes are essentially discrete, and consequently parcel out into bundles the several quantities involved. If for a certain quantity and a particular process these bundles are all alike, it is now customary to call them quanta, without implying that the quantity so bundled has in itself any atomistic properties. 2. **Planck's quantum.** *See* Planck.

Radian.—An angle which encloses, of the circumference of a concentric circle, an arc = radius.

Radiance.—The radiance of a body, within the spectral range λ_1 to λ_2, is defined as the intensity of the radiant energy, having wave-lengths lying between λ_1 and λ_2, which the body emits in a direction perpendicular to its radiating surface. If the spectral range is not mentioned, all wave-lengths are to be included; this is frequently called the **total radiance.** The **spectral, or monochromatic, intensity** of the radiance of wave-length λ is defined as the ratio of the radiance within the range $(\lambda - \frac{1}{2}d\lambda)$ to $(\lambda + \frac{1}{2}d\lambda)$ to $d\lambda$, when the latter is indefinitely small (*cf.* Emissivity).

Radiation constants.—*See* Black body.

Rankine.—A name sometimes applied to the absolute Fahrenheit scale of temperature.

Réaumur.—(R). A thermometric system in which the freezing point of water is called 0°, and the boiling point, 80°.

Reflectivity.—The ratio of the intensity of the light specularly reflected from a surface to the intensity of the light incident upon it. It is a pure numeric.

Refraction.—1. The **index of refraction, refractive index,** or **refractive exponent** is $n = \sin i/\sin r$; i = angle of incidence from a vacuum upon the substance, and r = angle of refraction, each measured from the normal to the surface. 2. **Refractivity** is $(n - 1)$. 3. **Specific refractivity** (r_G) is $(n - 1)/d$. **Specific refraction** (r_L) is $(n^2 - 1)/d(n^2 + 2)$. d = mass per unit of volume. 4. **Molecular refractivity** $= Mr_G$. **Molecular refraction** $= Mr_L$. M = molecular weight. By replacing M by the atomic weight, the corresponding **atomic values** are obtained. 5. **Refractive constant** of a solute is its specific refractivity computed on the assumption that the refractivity of the solution is equal to the sum of the refractivities of its pure constituents each multiplied by the ratio of its mass per unit volume of the solution to its own density when pure.

Reluctance.—The magnetic reluctance of a body between two specified equipotential surfaces is the ratio of the difference in the two potentials divided by the flux of magnetic induction from [to] either surface to [from] the body. It has no significance unless these two fluxes are the same.

Resistance.—1. The **electrical resistance** of a body between two specified equipotential surfaces is E/I, where E is the unchanging difference in the potentials of the surfaces and I is the resulting current across any transverse section between them. 2. **Specific resistance.** *See* Resistivity.

Resistivity.—1. [resistance × length]. **Resistivity,** or **volume resistivity,** of a substance is the longitudinal resistance per unit of length of a uniform bar of the substance of unit sectional area. 2. [resistance × mass/(length)^2]. **Mass resistivity** of a substance is the longitudinal resistance per unit of length of a uniform bar of the substance of such a sectional area that it contains one unit of mass per unit of length. 3. [resistance]. **Surface resistivity** is the resistance per unit of length of a strip of the surface of unit width. It has reference solely to the current which is restricted to the surface.

Rhe.—Name proposed for cgs unit of fluidity; = one reciprocal poise.

Right ascension.—*See* Celestial sphere.

Rigidity.—If to the four faces of a cube which are parallel to a given edge there be applied tangential stresses which are equal in absolute value, perpendicular to the given edge, and so directed as to produce a pure distortion, the other two faces will be deformed into diamond shaped figures if the material is isotropic. The modulus of rigidity is defined as the quotient of the stress on any one of the faces divided by the resulting change in any one of the angles of a distorted face. Also called **modulus of shear, Coulomb's modulus, modulus of torsion** (the last is undesirable).

Rotation.—*See* Rotatory power.

Rotatory power, Optical.—1. The **natural rotatory power** is θ/l, where θ is the rotation of the plane of polarization which occurs in a path of length l. The **specific rotatory power** ($[\alpha]$) is θ/dl, d = density. The **molecular** [or **atomic**] **rotatory power** is $M\theta/dl$ [or $A\theta/dl$]; M = molecular, A = atomic weight. 2. The **magnetic rotatory power** is $\theta/(lH \cos \alpha)$, where H = intensity of the magnetic field and α = angle between H and the path of the light. It is commonly called **Verdet's constant.** From the magnetic rotatory power, the **specific** ($[\omega]$), **molecular,** and **atomic magnetic rotatory powers** are derived exactly as in the case of natural rotation. The ratio of any one of these quantities to the corresponding one for a chosen reference substance is called the **relative power.** Water is the reference substance commonly chosen, and $[\Omega]$ is used to denote the molecular magnetic rotatory power relative to water.

Rydberg's fundamental frequency, and series constant.—*See* Series, spectral.

Secohm.—A superseded name for the henry.

Second.—1. (sec). **Time,** $1/86400$ day. Mean solar day, unless contrary is indicated. 2. (″). Unit of **angle,** $1/3600$ degree. 3. (‶). **Centesimal second** = 0.0001 grade.

Seger cone.—One of a graded series of cones of refractory material which, by their softening and the resultant deformation, indicate the heat treatment to which they have been subjected.

Series, Spectral.—Spectral lines, or groups of lines, which occur in orderly sequence. Most of these sequences can be represented by an equation of the form $\frac{1}{\lambda} = A - \frac{BN}{(m + \alpha + \beta/m^2)^2}$; λ = wave-length in vacuo; m is an integer varying from one line (or group) to another; for any one series, A, B, N, α and β are constants; B is an integer; N is known as **Rydberg's constant,** its value is determined by the constitution of the radiating atom. On Bohr's theory, $N = N_\infty \frac{M}{M + \mathbf{m}_0}$, where M = mass of the atom, $\mathbf{m}_0$ = electronic mass, and $N_\infty = 2\pi^2\mathbf{m}_0\mathbf{e}^4/\mathbf{h}^3\mathbf{c}\epsilon_o{}^2$; N_∞ is known as **Rydberg's universal series constant;** $\mathbf{e}$ = electronic charge; $\mathbf{h}$ = Planck's constant; ϵ_o = dielectric constant of vacuum; $\mathbf{c}$ = velocity of light in vacuo. On this theory, B denotes the number of electrons displaced from their normal positions, m is the **principal quantum number,** α depends upon the subordinate, or azimuthal, quantum number, and $\beta = 0$. For atoms of the type of hydrogen, $\alpha = 0$, $\beta = 0$; for others $(m + \alpha + \beta/m^2)$ is frequently called the **effective quantum number,** generally it is not an integer. **Rydberg's fundamental frequency** is $\nu_\infty = \mathbf{c}N_\infty$.

Sidereal month.—The time required for the moon to complete one apparent circuit among the stars.

Siemens unit.—(S.E.). A superseded unit of electrical resistance proposed in 1860 by Werner von Siemens; defined as the resistance at 0°C of a column of mercury one meter long and of a uniform cross section = one mm^2.

Slug.—A unit of mass. 1. The mass which will acquire an acceleration of one foot per sec^2 when continuously acted upon by a force of one pound weight. Also called **geepound,** and **engineer's unit of mass.** 2. The **metric slug** is the mass which will acquire an acceleration of one meter per sec^2 when continuously acted upon by a force of one kilogram weight.

Solar month.—$1/12$ tropical year.

Solubility.—1. By solubility of the **non-gas** a in b is meant the mass of a per unit mass of b which is contained in the mixture which is in equilibrium with an excess of a. In this mixture b is said to be saturated with a. Data are frequently restricted to mass of a per unit mass of mixture, mass of a per unit volume of mixture, or moles of a per mole of mixture. 2. Solubility of a **gas** is C_s/C_g, C_s = concentration of gas in the solution, C_g = concentration of gas in overlying gas phase. 3. **Solubility product** of an ionized substance (A_nB_m) in a stated solvent = $[A]^n \cdot [B]^m$, where $[A]$ and $[B]$ denote the concentrations of the two ions when the solution is saturated with the substance.

Specific gravity.—($d_{t_1}^{t_2}$). The ratio of the mass of a certain volume of the substance at the temperature t_2 to that of the same volume of a reference substance (usually water) at temperature t_1. Frequently, but incorrectly, called density.

Specific heat.—1. **Heat capacity.** *See* Capacity. 2. **Specific heat of electricity.**—*See* Thomson effect. 3. **Einstein's specific heat constant** (β) = ratio of Planck's constant (**h**) to Boltzmann's molecular gas constant (k_0). 4. **Ratio of specific heats** = $\gamma = c_p/c_v$; c_p, c_v = specific heat at constant pressure and at constant volume, respectively.

Specific inductive capacity.—The ratio of the dielectric constant of the substance to that of a vacuum.

Specific refractive power.—Used indifferently to denote several of the refractive constants (*cf.* Refraction).

Sperm candle, English.—A superseded unit of luminous intensity = one Int. candle.

Spheradian.—*See* Steradian.

Spherical candlepower, Mean.—*See* Mean spherical candlepower.

Square.—(sq.), (^{2}). Used in conjunction with the name of a unit of length to form the name of a related unit of area; *e.g.*, square foot (sq. ft.), (ft.^{2}) is the name of a unit of area equivalent to the area of a square with edges one foot long.

Square degree.—The solid angle enclosed by a cone of vanishingly small vertex angle 2θ is $k\pi\theta^2$. If θ is expressed in radians and the unit of solid angle is so chosen that $k = 1$, that unit is called a **steradian.** If θ is expressed in degrees, and $k = 1$, the corresponding unit of solid angle is called a **square degree.** One square degree = $(\pi/180)^2$ steradians. This procedure defines a definite unit of solid angle although the solid angles enclosed in cones of finite vertex angles are not proportional to the squares of those angles.

Stefan's constant.—*See* Black body.

Steradian.—The solid angle which encloses on the surface of a concentric sphere an area = (radius)^2.

Stoichiometric.—Pertaining to the ratio of the masses of the several elements contained in a pure chemical compound.

Strain.—1. For pure distortion the strain is measured by the change in a significant angle. 2. The ratio of change in size to original size.

Stress.—The force per unit of area over which it acts.

Surface tension.—(γ). $[m/t^2]$. Owing to molecular attraction, two fluids in contact adjust themselves so that the area of their interface is a minimum, consistent with other requirements. This adjustment may be pictured as arising from a tension residing in the surface itself; to this is given the name **surface tension.** Its value is defined as the normal, tensile force, per unit of length, across any line traced on the surface.

Susceptibility.—(κ). In the electromagnetic systems of units, $4\pi\kappa$ is the excess of the magnetic permeability of the substance over that of a vacuum.

Synodical.—In astronomy, the synodical period of a body is the interval between its successive returns to the same position with reference to the plane which is perpendicular to the plane of the ecliptic and which continuously passes through the centers of the earth and the sun.

Synonical month.—*See* Lunar month.

Temperature conductivity.—*See* Diffusivity.

Tension, Surface.—*See* Surface tension.

Tenth-meter.—10^{-10} meter; one Ångstrom unit.

Thermal.—*See* Heat.

Thermoelectric power.—*See* Power.

Thomson effect.—In a region in which the temperature of a homogeneous metallic conductor varies from section to section, there exists a potential gradient which is proportional to the product of the temperature and its gradient. This is the Thomson (or Kelvin) thermoelectric effect. The constant of proportionality is called the coefficient of the effect. If the coefficient is positive, a positive electric current flowing from hot section to cooler section tends to make the temperature more uniform; it is as if the current carried heat from hot portion to cooler portion, as if the electricity had a certain specific heat. This is what Thomson called the **specific heat of electricity.** It may be either positive or negative, depending upon the metal.

Time.—**True noon,** or **local true noon,** is the instant at which the sun is bisected by the meridional plane of the observer. **Mean noon,** or **local mean noon,** is the instant at which a fictitious mean sun is bisected by the meridional plane. This **mean sun** is one endowed with such a uniform, apparent angular velocity in the equatorial plane that in one tropical year it will make exactly the same number of apparent revolutions around the earth as are made by the true sun. Time measured from the true noon is called **true,** or **apparent, solar time;** that from mean noon is called **mean time.** The excess of mean time over true time is called **equation of time.** The earth has been divided into a series of time zones, each 15° of longitude in width, so that intercourse may be facilitated by all places in each zone using the mean time corresponding to the center of the zone; this is known as **standard time.** The first zone is centered on Greenwich, England.

Titer.—*See* Concentration.

Torque.—The moment of a force.

Tropical month.—The yearly average of the time required for the moon to traverse 360° of astronomical longitude.

Twist.—If a uniform bar of free length l be clamped rigidly at one end and the other end be twisted, about the axis of the bar, through an angle θ, the twist of the bar is defined as θ/l. Similarly for other cases.

Units, Systems of.—The fundamental units in most absolute systems are those of mass, length, time, thermometric degree, and the dielectric constant (or the magnetic permeability) of a vacuum. Other units are defined in terms of these by the use of established relations, arbitrary factors being made unity. The most common systems are the centimeter-gram-second-degree Centigrade (cgs), and the foot-pound-second-degree Fahrenheit (fps) systems. *See also* International electric units, practical electric units, and absolute.

Van der Waals.—*See* Waals.

Violle unit.—A superseded unit of luminous intensity based upon the brightness of fused platinum at the temperature of solidification.

Viscosity.—If a fluid is flowing in the plane yz with velocity v it exerts upon an adjacent plane a tangential drag $= \eta(dv)/(dx)$, per unit of area. η is called the **viscosity, coefficient of viscosity,** or **coefficient of internal friction.** Unit: poise.

Viscosity, Kinematic.—Viscosity divided by density.

Volt.—The electrical potential difference which, when steadily applied to a conductor having a resistance of one ohm, will produce in it a current of one ampere (*cf.* absolute and international units). The Int. Committee authorized by the London Conference, 1908, agreed to regard the emf of the Weston normal cell at 20°C as exactly 1.0183 Int. volts. This furnishes a subsidiary definition which is slightly discordant with the primary one. These tables distinguish between the two, and between units derived from them, by using (a) to denote those based on ampere and ohm, and (v) to denote those based on volt as defined by the Weston cell.

Volt-electronic charge.—Analogous to volt-faraday.

Volt-faraday.—The work which must be done in order to transfer one faraday of positive electricity from any point to another having a potential one volt higher than the former.

Volt-second.—Unit of flux of magnetic induction. The amount defined by the change per second, of the magnetic induction through an area, required to induce around the area an emf of one volt.

Volume, Specific.—Reciprocal of the density.

Waals, Van der.—In the equation $(p + a/v^2)(v - b) = 1 + \alpha t$, a and b are known as Van der Waals' constants; $a[b]$ = pressure [volume] constant.

Watt.—Unit of power; work done at rate of one joule per second.

Watt-hour.—Work expended by one watt in one hour (*cf.* kilowatt-hour).

Wave-length.—(λ). Distance between consecutive corresponding points in a monofrequent wave train. Occasionally applied to complex waves.

Wave number.—Reciprocal of wave-length.

Weight.—The force with which a body, left to itself, is urged towards the earth. In the absolute systems of units it is numerically equal to the mass of the body multiplied by the acceleration of gravity (g) at the position considered; hence varies with position. Such expressions as **gram weight [pound weight]** are to be interpreted as meaning the weight of a gram [a pound] at a place where g has the standard value, 980.665 cm/sec.^{2}

Wien's displacement constant.—(w). *See* Black body.

Year.—(yr). Time required for earth to make one complete circuit of its orbit, as defined by its return to the same position as determined by the sun and some celestial point of reference. For the **tropical, equinoctial,** or **ordinary** year the reference point is the mean vernal equinox; for the **sidereal,** or **true,** year, it is a fixed star; for **anomalistic** year, it is perihelion of earth's orbit; for **eclipse** year, it is ascending node of moon's orbit.

Young's modulus.—If a bar of uniform section be subjected to a longitudinal tension, the ratio of this stress to the resulting elongation per unit of length is called its Young's modulus. Also called **modulus of elasticity, elastic modulus, longitudinal elasticity, coefficient of resistance to extension, modulus of traction.**

ELEMENTS AND ATOMS

ATOMIC WEIGHTS

The values given in column four were compiled for International Critical Tables (I. C. T.) by Prof. G. P. Baxter in 1923 and are those upon which all the data given in International Critical Tables are based.

Following these are shown the accepted atomic weights back to 1882. For the period since 1903 these are taken from the reports of the International Committee on Atomic Weights; for the period 1894 to 1903, from the reports of the American Chemical Society's Committee on Atomic Weights; for the year 1882, from F. W. Clarke's "A Recalculation of the Atomic Weights," reproduced in the first (1883) edition of "Landolt-Börnstein." These 1882 values (to two decimals) are given in parentheses. A date in parentheses indicates the first appearance of the element in the atomic weight table. All the values given are based upon O = 16.000.

Symbol	Atomic number	Name	I. C. T. at. wt.	Atomic weights (1925–1882)
A	18	Argon	39.91	'25, 39.91; '24–'19, 39.9; '18–'11, 39.88; '10–'03, 39.9; '02, 39.96 (1902)
Ac	89	Actinium	?	
Ag	47	Silver	107.880	'25, 107.880; '24–'09, 107.88; '08–'03, 107.93; '02–'94, 107.92 (107.92)
Al	13	Aluminium	26.96	'25, 26.97; '24–'22, 27.0; '21–'00, 27.1; '99–'96, 27.11; '95–'94, 27 (27.08)
As	33	Arsenic	74.96	'25–'10, 74.96; '09–'00, 75.0; '99–'97, 75.01; '96, 75.09; '95–'94, 75.0 (75.09)
Au	79	Gold	197.2	'25–'00, 197.2; '99–'97, 197.23; '96, 197.24; '95–'94, 197.3 (196.61)
B	5	Boron	10.82	'25, 10.82; '24–'19, 10.9; '18–'00, 11.0; '99–'96, 10.95; '95–'94, 11 (10.97)
Ba	56	Barium	137.37	'25–'09, 137.37; '08–'00, 137.40; '99–'94, 137.43 (137.01)
Be	4	Beryllium	9.02	'25, 9.02; '24–'00, 9.1; '99–'96, 9.08; '95–'94, 9 (9.11)
Bi	83	Bismuth	209.00	'25–'22, 209.0; '21–'07, 208.0; '06–'03, 208.5; '02–'00, 208.1; '99–'96, 208.11; '95, 208; '94, 208.9 (208.00)
Br	35	Bromine	79.916	'25, 79.916; '24–'09, 79.92; '08–'03, 79.96; '02–'94, 79.95 (79.95)
C	6	Carbon	12.000	'25, 12.000; '24–'16, 12.005; '15–'98, 12.00; '97–'96, 12.01; '95–'94, 12 (12.00)
Ca	20	Calcium	40.07	'25–'12, 40.07; '11–'09, 40.09; '08–'00, 40.1; '99–'97, 40.07; '96, 40.08; '95–'94, 40 (40.08)
Cb	41	Columbium	93.1	'25–'17, 93.1; '16–'09, 93.5; '08–'03, 94; '02–'00, 93.7; '99–'97, 93.73; '96–'94, 94.0 (94.03)
Cd	48	Cadmium	112.41	'25, 112.41; '24–'09, 112.40; '08–'00, 112.4; '99, 112.38; '98–'97, 111.95; '96, 111.93; '95–'94, 112 (112.09)
Ce	58	Cerium	140.25	'25–'04, 140.25; '03, 140; '02–'00, 139; '99–'98, 139.35; '97–'94, 140.25 (140.75)
Cl	17	Chlorine	35.458	'25, 35.457; '24–'09, 35.46; '08–'94, 35.45 (35.45)
Co	27	Cobalt	58.97	'25, 58.94; '24–'09, 58.97; '08–'00, 59.0; '99–'98, 58.99; '97, 58.93; '96, 58.95; '95, 59.5; '94, 59 (59.02)
Cp	71	Cassiopeium	175.0	*See* Lu
Cr	24	Chromium	52.01	'25, 52.01; '24–'10, 52.0; '09–'00, 52.1; '99–'96, 52.14; '95–'94, 52.1 (52.13)
Cs	55	Cesium	132.81	'25–'09, 132.81; '08–'04, 132.9; '03, 133.0; '02–'00, 132.9; '00–'96, 132.89; '95–'94, 132.9 (132.92)
Ct	72	Celtium		Same as Hf
Cu	29	Copper	63.57	'25–'09, 63.57; '08–'94, 63.6 (63.32)
Ds Dy	66	Dysprosium	162.52	'25, 162.52; '24–'08, 162.5 (1908)
Em	86	Ra-emanation	222.	*See* Rn
Er	68	Erbium	167.7	'25–'12, 167.7; '11–'09, 167.4; '08–'00, 166.0; '99–'97, 166.32; '96–'94, 166.3 (166.27)
Eu	63	Europium	152.0	'25–'07, 152.0 (1907)
F	9	Fluorine	19.00	'25–'03, 19.0; '02–'00, 19.05; '99–'97, 19.06; '96, 19.03; '95–'94, 19 (19.03)
Fe	26	Iron	55.84	'25–'12, 55.84; '11–'09, 55.85; '08–'01, 55.9; '00, 56.0; '99–'96, 56.02; '95–'94, 56 (56.04)
Ga	31	Gallium	69.72	'25, 69.72; '24–'19, 70.1; '18–'09, 69.9; '08–'00, 70.0; '99–'97, 69.91; '96–'94, 69.0 (68.96)
Gd	64	Gadolinium	157.26	'25, 157.26; '24–'09, 157.3; '08–'03, 156; '02, 156.4; '01–'00, 157.0; '99–'97, 156.76; '96–'94, 156.1

Symbol	Atomic number	Name	I. C. T. at. wt.	Atomic weights (1925–1882)
Ge	32	Germanium	72.38	’25, 72.60; ’24–’00, 72.5; ’99–’97, 72.48; ’96–’94, 72.3
Gl	4	Glucinium	9.02	*See* Be
H	1	Hydrogen	1.0077	’25, 1.0077; ’24–’94, 1.008 (1.00)
He	2	Helium	4.00	’25–’16, 4.00; ’15–’11, 3.99; ’10–’03, 4.0; ’02, 3.96 (1902)
Hf	72	Hafnium	178.6	
Hg	80	Mercury	200.61	’25, 200.61; ’23–’12, 200.6; ’11–’94, 200.0 (200.17)
Ho	67	Holmium	163.4	’25, 163.4; ’23–’13, 163.5 (1913)
I (J)	53	Iodine	126.932	’25, 126.932; ’24–’09, 126.92; ’08–’05, 126.97; ’04–’94, 126.85 (126.85)
In	49	Indium	114.8	’25–’09, 114.8; ’08–’05, 115; ’04–’00, 114; ’99–’97, 113.85; ’96–’94, 113.7 (113.66)
Ir	77	Iridium	193.1	’25–’09, 193.1; ’08–’03, 193.0; ’02–’00, 193.1; ’99–’96, 193.12; ’95–’94, 193.1 (193.09)
K	19	Potassium	39.095	’25, 39.096; ’24–’09, 39.10; ’08–’03, 39.15; ’02–’94, 39.11 (39.11)
Kr	36	Krypton	82.9	’25, 82.9; ’24–’11, 82.92; ’10, 83.0; ’09–’03, 81.8; ’02, 81.76 (1902)
La	57	Lanthanum	138.91	’25, 138.90; ’24–’09, 139.0; ’08–’03, 138.9; ’02–’00, 138.6; ’99–’97, 138.64; ’96, 138.6; ’95–’94, 138.2 (138.84)
Li	3	Lithium	6.939	’25, 6.940; ’24–’11, 6.94; ’10–’09, 7.00; ’08–’96, 7.03; ’95–’94, 7.02 (7.02)
Lu	71	Lutecium	175.0	’25–’16, 175.0; ’15–’09, 174.0 (1909)
Ma	43	Masurium		
Mg	12	Magnesium	24.32	’25–’09, 24.32; ’08–’03, 24.36; ’02–’00, 24.3; ’99–’97, 24.28; ’96, 24.29; ’95–’94, 24.3 (24.01)
Mn	25	Manganese	54.93	’25–’09, 54.93; ’08–’00, 55.0; ’99–’96, 54.99; ’95–’94, 55 (54.03)
Mo	42	Molybdenum	96.0	’25–’00, 96.0; ’99–’97, 95.99; ’96, 95.98; ’95–’94, 96 (95.75)
N	7	Nitrogen	14.008	’25–’19, 14.008; ’18–’07, 14.01; ’06–’96, 14.04; ’95, 14.05; ’94, 14.03 (14.03)
Na	11	Sodium	22.997	’25, 22.997; ’24–’09, 23.00; ’08–’94, 23.05 (23.05)
Nb	41	Niobium	93.1	*See* Cb
Nd	60	Neodymium	144.27	’25, 144.27; ’24–’09, 144.3; ’08–’99, 143.6; ’98–’97, 140.80; ’96–’94, 140.5
Ne	10	Neon	20.2	’25–’09, 20.2; ’10–’04, 20.0 (1904)
Ni	28	Nickel	58.69	’25, 58.69; ’24–’09, 58.68; ’08–’00, 58.7; ’99–’96, 58.69; ’95–’94, 58.7 (58.06)
Nt	86	Niton	222.	*See* Rn
O	8	Oxygen	16.000	’25–’94, 16.000 (16.00)
Os	76	Osmium	190.8	’25, 190.8; ’23–’09, 190.9; ’08–’00, 191.0; ’99–’96, 190.99; ’95–’94, 190.8 (198.95?)
P	15	Phosphorus	31.024	’25, 31.027; ’24–’11, 31.04; ’10–’00, 31.0; ’99–’94, 31.02; ’95–’94, 31 (31.03)
Pa	91	Protoactinium	?	
Pb	82	Lead	207.20	’25–’16, 207.20; ’15–’09, 207.10; ’08–’03, 206.9; ’02–’96, 206.92; ’95–’94, 206.95 (206.95)
Pd	46	Palladium	106.7	’25–’09, 106.7; ’08–’03, 106.5; ’02–’00, 107.0; ’99–’96, 106.36; ’95, 106.5; ’94, 106.6 (105.98)
Po	84	Polonium	(210)	
Pr	59	Praseodymium	140.92	’25, 140.92; ’24–’16, 140.9; ’15–’09, 140.6; ’08–’00, 140.5; ’99–’97, 143.60; ’96–’94, 143.5
Pt	78	Platinum	195.23	’25, 195.23; ’24–’11, 195.2; ’10–’09, 195.0; ’08–’03, 194.8; ’02–’00, 194.9; ’99–’96, 194.89; ’95–’94, 195 (194.87)
Ra	88	Radium	225.95	’25, 225.95; ’24–’16, 226; ’15–’09, 226.4; ’08–’03, 225 (1903)
Rb	37	Rubidium	85.44	’25, 85.44; ’24–’09, 85.45; ’08–’05, 85.5; ’04–’00, 85.4; ’99–’96, 85.43; ’95–’94, 85.5 (85.53)
Re	75	Rhenium		
Rh	45	Rhodium	102.91	’25, 102.91; ’24–’09, 102.9; ’08–’00, 103.0; ’99–’96, 103.01; ’95–’94, 103 (104.29)
Rn	86	Radon	222.	’25, 222; ’24–’12, 222.4 (1912)
Ru	44	Ruthenium	101.7	’25–’00, 101.7; ’99–’96, 101.68; ’95–’94, 101.6 (104.46?)
S	16	Sulfur	32.065	’25, 32.065; ’24–’16, 32.06; ’15–’09, 32.07; ’08–’03, 32.06; ’02–’96, 32.07; ’95–’94, 32.06 (32.06)
Sa	62	Samarium	150.43	’25, 150.43; ’24–’09, 150.4; ’08–’05, 150.3;

Symbol	Atomic number	Name	I. C. T. at. wt.	Atomic weights (1925–1882)
Sa	62	Samarium	150.43	'04–'03, 150; '02–'00, 150.3; '99–'97, 150.26; '96–'94, 150.0
Sb	51	Antimony	121.77	'25, 121.77; '24–'03, 120.2; '02–'00, 120.4; '99–'96, 120.43; '95–'94, 120 (120.23)
Sc	21	Scandium	45.10	'25–'21, 45.10; '20–'00, 44.1; '99–'97, 44.12; '96–'94, 44.0 (44.08)
Se	34	Selenium	79.2	'25–'00, 79.2; '99, 79.17; '98–'97, 79.02; '96–'94, 79.0 (78.98)
Si	14	Silicon	28.06	'25, 28.06; '24–'22, 28.1; '21–'09, 28.3; '08–'94, 28.4 (28.26)
Sm	62	Samarium	150.43	*See* Sa
Sn	50	Tin	118.70	'25–'16, 118.70; '15–'00, 119.0; '99–'96, 119.05; '95–'94, 119 (117.97)
Sr	38	Strontium	87.62	'25–'11, 87.63; '10–'09, 87.62; '08–'00, 87.6; '99–'96, 87.61; '95, 87.66; '94, 87.6 (87.58)
Ta	73	Tantalum	181.5	'25–'10, 181.5; '11–'07, 181.0; '06–03, 183; '02–'00, 182.8; '99–'97, 182.84; '96–'94, 182.6 (182.56)
Tb	65	Terbium	159.2	'25–'07, 159.2; '06–'94, 160
Te	52	Tellurium	127.5	'25–'09, 127.5; '08–'03, 127.6; '02, 127.7; '01–'00, 127.5; '99–'97, 127.49; '96, 127; '95–'94, 125 (128.252)
Th	90	Thorium	232.15	'25–'19, 232.15; '18–'11, 232.4; '10–'09, 232.42; '08–'03, 232.5; '02–'00, 232.6; '99–'96, 232.63; '95–'94, 232.6 (233.95)
Ti	22	Titanium	47.9	'25–'03, 48.1; '02–'96, 48.15; '95–'94, 48 (49.96?)
Tl	81	Thallium	204.4	'25, 204.39; '24–'09, 204.0; '08–'03, 204.1; '02–'96, 204.15; '95–'94, 204.18 (204.18)
Tm Tu	69	Thulium	169.4	'25, 169.4; '24–'22, 169.9; '21–'09, 168.5; '08–'03, 171; '02–'94, 170.7
U	92	Uranium	238.17	'25, 238.17; '24–'16, 238.2; '15–'03, 238.5; '02–'00, 239.6; '99–'96, 239.59; '95–'94, 239.6 (239.03)
UX_2	91	Uranium-X_2	(234)	Isotope of Pa
V	23	Vanadium	50.96	'25, 50.96; '24–'12, 51.0; '11, 51.06; '10–'03, 51.2; '02–'00, 51.4; '99–'96, 51.38; '95–'94, 51.4 (51.37)
W	74	Tungsten	184.0	'25–'00, 184.0; '99–'97, 184.83; '96, 184.84; '95, 184.9; '94, 184 (184.03)
Xe	54	Xenon	130.2	'25–'11, 130.2; '10, 130.7; '09–'02, 128 (1902)
Y Yt	39	Yttrium	89.0	'25, 88.9; '24–'19, 89.33; '18–'16, 88.7; '15–'00, 89.0; '99–'97, 89.02; '96, 88.95; '95–'94, 89.1 (90.02?)
Yb	70	Ytterbium	173.6	'25, 173.6; '24–'16, 173.5; '15–'09, 172.0; '08–'03, 173; '02–'00, 173.2; '99–'97, 173.19; '96–'94, 173.0 (173.16)
Zn	30	Zinc	65.38	'25, 65.38; '24–'10, 65.37; '09, 65.7; '08–'00, 65.4; '99–'96, 65.41; '95–'94, 65.3 (65.05)
Zr	40	Zirconium	91.	'25, 91; '24–'09, 90.6; '01–'97, 90.4; '96–'94, 90.6 (89.57)

TABLE OF ISOTOPES

F. W. Aston

Element	Atomic number	I. C. T. atomic weight	Minimum number of isotopes	Mass numbers in order of the intensities of the mass-spectrum lines	Lit.
A	18	39.91	2	40, 36	(3, 5, 21)
Ag	47	107.880	2	107, 109	(15, 26)
Al	13	26.96	1	27	(10)
As	33	74.96	1	75	(4, 22)
B	5	10.82	2	11, 10	(4, 22)
Ba	56	137.37	1	138, 136	(17, 18)
Be	4	9.02	1	9	(33)
Bi	83	209.00	1	209	(19)
Br	35	79.916	2	79, 81	(4, 22)
C	6	12.000	1	12	(2, 21)
Ca	20	40.07	2	40, 44	(31, 32)
Cd	48	112.41	6	110, 111, 112, 113, 114, 116	(19)
Ce	58	140.25	2	140, 142	(18)
Cl	17	35.458	2	35, 37	(2, 21, 23)
Co	27	58.97	1	59	(15, 26)
Cr	24	52.01	1	52	(15, 26)
Cs	55	132.81	1	133	(6, 24)
Cu	29	63.57	2	63, 65	(14, 26)
F	9	19.00	1	19	(4, 22)
Fe	26	55.84	2	56, 54	(9, 17)
Ga	31	69.72	2	69, 71	(15, 26)
Ge	32	72.38	3	74, 72, 70	(13, 26)
Gl	4	9.02	1	9	(33)
H	1	1.0077	1	1	(3, 21)
He	2	4.00	1	4	(3, 21)
Hg	80	200.61	2,6	197–200, 202, 204	(2, 3, 21)
I	53	126.932	1	127	(5, 23)
In	49	114.8	1	115	(16)
K	19	39.095	2	39, 41	(6, 24)
Kr	36	82.9	6	84, 86, 82, 83, 80, 78	(3, 21)
La	57	138.91	1	139	(17)

Continued on p. 47.

PERIODIC CHART OF THE ELEMENTS WITH ATOMIC NUMBERS AND ATOMIC WEIGHTS

★			
	57 La 138.91	58 Ce 140.25	59 Pr 140.92
60 Nd 144.27	61	62 Sa 150.43	63 Eu 152.0
64 Gd 157.26	65 Tb 159.2	66 Dy 162.52	67 Ho 163.4
68 Er 167.7	69 Tu 169.4	70 Yb 173.6	71 Lu 175.0

I	II	III	IV	V	VI	VII	VIII or 0			
1 H 1.0077							2 He 4.00			
3 Li 6.939	4 Be 9.02	5 B 10.82	6 C 12.00	7 N 14.008	8 O 16.000	9 F 19.00	10 Ne 20.2			
11 Na 22.997	12 Mg 24.32	13 Al 26.96	14 Si 28.06	15 P 31.024	16 S 32.065	17 Cl 35.458	18 A 39.91			
19 K 39.095	20 Ca 40.07	21 Sc 45.10	22 Ti 47.9	23 V 50.96	24 Cr 52.01	25 Mn 54.93		26 Fe 55.84	27 Co 58.97	28 Ni 58.69
29 Cu 63.57	30 Zn 65.38	31 Ga 69.72	32 Ge 72.38	33 As 74.96	34 Se 79.2	35 Br 79.916	36 Kr 82.9			
37 Rb 85.44	38 Sr 87.62	39 Yt 89.0	40 Zr 91	41 Cb 93.1	42 Mo 96.0	43 Ma		44 Ru 101.7	45 Rh 102.91	46 Pd 106.7
47 Ag 107.880	48 Cd 112.41	49 In 114.8	50 Sn 118.70	51 Sb 121.77	52 Te 127.5	53 I 126.932	54 Xe 130.2			
55 Cs 132.81	56 Ba 137.37	★ 57 La 138.91	72 Hf (178.6)	73 Ta 181.5	74 W 184.0	75 Re		76 Os 190.8	77 Ir 193.1	78 Pt 195.23
79 Au 197.2	80 Hg 200.61	81 Tl 204.4	82 Pb 207.20	83 Bi 209.00	84 Po (210)	85	86 Rn 222			
87	88 Ra 225.95	89 Ac	90 Th 232.15	91 Pa	92 U 238.17					

★ Indicates rare earths. See above

α – ray ⟵

THE RADIOACTIVE ELEMENTS

FREDERICK SODDY

⟶ β – ray (or rayless)

Group	III	IV	V	VI	VII	VIII or 0	I	II	III	IV	V	VI
Principal element	Tl	Pb	Bi	Po	—	Rn	—	Ra	Ac	Th	Pa	U
Atomic number	81	82	83	84	85	86	87	88	89	90	91	92

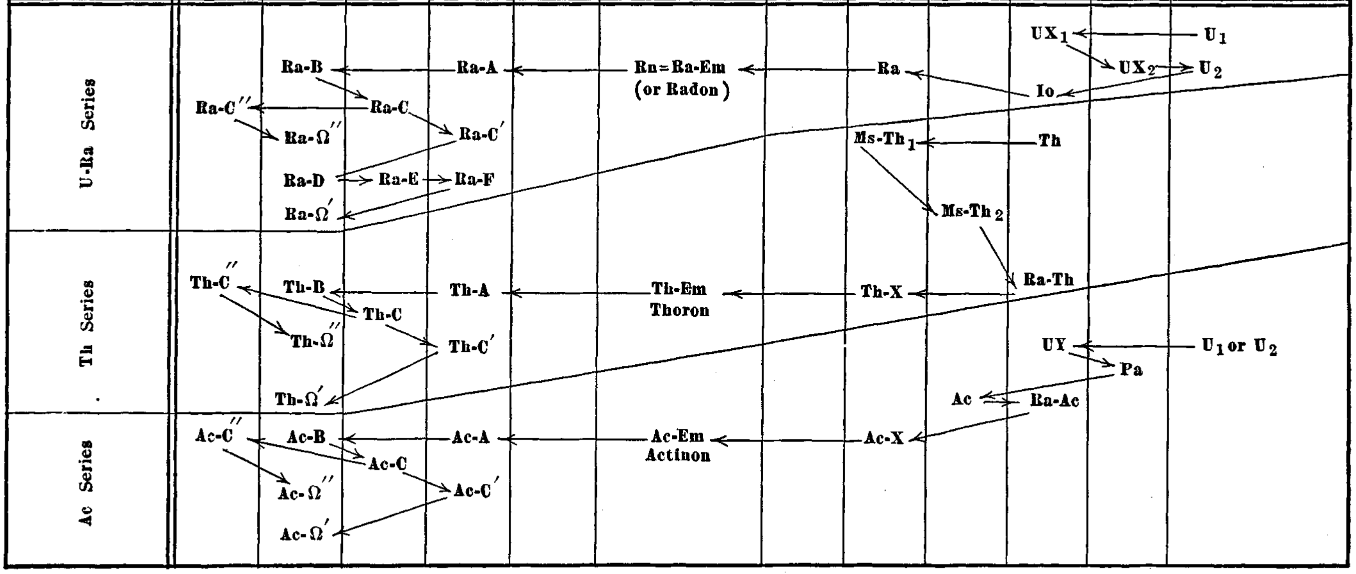


TABLE OF ISOTOPES.—*Continued*

Element	Atomic number	I. C. T. atomic weight	Minimum number of isotopes	Mass numbers in order of the intensities of the mass-spectrum lines	Lit.
Li	3	6.939	2	7, 6	(24, 27, 29, 30)
Mg	12	24.32	3	24, 25, 26	(28, 30)
Mn	25	54.93	1	55	(15, 26)
N	7	14.008	1	14	(3, 21)
Na	11	22.997	1	23	(6, 24)
Nd	60	144.27	3	142, 144, 146, 145	(17, 18)
Ne	10	20.2	2	20, 22	(1, 20, 21)
Ni	28	58.69	2	58, 60	(7)
O	8	16.000	1	16	(2, 21)
P	15	31.024	1	31	(4, 22)
Pr	59	140.92	1	141	(17)
Rb	37	85.44	2	85, 87	(6, 24)
S	16	32.065	1	32	(4, 22)
Sb	51	121.77	2	121, 123	(11, 25)
Sc	21	45.10	1	45	(15, 26)
Se	34	79.2	6	80, 78, 76, 82, 77, 74	(10)
Si	14	28.06	3	28, 29, 30	(4, 18, 22)
Sn	50	118.70	7,8	120, 118, 116, 124, 119, 117, 122, 121	(8)
Sr	38	87.62	2	88, 86	(15, 17, 26)
Te	52	127.5	3	128, 130, 126	(19)
Ti	22	47.9	1	48	(15, 26)
V	23	50.96	1	51	(15, 26)
Xe	54	130.2	7,9	129, 132, 131, 134, 136, 128, 130, 126, 124	(3, 5, 10, 21, 23)
Yt	39	89.0	1	89	(15, 26)
Zn	30	65.38	4	64, 66, 68, 70	(31)
Zr	40	91	3	90, 94, 92	(18)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Aston, *58*, **104**: 334; 19. (2) *Ibid.*, **104**: 393; 19. (3) *Ibid.*, **105**: 8; 20. (4) *Ibid.*, **105**: 547; 20. (5) *Ibid.*, **106**: 468; 20. (6) *Ibid.*, **107**: 72; 21. (7) *Ibid.*, **107**: 520; 21. (8) *Ibid.*, **109**: 813; 22. (9) *Ibid.*, **110**: 312; 22.

(10) Aston, *58*, **110**: 664; 22. (11) *Ibid.*, **110**: 732; 22. (12) *Ibid.*, **111**: 739; 23. (13) *Ibid.*, **111**: 771; 23. (14) *Ibid.*, **112**: 162; 23. (15) *Ibid.*, **112**: 449; 23. (16) *Ibid.*, **113**: 192; 24. (17) *Ibid.*, **113**: 856; 24. (18) *Ibid.*, **114**: 273; 24. (19) *Ibid.*, **114**: 717; 24.

(20) Aston, *3*, **39**: 449; 20. (21) *Ibid.*, **39**: 611; 20. (22) *Ibid.*, **40**: 628; 20. (23) *Ibid.*, **42**: 140; 21. (24) *Ibid.*, **42**: 436; 21. (25) *Ibid.*, **45**: 924; 23. (26) *Ibid.*, **47**: 385; 24. (27) Aston and Thomson, *58*, **106**: 827; 21. (28) Dempster, *166*, **52**: 559; 20. (29) Dempster, *166*, **53**: 363; 21.

(30) Dempster, *2*, **18**: 415; 21. (31) *Ibid.*, **19**: 431; 22. (32) *Ibid.*, **20**: 631; 22. (33) Thomson, *3*, **42**: 837; 21.

THE STRUCTURE OF THE ISOLATED ATOM

(Symbols, p. 50)

H. A. Kramers

According to the fundamental postulates of Bohr's atomic theory, a series of discrete "stationary states" has to be correlated with each atom. A definite "energy-content" can be assigned to every state, and an atom in a given state can change its energy only by performing a process of "transition" to another state. The emission of a spectral line of frequency ν is correlated with a spontaneous transition from a stationary state of energy content E_1 to another of energy content E_2 by equation (1)

$$\nu = \frac{1}{\mathbf{h}}(E_1 - E_2) \tag{1}$$

The stationary state with the smallest energy is termed the "normal state" of the atom. The properties of the stationary states can, to a considerable extent, be accounted for by assuming that the electrons surrounding the nucleus have definite motions, characterized by integral values of certain quantities. These integers are called the "quantum numbers" of the stationary state in question; by their values the energy of the state is completely fixed. For general treatment of the subject, see (1, 3, 4, 10, 11, 18).

Of special interest are the recent attempts (21) to develop a rational "quantum mechanics" of the atom. This work clearly demonstrates the limited applicability of a picture of atomic structure, in which the behavior of the electrons inside the atom is visualized by orbits possessing definite kinematical properties.

Atoms Containing One Electron.—Only for atoms containing a single electron, can a fairly complete description of the electronic motion in the stationary state, and of the significance of the quantum numbers be given. The motion of the electron obeys quite approximately the laws of electrodynamics, and can be described as a Keplerian elliptic motion, with the centre of gravity of the nucleus and the electron in one focus. On this motion, a slow uniform precession in the plane of motion is superposed (effect of variability of mass or "relativity-effect"). Two quantum numbers (n, k) define the stationary states $(n, k = 1, 2, 3 \ . \ . \ .; k \leq n)$, k/n being the ratio of the minor to the major axis of the ellipse. The states are denoted by the symbol n_k.

In the **normal state,** $1_1 (n = k = 1)$, the orbit is circular; and, omitting the correction due to the relativity effect, its constants are given by equations (2)

$$\begin{aligned} a_1 &= \frac{1}{Z}\cdot\frac{\mathbf{h}^2}{4\pi^2\mathbf{e}^2\mathbf{m}_0} = \frac{r_1}{Z} = \frac{0.53}{Z} \times 10^{-8} \text{ cm} \\ \omega_1 &= \frac{Z^2}{1+\frac{\mathbf{m}_0}{M}} \times \frac{4\pi^2\mathbf{e}^4\mathbf{m}_0}{\mathbf{h}^3} = \frac{2\nu_\infty Z^2}{1+\frac{\mathbf{m}_0}{M}} = \frac{6.6Z^2}{1+\frac{\mathbf{m}_0}{M}} \times 10^{15} \text{ sec}^{-1} \\ W_1 &= \frac{Z^2}{1+\frac{\mathbf{m}_0}{M}} \times \frac{2\pi^2\mathbf{e}^4\mathbf{m}_0}{\mathbf{h}^2} = \frac{Z^2\nu_\infty\mathbf{h}}{1+\frac{\mathbf{m}_0}{M}} = \frac{2.15Z^2}{1+\frac{\mathbf{m}_0}{M}} \times 10^{-11} \text{ erg.} \end{aligned} \tag{2}$$

In **higher quantum states,** the orbital constants are, with the same approximation, given by (3, 4):

$$\begin{aligned} a_n &= n^2 a_1 = \frac{n^2}{Z} r_1 \\ \omega_n &= \frac{\omega_1}{n^3} = \frac{2Z^2\nu_\infty}{n^3\left(1+\frac{\mathbf{m}_0}{M}\right)} \\ W_n &= \frac{W_1}{n^2} = \frac{Z^2\nu_\infty\mathbf{h}}{n^2\left(1+\frac{\mathbf{m}_0}{M}\right)} \end{aligned} \tag{3}$$

$$b_{n,k} = nka_1 = \frac{nkr_1}{Z}; \ p_k = k^2 a_1 = \frac{k^2 r_1}{Z} \tag{4}$$

The number of revolutions corresponding to one rotation of the major axis, is, to a first approximation, given by (5):

$$\frac{\omega_n}{\sigma_{n,k}} = \frac{k^2}{Z^2} \times \frac{2}{\alpha^2} = \frac{k^2}{Z^2} \times 37{,}700 \tag{5}$$

$$\left(\alpha = \frac{2\pi\mathbf{e}^2}{\mathbf{hc}} = 7.30 \times 10^{-3} \cong \frac{1}{137}; \ \alpha^2 = 5.31 \times 10^{-5}\right)$$

The exact energy formula, neglecting terms containing $\mathbf{m}_0/M$, is given by (6):

$$\begin{aligned} W_{n,k} &= \mathbf{m}_0\mathbf{c}^2\left[\left\{1 + \left(\frac{\alpha Z}{n - k + \sqrt{k^2 - \alpha^2 Z^2}}\right)^2\right\}^{-\frac{1}{2}} - 1\right] \\ &= \frac{Z^2}{n^2} \times \frac{2\pi^2\mathbf{e}^4\mathbf{m}_0}{\mathbf{h}^2}\left\{1 + \alpha^2 Z^2\left(\frac{1}{kn} - \frac{3}{4n^2}\right) + \ . \ . \ . \ \right\} \end{aligned} \tag{6}$$

(For general formula for W, including terms in $\mathbf{m}_0/M$, see (9).) Figure 1 illustrates the stationary states in the hydrogen atom for which $n = 1, 2, 3, 4$. The arrows indicate the transitions giving rise to the fine-structure components of the spectral lines, H_α and H_β. The numerical constants for these states are given in Table 1.

TABLE 1.—HYDROGEN ORBITS; $r_1 = 5.286 \times 10^{-9}$ cm (11)

n_k	a/r_1	b/r_1	p/r_1	$\omega \times 10^{-14}$	$\sigma \times 10^{-8}$	ω/σ
1_1	1	1	1	65.78	1746	37 700
2_1	4	2	1	8.222	218.3	37 700
2_2	4	4	4	8.222	54.57	150 700
3_1	9	3	1	2.436	64.68	37 700
3_2	9	6	4	2.436	16.17	150 700
3_3	9	9	9	2.436	7.187	339 300
4_1	16	4	1	1.029	27.29	37 700
4_2	16	8	4	1.029	6.822	150 800
4_3	16	12	9	1.029	3.032	339 300
4_4	16	16	16	1.029	1.705	603 200

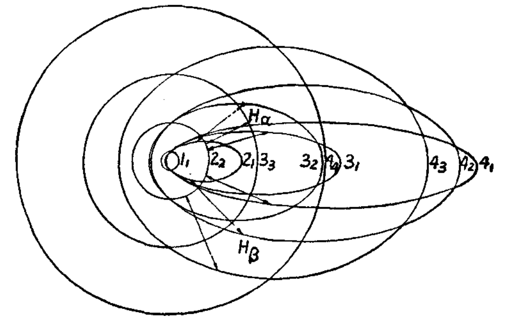


FIG. 1.—Orbits in hydrogen to $n = 4$. (*Reproduced by permission from The Journal of the Franklin Institute.*)

Atoms Containing More than One Electron.—A complete theory of stationary states is lacking. Many properties of these states can be accounted for, however, on the basis of the principles applied to atoms containing one electron. As a first approximation, each electron may be considered as moving in a central field of force due to the nucleus and the other electrons, its motion being characterized by a "principal quantum number" n and a "subordinate quantum number" k. The electronic orbit can be described as a plane periodic orbit on which a uniform precession in the plane is superposed ("central orbit" *cf.* Fig. 2).

If the position of the electron in the orbital plane is defined by polar coordinate (r, φ), the quantum numbers are defined by Sommerfeld's quantum conditions (7)

$$k = \frac{2\pi \mathbf{m}_0 \beta r^2}{\mathbf{h}} \frac{d\phi}{dt} = \frac{2\pi P}{\mathbf{h}} \qquad (n-k) = \frac{1}{\mathbf{h}} \oint \mathbf{m}_0 \beta \left(\frac{dr}{dt}\right)^2 dt \quad (7)$$

where the factor β becomes equal to 1 if the relativity effect is neglected. P is equal to the angular momentum of the electron with respect to the nucleus; the integral has to be taken over a complete period of the radial motion, from A to B (Fig. 2).

In the **normal state** the electrons are distributed in groups, each of which is characterized by its quantum numbers (n, k). On passing from the nucleus to the surface of the atom, the successive groups correspond to successive integral values of the main quantum number n ("n-quantum group"), the innermost group being characterized by $n = 1$; each group is divided into subgroups corresponding to the different values which k may take. The possibility of reconciling such a picture with the dynamical properties of quantized central orbits is closely connected with the fact that in an orbit for which $k < n$ the electron will, in each revolution, dive into and leave again all regions occupied by electronic orbits for which the principal quantum number is smaller than n but equal to or greater than k (conception of "penetrating orbits").

The maximum number of electrons which an n-quantum group can contain is equal to $2n^2$. If it contains this number, it contains sub-groups corresponding to all possible values for k ($k = 1, 2 \ldots n$), and it is said to be a **"finally completed"** group. If a group, due to the dynamical properties of the atom under consideration, contains only sub-groups corresponding to $k = 1, 2 \ldots k_0$ ($k_0 < n$) it will be in a state which is termed **"provisionally completed,"** if it contains $2k_0^2$ electrons. For example, the 4-quantum group has reached the state of a 2-group ($k_0 = 1$) in Ca (20), the state of an 8-group or 8-shell ($k_0 = 2$) in Kr (36), the state of an 18-group or 18-shell ($k_0 = 3$) in Ag (47), and its final state of a completed 32-group or 32-shell ($k_0 = 4$) in Lu (71). With the exception of the 2-groups it seems impossible to assign definite values to the number of electrons in the several sub-groups of a provisionally, or finally, completed group; in fact, the actual properties of the electronic groups seem to show that the simple conception of central orbits characterized by the symbol n_k is essentially insufficient for their description. (Originally Bohr assumed that a group of $2k_0^2$ electrons contained $2k_0$ electrons in each sub-group.) Closely connected herewith is the impossibility of assigning definite spatial arrangements to the orbits belonging to one and the same group. In Table 2 the number of electrons in each group is given as far as the theory allows of a definite statement; those in parentheses are uncertain.

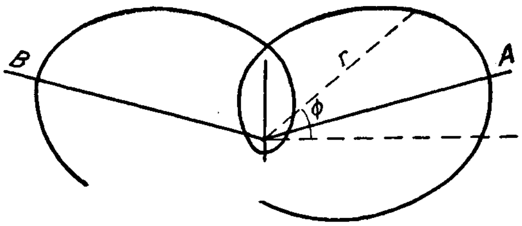


FIG. 2.—Central orbit.

From calculations based on Sommerfeld's quantum conditions and certain simplifying assumptions, a rough estimate of the dimensions of the different types of orbits may be made. Such estimates for neutral atoms and for positive ions containing only finally, or provisionally, completed groups are schematically represented in Fig. 3. The small vertical lines are so drawn that their distances from the dot at the left are proportional to the radius of the sphere inside which the electrons belonging to the respective groups are moving. The symbols $g\ (n_{1,2\ \ldots\ k_0})$ means that the corresponding groups contain g electronic orbits of principal quantum number n, and of subordinate quantum numbers from 1 to k_0.

For the calculation of the dimensions of the outermost groups it has been necessary to consider also experimental data relative to the effective gas-kinetic radii of the atoms of the inert gases, the effective radii of ions in crystals, ionic refraction, etc. As a rule the effective radii are 1.5 to 2.5 times larger than the orbital dimensions. As regards the inner groups, the estimate is rather accurate; for the outer groups, errors of the order of 10% might be expected Special mention must be made of the uncertainty in the radius of the 5-quantum group for elements heavier than barium; the radii of this group as given in Fig. 3 for the elements (72), 79, 80, 81, 82 are perhaps some 10% too high, as compared with radii of the homologous elements 47, 48, 49, 50.

For atoms containing only one electron in the outermost group, the dimensions of the orbit of this electron, and its frequency of revolution can with considerable accuracy be derived from the

TABLE 2

	1_1	2_1 2_2	3_1 3_2 3_3	4_1 4_2 4_3 4_4	5_1 5_2 5_3 5_4 5_5	6_1 6_2 6_3 6_4 6_5 6_6	7_1 7_2
1 H	1						
2 He	2						
3 Li	2	1					
4 Be	2	2					
5 B	2	2 1					
6 C	2	2 (2)					
— —	—	— —					
10 Ne	2	8					
11 Na	2	8	1				
12 Mg	2	8	2				
13 Al	2	8	2 1				
14 Si	2	8	2 (2)				
— —	—	— —	— —				
18 A	2	8	8				
19 K	2	8	8	1			
20 Ca	2	8	8	2			
21 Sc	2	8	8 1	(2)			
22 Ti	2	8	8 2	(2)			
— —	—	— —	— — —	—			
29 Cu	2	8	18	1			
30 Zn	2	8	18	2			
31 Ga	2	8	18	2 1			
— —	—	— —	— — —	— —			
36 Kr	2	8	18	8			
37 Rb	2	8	18	8	1		
38 Sr	2	8	18	8	2		
39 Y	2	8	18	8 1	(2)		
40 Zr	2	8	18	8 2	(2)		
— —	—	— —	— — —	— — —	—		
47 Ag	2	8	18	18	1		
48 Cd	2	8	18	18	2		
49 In	2	8	18	18	2 1		
— —	—	— —	— — —	— — —	— —		
54 X	8	8	18	18	8		
55 Cs	2	8	18	18	8	1	
56 Ba	2	8	18	18	8	2	
57 La	2	8	18	18	8 1	(2)	
58 Ce	2	8	18	18 1	8 1	(2)	
59 Pr	2	8	18	18 2	8 1	(2)	
— —	—	— —	— — —	— — — —	— — —	—	
71 Lu	2	8	18	32	8 1	(2)	
72 Hf	2	8	18	32	8 2	(2)	
— —	—	— —	— — —	— — — —	— — —	—	
79 Au	2	8	18	32	18	1	
80 Hg	2	8	18	32	18	2	
81 Tl	2	8	18	32	18	2 1	
— —	—	— —	— — —	— — — —	— — —	— —	
86 Rn	2	8	18	32	18	8	
87 —	2	8	18	32	18	8	1
88 Ra	2	8	18	32	18	8	2
89 Ac	2	8	18	32	18	8 1	(2)
90 Th	2	8	18	32	18	8 2	(2)
— —	—	— —	— — —	— — — —	— — —	— — —	—
— —	—	— —	— — —	— — — —	— — — —	— — —	—
[118 —	2	8	18	32	32	18	8]

frequency of the lowest frequency term in the corresponding spectral series, provided we may adhere to the simple central orbit model. Figure 4 contains a schematic picture of the orbits of the outer electron in the normal state of neutral atoms of the alkali metals, and of Cu, Ag, Au. They are all penetrating orbits, since they correspond to $k = 1$. The regions inside which the electrons of the completed groups are moving are designated by circles. The atoms of the inert gases are added for the sake of comparison. The numbers at the left of the nucleus indicate the number of electrons contained in each group; the symbols $n_{1,2}$ . . . at the right indicate the quantum numbers of the orbits contained in each group.

[For detailed calculations of electronic orbits, based on simplifying assumptions, see (12, 13, 20) (Cs and U); the work is semi-empirical. For detailed calculations on purely theoretical basis, see (15) (Ne, Na, Mg$^+$, Al^{++}, Si^{+++}, P^{++++}) and (16) (alkali metals); in Lindsay's work, the radii of outer groups in K$^+$, Rb$^+$, and Cs$^+$ seem too large, probably on account of inadequacy of assumptions regarding numbers of electrons in sub-groups, as well as of the simplifying assumptions made. For critical review of work on effective atomic radii, see (14) and for recent work (8). There is no simple direct connection between effective atomic radii and the magnitude of the space occupied by electronic orbits.]

In experiments on optical and X-ray spectra, we meet neutral atoms or atomic ions in **higher quantum states.** Several features of these states can be described on the simple central orbit model. In the case of "single excitation" all electronic orbits except one remain normal, and the other electron describes an orbit with quantum numbers which differ from those of the normal state. "Double excitation" corresponds to two electrons describing orbits different from those in the normal state, etc. We will here consider only singly-excited states.

In the stationary states (energy levels) involved in the emission of the ordinary X-ray spectra, one electron in the inner groups of the atom is lacking. In the states involved in the emission of the ordinary series-spectra, one electron belonging to the outermost group of the atom, the "series electron," moves in a central n_k orbit the dimensions of which are large as compared with those of the rest of the atom. It may move either quite outside the atomic residue or it may penetrate into it in each revolution.

As a first approximation, a non-penetrating orbit may be described as a Keplerian elliptical orbit performing a uniform precession in its plane, the shape of the ellipse being very nearly that of an n_k-orbit in an atom containing only one electron and having a nuclear charge Z^*e equal to the net-charge of the atomic residue. If the electron orbit is of the penetrating type, it may, as a first approximation, be described as a set of congruent outer Keplerian elliptical loops, connected by congruent inner loops, the angular distance between successive loops being the same. The semi-major axis, the semi-parameter p, and the semi-minor axis b of the outer loop can be found from the value of the corresponding spectral term (T) by means of the formulae

$$a = \frac{Z^*Nr_1}{T} \qquad p = \frac{k^2}{Z^*}r_1 \qquad b = \sqrt{ap} \qquad (8)$$

where $N\left(= \frac{\nu_\infty}{c} \times \frac{1}{1 + m_0/M}\right)$ is the Rydberg constant for the element in question, and Z^*e is the net-charge of the atomic residue. If we introduce the effective quantum number n^* ($n^{*2} = Z^{*2}N/T$), these formulae may be written:

$$a = \frac{n^{*2}}{Z^*}r_1 \qquad p = \frac{k^2}{Z^*}r_1 \qquad b = \frac{n^*k}{Z^*}r_1 \qquad (9)$$

The greater the ratio n^*/k (or a/b) the closer the approximation to which this description of the outer loops may be considered to hold. The maximum distance of the electron from the nucleus is equal to $a + \sqrt{a^2 - b^2}$, or very nearly equal to $2a - \frac{1}{2}p$.

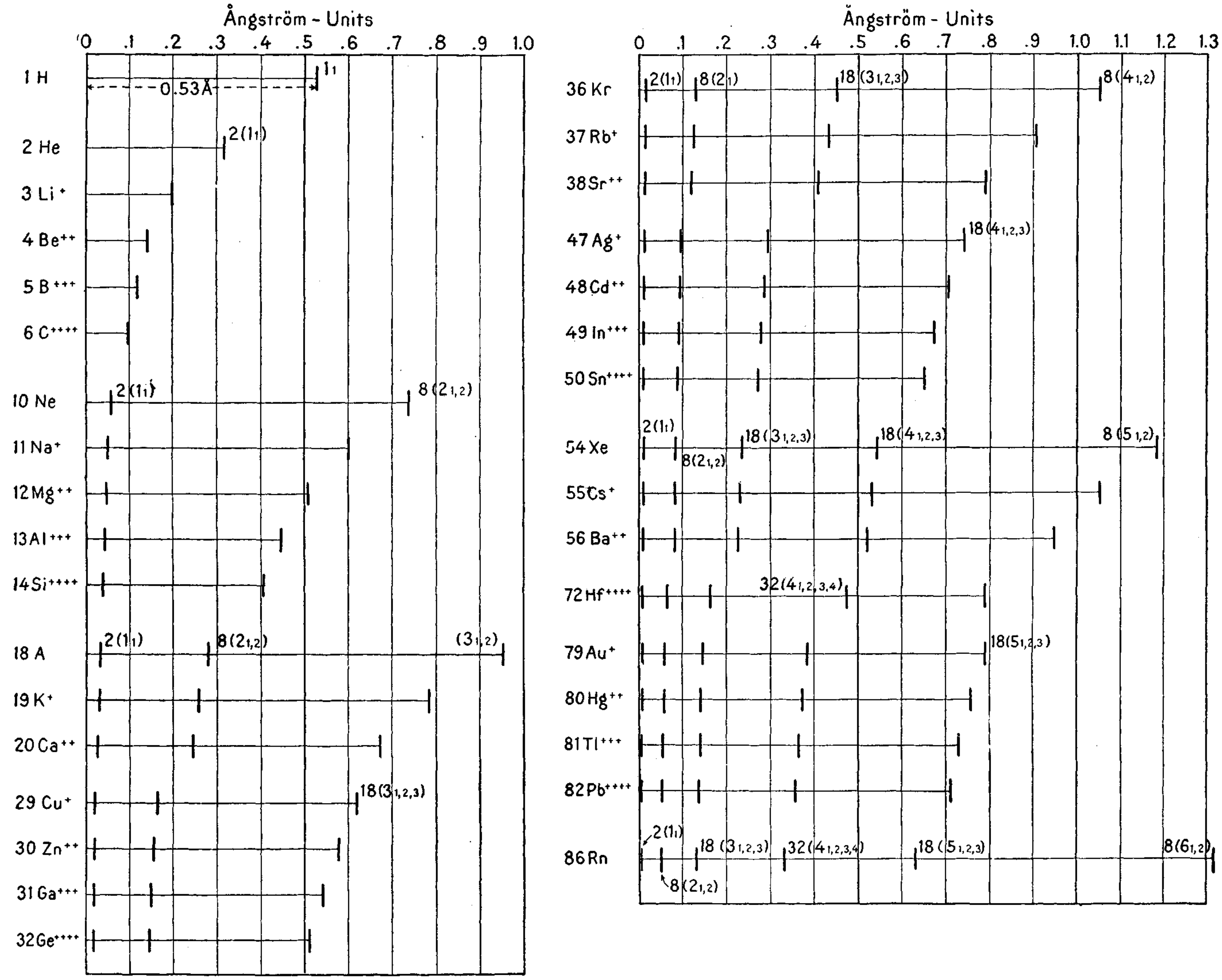


FIG. 3.—Maximum elongations of electrons of several groups.

The values to be assigned to the precessional frequency characterizing the penetrating central orbits are very uncertain. For the alkali elements, the ratio ω/σ for the n_1 orbits probably lies between 0.3 and 0.5, for the n_2 orbits (except lithium) between 0.5 and 1.0. Based on the above formulae, an illustration of the shapes of the orbits of the series electron corresponding to the stationary states of the K-atom, is given in Fig. 5. [For connection between spectra and the group structure of atoms, see ($^{6,\ 5}$); for spectra and central field of force, see ($^{12,\ 13}$); for series spectra and electronic orbits, see ($^{2,\ 7}$); for recent development of formal theory of electronic groups, see ($^{17,\ 19}$)].

SYMBOLS

The symbols **c**, **e**, **h**, **m**$_0$, λ have their usual significance (see p. 16); others which occur more than once are:

a_n	Semi-major axis of electronic orbit, state n.
$b_{n,k}$	Semi-minor axis of electronic orbit, state n, k.
k	Subordinate, or azimuthal, quantum number defining a stationary state.
M	Nuclear mass.
n	Principal quantum number defining a stationary state.

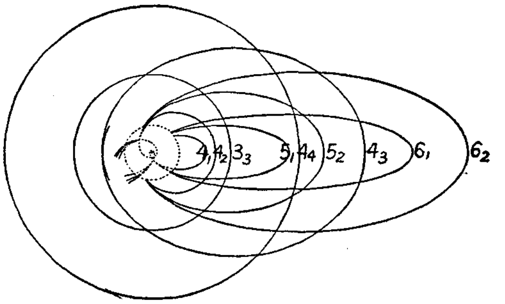


FIG. 5. —Orbits of the series electron of potassium. (*Reproduced by permission from The Journal of the Franklin Institute.*)

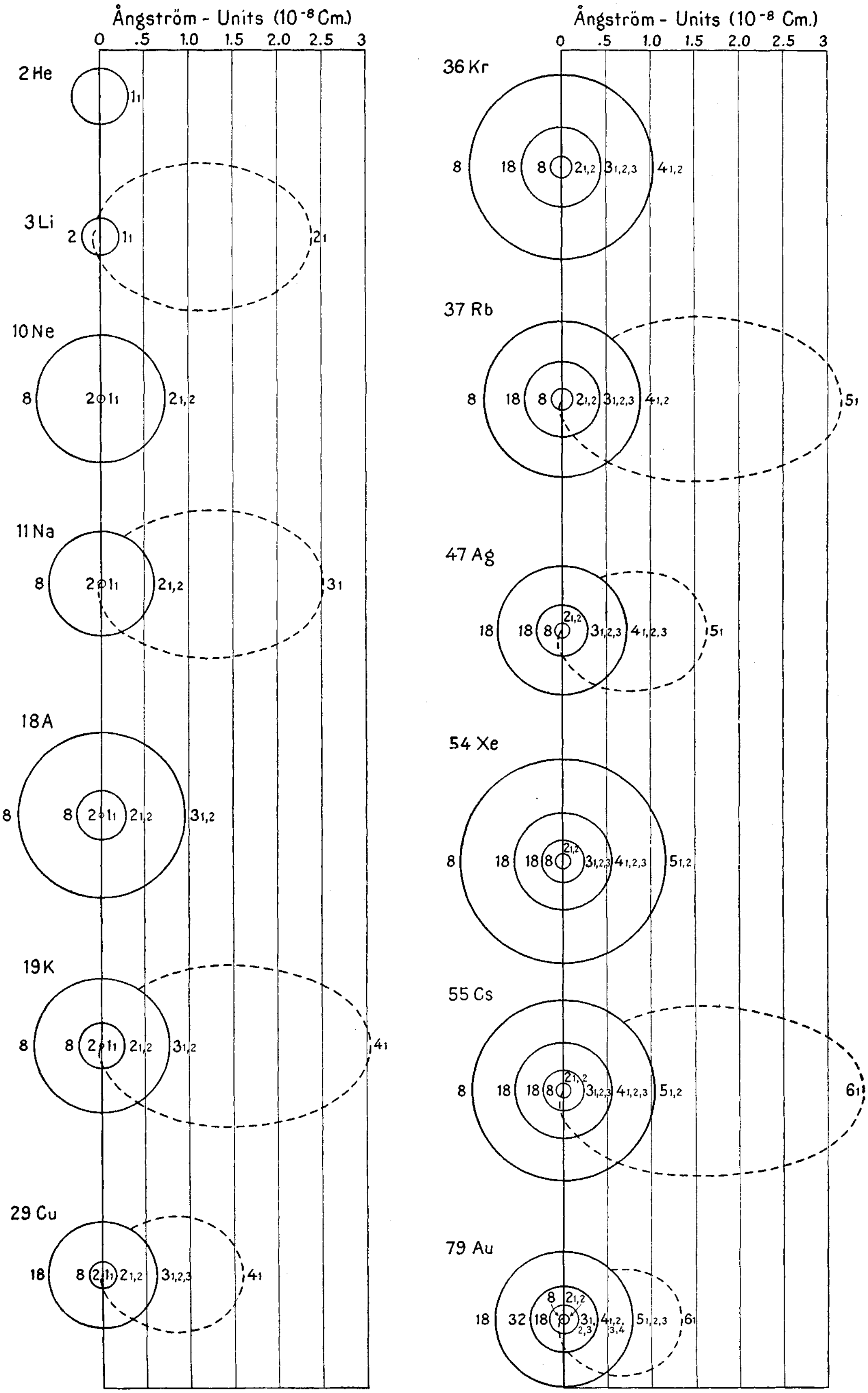


FIG. 4.—Normal orbit of outer electron.

n^*	Effective quantum number $= Z^*N/T$.
n_k	Designation of the state characterized by the numbers n, k.
N_∞	Rydberg constant.
p	Semi-parameter of the electronic orbit (semi-latus rectum).
r_1	Radius of first Bohr ring for hydrogen.
T	Spectral term = a wave number $(1/\lambda)$ of a spectral series.
v	Speed of electron in its orbit.
W_n	Energy expenditure required to remove the electron to infinity.
Z	Atomic number: Ze = nuclear charge.
Z^*e	Charge of atomic residue.
α	$2\pi e^2/hc$.
β	$(1 - v^2/c^2)^{-1/2}$
ν	Frequency of emitted radiation.
ν_∞	Rydberg fundamental frequency.
$\sigma_{n,k}$	Frequency of precession of electronic orbit.
ω_n	Frequency of revolution of electron; for penetrating orbits, the radial frequency, one revolution being from A to B, Fig. 2.

LITERATURE

(For a key to the periodicals, see end of volume)

(1) Andrade, The Structure of the Atom, 1923. (2) Birge and Blackett, *48*, **8**: 213; 24. (3) Bohr, The Theory of Spectra and Atomic Constitution, 2nd ed., 1924. (4) Bohr, *58*, **112**: 29; 23. *218*, **11**: 606; 23. (5) Bohr, *8*, **71**: 228; 23. (6) Bohr and Coster, *96*, **12**: 342; 23. (6a) Born, Vorlesungen über Atommechanik. (7) Born and Heisenberg, *96*, **23**: 388; 24. (8) Davey, *2*, **22**: 211; 23. (9) Darwin, *3*, **39**: 537; 23.

(10) Foote and Mohler, Origin of Spectra, 1923. (11) Foote, *143*, **198**: 344, 517; 24. (12) Fuess, *96*, **11**: 364; 22. **12**: 1; 22. **21**: 265; 24. *8*, **76**: 299; 25. (13) Hartree, *201*, **21**: 630; 23. **22**: 409, 464; 24. *5*, **106**: 552; 24. (14) Herzfeld, *200*, **19**: 259; 23. (15) Kramers and Urey, *O*. (16) Lindsay, *2*, **23**: 552; 24. *285*, **3**: 191; 24. *2*, **25**: 239; 25. (17) Pauli, Jr., *96*, **31**: 765; 25. (18) Sommerfeld, Atombau und Spektrallinien, 4th ed., 1925. (19) Stoner, *3*, **48**: 719; 24.

(20) Urey, *O*. (21) Heisenberg, *96*, **33**: 879; 25.

THERMOMETRY

E. F. Mueller, L. H. Adams, F. O. Fairchild and H. T. Wensel

1. THERMOMETRIC SCALES

E. F. Mueller

Centigrade or Celsius scale, °C
Fahrenheit scale, °F
Réamur scale, °R
Centigrade absolute or Kelvin scale, °K
Fahrenheit absolute or Rankine scale, °R′

By definition or as basic values adopted for I. C. T., the ice and steam points under a pressure of $1A_n$ have the following values:

Ice point: 0°C = 32°F = 0°R = 273.1°K = 491.58°R′.
Steam point: 100°C = 212°F = 80°R = 373.1°K = 703.58°R′.
°C = 5/9 (°F − 32) = 5/4°R = °K − 273.1.
°F = 9/5°C + 32 = °R′ − 459.58.

2. THE STANDARD THERMODYNAMIC SCALE

E. F. Mueller

The thermodynamic scale, which is based solely on the laws of thermodynamics and is independent of the properties of any material substance, is accepted as the standard scale of temperature. Temperatures on the thermodynamic scale are proportional to the pressures (or to the volumes) of an ideal gas in a perfect constant volume (or constant pressure) gas thermometer. The standard scale is realized in practice by use of gas thermometers, the indications of which can be reduced to the standard scale, or for higher temperatures, by use of the relations between the intensity of radiation from a black body and its temperature.

The experimental difficulties in the use of gas thermometers and the relatively low precision attainable in a single measurement have led to the introduction of a standard practical or working scale. This working scale is defined by certain base points, the temperatures of which have been determined by gas thermometer measurements, and by the indications of suitable instruments used for interpolation between the base points or for extrapolation to higher temperatures. It is possible in this way, without actually using a gas thermometer, to establish a working scale which does not differ to a demonstrable extent from the standard scale at any temperature within the range of the working scale. The practice of the various national standardizing laboratories in defining the working scale is substantially uniform at present, and it requires only minor adjustments and formal agreement to give the working scales of these laboratories the status of an international temperature scale. Such a scale would bear essentially the same relation to the standard scale, as do the international electric units to the absolute units.

The standard working scale may be defined by assigning numerical values to the temperatures defined by the boiling point of oxygen, the melting point of ice, the boiling point of water, the boiling point of sulfur, and the freezing points of antimony, silver and gold. The platinum resistance thermometer is the standard for interpolation in the range −195° to 0°C and from 0° to 650°C; the platinum-platinum rhodium thermocouple for the range from 650° to 1063°; and the luminous filament pyrometer above 1063°C.

Wien's law is accepted as expressing the brightness-temperature relation for a black body. For the purpose of defining the temperature scale above 1063°C the present practice of the national laboratories tends to favor the use of the value 1.430 cm degrees for the constant C_2 in this equation but the value 1.433 cm degrees has been adopted for I. C. T.

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(1) Reichsanstalt, *8*, **48**: 1034; 15. (2) Griffiths and Schofield, *83*, **13**: 222; 18. (3) Waidner, Mueller and Foote, Pyrometry, p. 46 (pub. by Am. Soc. Min. and Met. Engrs., 1920). (4) Day and Sosman, Dictionary of Applied Physics, **1**: 836; 22. (5) Henning, *243*, **44**: 349; 24. (6) Riechsanstalt, *243*, **44**: 517; 24.

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Reduction of Gas Thermometer Indications to the Thermodynamic Scale

The temperature t_g on the scale of a constant volume or constant pressure gas thermometer filled with any real gas, is proportional to the pressure the gas would exert or the volume it would occupy, respectively, if all of the gas were at the uniform temperature to be measured, and if the volume or the pressure, respectively, were the same at all temperatures. At 0° and 100°C, the temperature t_g is by definition identical with the thermodynamic temperature t, while at other temperatures t_g departs from t by amounts which are proportional to the pressure at 0°, called the initial pressure. The tabular values are accordingly given only for an initial pressure equivalent to 1 m of mercury.

The values of $t - t_g$ obtained by various methods cover a wide range, so that only the order of magnitude of the values can be considered as known with any certainty. The tendency in modern work in gas thermometry has been to employ hydrogen or helium as the thermometric gas, and for these gases the magnitude of $t - t_g$ is comparable with the experimental error of the gas thermometer itself, so that the importance of an exact knowledge of the departure of the scales of these gas thermometers from the thermodynamic scale is correspondingly reduced.

REDUCTION OF GAS THERMOMETER INDICATIONS, t_g, TO THE THERMODYNAMIC CENTIGRADE SCALE, t

Values of $t - t_g$ for an initial pressure of 1 meter of mercury

t °C	Helium		Hydrogen		Nitrogen	
	Const. vol.	Const. press.	Const. vol.	Const. press.	Const. vol.	Const. press.
− 250	+0.04	....	+0.12			
− 200	+ .02	+0.04	+ .06	+0.3	+0.5	
− 150	+ .01	+ .02	+ .03	+ .1	+ .2	+1.3
− 100	+ .005	+ .005	+ .015	+ .04	+ .06	+ .4
− 50	+ .002	+ .002	+ .005	+ .02	+ .03	+ .12
0	.000	.000	.000	.000	.00	.00
+ 25	− .001	− .001	− .001	− .003	− .008	− .02
50	− .001	.000	− .002	− .004	− .010	− .03
75	− .001	.000	− .001	− .003	− .005	− .02
100	.000	.000	.000	.000	.000	.00
150	+ .002	+ .001	+ .01	+ .01	+ .01	+ .05
200	+ .006	+ .001	+ .02	+ .02	+ .02	+ .12
250	+ .01	+ .002	....	+ .03	+ .04	+ .2
300	+ .02	+ .003	....	+ .04	+ .07	+ .3
350	+ .03	+ .005	....	....	+ .10	+ .4
400	+ .04	+ .006	....	....	+ .14	+ .5
450	+ .05	+ .008	....	....	+ .17	+ .6
500	....	....	....	....	+ .2	+ .7
600	....	....	....	....	+ .3	+ .9
800	....	....	....	....	+ .5	+1.3
1000	....	....	....	....	+ .7	+1.8
1200	....	....	....	....	+1.0	+2.3

LITERATURE

(For a key to the periodicals see end of volume)

(1)Rose-Innes, *3*, **2**: 131; 01. **15**: 301; 08. (2)Callendar, *3*, **5**: 48; 03. (3) Berthelot, *238*, **13B**: 113p.; 07. (4)Buckingham, *31A*, **3**: 237; 07. (5)Cath and Onnes, *168*, No. **156a**; 22. *18*, **6**: 1; 22. (6)Holborn and Otto, *96*, **23**: 77; 24. **30**: 320; 24. (7)Keesom and Onnes, *B60*: 15; 24.

3. FIXED POINTS

E. F. MUELLER

t = Temperature on standard scale.
p = Pressure in millimeters of Hg (1 mm Hg = $\frac{1}{760}$ A_n) where p is between 680 and 780 mm.

BASE POINTS USED IN DEFINING THE STANDARD WORKING SCALE

(I. C. T. temperature scale)

Substance	Phenomenon	Temperature, °C
Liquid O_2	Vapor pressure	$t = \left[\begin{array}{l} -183.00 + 0.245\,(t + 273.1)\log_{10} p/760 \text{ or} \\ -183.00 + 0.0126\,(p-760) - 0.0000065\,(p-760)^2 \end{array}\right]$
Solid CO_2*	Vapor pressure	$t = \left[\begin{array}{l} -78.51 + 0.1443\,(t + 273.1)\log_{10} p/760 \text{ or} \\ -78.51 + 0.01595\,(p-760) - 0.000011\,(p-760)^2 \end{array}\right]$
Mercury*	Freezing	$t = -38.87°$
Ice	Melting	$t = 0.000°$
Steam	Condensing	$t = \left[\begin{array}{l} 100.000 + 0.1727\,(t + 273.1)\log_{10} p/760 \text{ or} \\ 100.000 + 0.0367\,(p-760) - 0.000023\,(p-760)^2 \end{array}\right]$
Sulfur	Condensing	$t = \left[\begin{array}{l} 444.60 + 0.2215\,(t + 273.1)\log_{10} p/760 \text{ or} \\ 444.60 + 0.0909\,(p-760) - 0.000048\,(p-760)^2 \end{array}\right]$
Antimony	Freezing	To be determined with resistance thermometer. t = approx. 630.5°
Silver	Freezing	t = 960.5° (reducing atmosphere).
Gold	Freezing	t = 1063°

* Not needed according to one suggested definition of the scale.

SECONDARY FIXED POINTS USEFUL IN CALIBRATING TEMPERATURE MEASURING INSTRUMENTS

(I. C. T. temperature scale)

Substance	Phenomenon	Temperature °C
Hydrogen	Boiling	$t = -252.7_5 + 0.0044\,(p-760)$
Nitrogen	Vapor pressure	$t = -195.80 + 0.0109\,(p-760)$
Naphthalene	Condensing	$t = 217.96 + 0.207_5\,(t + 273.1)\log_{10}(p/760)$
Tin	Freezing	$t = 231.8_5$
Benzophenone	Condensing	$t = 305.9 + 0.194\,(t + 273.1)\log_{10}(p/760)$
Cadmium	Freezing	$t = 320.9$
Lead	Freezing	$t = 327.4$
Zinc	Freezing	$t = 419.4_5$
Aluminum (99.85 %)	Freezing	$t = 658.9$
Copper	Freezing	t = 1083 (reducing atmosphere)
Palladium	Freezing	$t = 1555 \pm 2$
Platinum	Melting	$t = 1755 \pm 6$
Tungsten	Melting	$t = 337_0 \pm 30$

The above values are in accord with the temperature scale used throughout I. C. T. For the last three points the following slightly different values have been suggested for future adoption as secondary points on an international practical scale.

Palladium	Freezing	$t = \left[\begin{array}{l} 1555 \text{ for } C_2 = 1.430 \\ 1554 \text{ for } C_2 = 1.433 \end{array}\right]$
Platinum	Melting	$t = \left[\begin{array}{l} 1765 \text{ for } C_2 = 1.430 \\ 1763 \text{ for } C_2 = 1.433 \end{array}\right]$
Tungsten	Melting	$t = \left[\begin{array}{l} 3400 \text{ for } C_2 = 1.430 \\ 3386 \text{ for } C_2 = 1.433 \end{array}\right]$

Additional Useful Secondary Points

Substance	Formula	Phenomenon	Temperature, °C
Isopentane	C_5H_{12}	Freezing	− 159.6
Methylcyclohexane	$C_6H_{11}CH_3$	Freezing	− 126.3
Ether	$(C_2H_5)_2O$	Slow freezing (unstable)	− 123.3
Ether	$(C_2H_5)_2O$	Rapid freezing or slow melting	− 116.3
Carbon disulfide	CS_2	Freezing	− 111.6
Toluene	C_7H_8	Freezing	− 95.1
Ethyl acetate	$CH_3CO_2C_2H_5$	Freezing	− 83.6
Chloroform	$CHCl_3$	Freezing	− 63.5
Chlorobenzene	C_6H_5Cl	Freezing	− 45.2
Carbon tetrachloride	CCl_4	Freezing	− 22.9
Sodium sulfate	$Na_2SO_4\cdot 10H_2O$	Transition	32.38$_4$
Potassium dichromate	$K_2Cr_2O_7$	Melting	397.5
30.5 NaCl + 69.5 Na_2SO_4	....	Melting	637.0
Potassium chloride	KCl	Melting	770.3
Sodium chloride	NaCl	Melting	800.4
Sodium sulfate	Na_2SO_4	Melting	884.7
Potassium sulfate	K_2SO_4	Inversion	583.0
Potassium sulfate	K_2SO_4	Melting	1069.1
Nickel	Ni	Melting or freezing	1452
Cobalt	Co	Melting or freezing	1490
Lithium metasilicate	Li_2SiO_3	Melting	1202
Diopside	$CaMgSi_2O_6$	Melting	1395
Anorthite	$CaAl_2Si_3O_8$	Melting	1555

LITERATURE

(For a key to the periodicals see end of volume)

(1)Holborn and Day, *8*, **2**: 505; 00. *12*, **10**: 171; 00 (Sb, Ag, Au, Cu). (2)Buckingham, *31A*, **3**: 281; 07 (Review of values for S boiling point). (3)Waidner and Burgess, *31A*, **7**: 1; 11 (Naphthalene, benzophenone, Sn, Cd, Zn). (4)Holborn and Henning, *8*, **35**: 761; 11 (Naphthalene, benzophenone, S, Sn, Cd, Zn). (5)Day and Sosman, *152*, No. **157**; 11 (Zn, Sb, Ag, Au, Cu, Pd, Pt). (6)Day and Sosman, *12*, **33**: 517; 12. *8*, **38**: 849; 12 (Benzophenone, Zn, Sb, S). (7)Henning, *8*, **43**: 282; 14 (O, CO_2, Hg). (8)Eumorfopoulous, *5*, **90A**: 189; 14 (S). (9)Wilhelm, *31A*, **13**: 655; 16. (Hg).

(10)Chappuis, *238*, **16**: 17 (S). (11)Bureau of Standards, Cir. No. **66**; 17 (Sn, Zn, Al, Cu). (12) Cath, *168*, No. **152d**; 18. *64P*, **21**: 656; 19 (O, N). (13)Martinez and Onnes, *168*, No. **156b**; 22. *18*, **6**: 31; 22 (H). (14)Worthing, *96*, **22**: 9; 24 (W). (15)Henning and Heuse, *8*, **23**: 104; 24 (O, N, H). (16)Finck and Wilhelm, *1*, **47**: 25 (Naphthalene, benzophenone). *See also* References under Standard Scale of Temperature.

Additional Fixed Points: Timmermans, Van der Horst and Onnes, *168*, No. **157**; 22 (Organic liquids below 0°). Dickinson and Mueller, *31A*, **3**: 641; 07 (Na_2SO_4 transition). Roberts, *2*, **23**: 386; 24 (Salts). Day and Sosman, Dictionary of Applied Physics, **1**: 836; 22 (Metals and silicates). Richards, *et al*, *1*, **36**: 485; 14 (Na_2CO_3 hydrates transitions). **40**: 89; 18 ($SrCl_2$ and $SrBr_2$ transitions). **41**: 2019; 19 (C_6H_6).

The Leiden Temperature Scale

In certain sections of International Critical Tables (where so indicated) the Leiden temperature scale will be employed. (Onnes and Hoist, *168*, No. **141a.** *64V*, **23**: 175; 14. Cath and Onnes, *168*, No. **152a.** *64V*, **26**: 437, 490; **17.** Cath, *168*, No. **152d.** *64V*, **27**: 553; 18.) The relation between the Leiden and the I. C. T. scales is shown by the following table:

Point	I. C. T.	Leiden	Leiden − I. C. T.
H_2 (B. P.)	−252.8°	−252.74°	+0.06°
O_2 (B. P.)	−183.0°	−182.95°	+0.05°
ca. −40°			+0.04

4. RESISTANCE THERMOMETERS

E. F. Mueller

Standard methods of calibration have been developed only for platinum resistance thermometers. Data on the resistance-temperature relation for particular thermometers of other metals, such as gold and lead, are available, and formulae to represent the relation have been published, but standardized methods for the calibration of such thermometers have not been developed.

The standard working scale, in the interval 0° to 650°C, is defined by means of a resistance thermometer of pure platinum, for which the relation between resistance R and temperature t is given by the equation:

$$R = R_0(1 + at + bt^2). \qquad (1)$$

This may be transformed into the Callendar equations:

$$(\mathrm{pt}) = \left(\frac{R - R_0}{R_{100} - R_0}\right)100; \; t - (\mathrm{pt}) = \delta\left[\left(\frac{t}{100} - 1\right)\frac{t}{100}\right]. \qquad (2)$$

The three constants in these equations, namely R_0, a, and b or R_0, R_{100} and δ respectively, are determined by calibration at the ice point, the steam point, and the sulfur boiling point.

The purity of the platinum must be such that $R_{100}/R_0 > 1.390$ and $R_{444.6}/R_0 > 2.645$, the latter requirement being equivalent to $\delta < 1.50$.

The Callendar equations were devised to facilitate computations by the method of successive approximations. The platinum temperature, symbol (pt), is proportional to the resistance above R_0 and the amount by which it differs from the true temperature is given by the correction term,

$$\delta\left(\frac{t}{100} - 1\right)\frac{t}{100}.$$

Consequently, a value of t sufficiently exact for use in computing the value of the correction term is readily obtained, if not by the first, then certainly by a second or third approximation.

In the interval −195° to 0°C the standard reference scale is defined by means of the platinum resistance thermometer, using the equation

$$t - (\mathrm{pt}) = \delta\left[\left(\frac{t}{100} - 1\right)\frac{t}{100}\right] + \beta\left[\left(\frac{t}{100} - 1\right)\frac{t^3}{100^3}\right]. \qquad (3)$$

The constants R_0, R_{100} and δ are determined just as for the range above 0° and the additional constant β is determined by a calibration at the boiling point of oxygen. A criterion for the purity of the platinum is that $R_{-183}/R_0 < 0.250$.

Thermometers which are not to be heated above ordinary temperatures may be calibrated at the freezing point of mercury, the CO_2 point and the oxygen point, using the interpolation formula:

$$R = R_0(1 + \mathrm{a}t + \mathrm{b}t^2 + \mathrm{c}t^4). \qquad (4)$$

The constant c in the equation is approximately equal to 5×10^{-12} and when this value is assumed, calibration at the CO_2 point may be omitted.

Equations (3) and (4) will yield substantially equivalent results, but they are not algebraically interconvertible.

Equation (1) or equation (2) may be used for temperatures up to 1000° or even 1100°C and the temperatures so determined will not depart appreciably from the standard scale.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Callendar, *62*, **178**: 160; 87. (2) Waidner and Burgess, *31A*, **6**: 149; **09.** (3) Holborn and Henning, *8*, **35**: 761; 11. (4) Henning, *8*, **40**: 635; 13 (Pt and Pb at low temperatures). (5) Henning, *8*, **43**: 282; 14. (6) Cath, Onnes and Burgers, *168*, No. **152c**; 17. *64*P, **20,** 1163; 18 (Pt and Au at low temperatures). (7) Henning and Heuse, *96*, **23**: 95; 24. (8) Van Dusen, *1*, **47**: 326; 25.

5. TEMPERATURE SCALES DEFINED BY LIQUID-IN-GLASS THERMOMETERS

E. F. Mueller

The readings of any particular thermometer, taken when all of the liquid in the thermometer is at a uniform temperature, may be reduced to those which would have been obtained if the thermometer had been perfect and used under ideal conditions, by applying corrections for non-uniformity of the capillary bore, corrections for the change of reading due to departure of the external and internal pressures from arbitrary constant values, a correction for the departure of the ice-point reading, taken immediately *after* the temperature measurement, from the 0° mark, and a correction to allow for the value of the mean scale degree, in case the difference between the readings of the thermometer taken first at 100°C and then at 0°C, does not correspond to 100 scale degrees. The reading of a thermometer, when so corrected, may be defined as the temperature on the liquid-in-glass scale for the particular liquid and the particular kind of glass of which the thermometer is made.

The temperature scales of mercury thermometers made of French hard glass (verre dur), Jena 16^{III}, Jena 59^{III}, Jena 1565^{III} and Jena combustion tubing are defined as above. For Kew glass, the temperature scale is defined in a somewhat different way, in that the point of reference is the (single) ice point reading taken after the thermometer has been held for a sufficiently long period at ordinary temperature (about 10°C) instead of the (variable) ice point reading taken immediately after each temperature measurement. It is apparent that temperatures on the mercury-in-glass scale are not proportional to the relative increase of volume of mercury-in-glass.

Constants characteristic of the several glasses are the ice-point depression, the softening point, and the average coefficient of expansion of mercury-in-glass, between 0° and 100°C.

The ice point depression is the difference between the ice point reading of the thermometer taken after it has been kept a sufficiently long time (a few days or weeks) at 0° and the ice point reading taken immediately after the thermometer has been kept a sufficiently long time (a few minutes or hours) at 100°C. Good thermometric glasses are characterized by small ice point depression (less than 0.1°C) and rapid recovery. Some glasses have an ice point depression of nearly 1°C.

The softening point determines the upper limit of temperature at which thermometers made of the glass can be used.

The expansion coefficient is useful in calculating corrections for emergent stem.

Values of these characteristic constants are:

Glass	Ice point depression °C	Softening point °C	Coefficient of cubical exp. of mercury-in-glass 0° to 100°C
Verre dur	0.07–0.11	500	0.000158
"Kew" glass	0.20		
Jena 16^{III}	0.04–0.08	505	0.000158
Jena 59^{III}	0.03–0.04	510	0.000164
Jena 1565^{III}	0.01	660	0.000172
Jena combustion	0.03	560	

Thermometers containing alcohol, toluene or pentane are not adapted for observation at 100°C, and for such thermometers the mean scale degree is conveniently referred to the interval 0° to −78.5°, the sublimation temperature of carbon dioxide serving to fix the latter temperature.

The tabular values are the result of comparisons of mercury-in-glass thermometers with gas thermometers or platinum resistance thermometers which served to establish the standard scale of temperature. The data for Jena 16^{III} glass and Jena 59^{III} glass may be used for Corning normal and Corning borosilicate thermometer glasses respectively.

Data of this kind were of great importance during the latter part of the 19th and even during the early part of this century, when calibrated mercury-in-glass thermometers were used to distribute the standard scale of temperature. At present the data are useful principally for minor purposes, such as calculation of factors for determining emergent stem correction, calculation of setting factors for metastatic thermometers, such as the Beckmann thermometer, graduation of thermometers by mercury thread calibration in the absence of standards and thermally controlled baths, etc.

In the tables, t represents the temperature on the standard working scale (platinum resistance thermometer) except for verre dur, where t represents temperatures on the former International hydrogen scale, which in practice is not distinguishable from the standard reference scale, while t_{gl} represents corresponding temperatures on the several liquid-in-glass scales.

VALUES OF $t - t_{gl}$ FOR MERCURY-IN-GLASS THERMOMETERS

t = temperature on standard scale, t_{gl} = temperature on mercury-in-glass scale.

t°C	French hard (verre dur)	Kew glass	Jena 16^{III}	Jena 59^{III}	Jena 1565^{III}	Jena combustion
− 39	+0.420					
− 30	+ .290		+0.28	+ 0.13		
− 20	+ .172		+ .16	+ .07		
− 10	+ .073		+ .07	+ .03		
0	.000	0.00	.00	.00	0.00	0.00
+ 10	− .052	.00	− .06	− .02	− .03	
20	− .085	.00	− .09	− .04	− .05	
30	− .102	+ .005	− .11	− .04	− .06	
40	− .107	+ .01	− .12	− .03	− .06	
50	− .103	+ .01	− .12	− .03	− .05	
60	− .090	+ .01	− .10	− .02	− .04	
70	− .072	+ .015	− .08	− .01	− .03	
80	− .050	+ .02	− .06	.00	− .02	
90	− .026	+ .025	− .03	+ .02	− .01	
100	.000	.00	.00	.00	.00	0.00
120	+ .06		+ .03	− .05	+ .06	
140	+ .07		+ .02	− .16	+ .03	
160	+ .03		− .02	− .31	− .13	
180	− .04		− .12	− .52	− .38	
200	− .12		− .29	− .84	− .90	− 1.13
220			− .5	− 1.3	− 1.3	− 1.6
240			− .9	− 1.9	− 1.8	− 2.2
260			−1.4	− 2.6	− 2.4	− 3.0
280			−2.0	− 3.4	− 3.1	− 4.0
300			−2.7	− 4.4	− 3.9	− 5.1
320				− 5.8	− 4.8	− 6.4
340				− 7.2	− 5.9	− 7.8
360				− 8.8	− 7.3	− 9.5
380				−10.6	− 8.9	−11.4
400				−12.6	−10.5	−13.5
420				−14.9	−12.4	−15.9
440				−17.4	−14.7	−18.6
460				−20.2	−17.2	−21.5
480				−23.3	−20.0	−24.8
500				−26.9	−23.1	−28.4
550					−32.	−39.
600					−44.	
650					−58.	

VALUES OF $t - t_g$ FOR LIQUID-IN-GLASS THERMOMETERS

t	Pentane in 16^{III} glass	Toluene in verre dur	Alcohol in verre dur
−190	−23.4		
−180	−21.0		
−170	−18.6		
−160	−16.2		
−150	−13.9		
−140	−11.6		
−130	− 9.4		
−120	− 7.3		
−110	− 5.3		

Values of $t - t_1$ for Liquid-in-glass Thermometers.—*Continued*

t	Pentane in 16^{111} glass	Toluene in verre dur	Alcohol in verre dur
−100	− 3.4		
− 90	− 1.7		
− 80	− 0.2	0.0	
− 78.5	0.0	0.0	0.0
− 70	+ 1.0	+ .4	+0.3
− 60	+ 2.0	+ .8	+ .6
− 50	+ 2.6	+ 1.1	+ .7
− 40	+ 3.0	+ 1.2	+ .9
− 30	+ 2.9	+ 1.2	+ .9
− 20	+ 2.4	+ 1.0	+ .8
− 10	+ 1.5	+ 0.6	+ .5
0	0.0	0.0	.0
+ 10	− 2.0		
20	− 4.4		
30	− 7.6		−3.6
100		−24.4	

LITERATURE

(For a key to the periodicals see end of volume)

Guillaume, Traite pratique de la thermometerie. Gauthier-Villars, Paris, 1889 (General). Chappuis, *238*, **6**: 1; 88 (Verre dur −25° to 100°). Harker, *5*, **78A**: 225; 06 (Kew glass). Scheel, *Deut. Mechan. Ztg.*, **1916**: 170 and Holborn, Scheel and Henning, *B63* (Jena glasses and organic liquids in glass).

Emergent Stem Correction for Liquid-in-glass Thermometers

If a liquid-in-glass thermometer standardized for total immersion is used with a portion of the liquid column at a temperature below that of the bulb, the reading will be too low for this reason, and an emergent stem correction should be applied to the observed reading.

The emergent stem correction is calculated by the formula,

$$\text{Correction} = Kn(t - t_s)$$

in which

K = coefficient of cubical expansion of mercury-in-glass, per °C,

t = temperature of bulb, °C,

t_s = average temperature °C of the mercury column n°C degrees in length.

The value of t is to be determined by means of an auxiliary thermometer or thermometers, preferably with a capillary thermometer. The sign as well as the magnitude of the correction is given by the formula.

For many purposes, in using mercury-in-glass thermometers K may be treated as a constant of the glass, using the values given above for the apparent coefficient of expansion of mercury-in-glass. The value of K does, however, change with temperature. For purposes of computing the emergent stem correction, it may be considered as depending on the average of t and t_s, that is $\frac{t + t_s}{2}$ and is here so tabulated.

If the coefficients of expansion of mercury and of glass were both constant, K would also be constant. Most of the change in K is the result of the varying coefficient of the mercury, so that the change in K with temperature for one glass may with some certainty be inferred from the change for some other glass.

The use of the formula requires that t, the temperature of the bulb, be known. In case t is not known, but is to be determined from the indication of the thermometer, the reading of the thermometer may be substituted in the formula in place of t, as a first approximation and the true magnitude of the correction then calculated by means of a second, or if necessary, a third approximation.

In many cases, in calculating the emergent stem correction for thermometers containing organic liquids, it is sufficient to use the approximate value, $K = 0.001$. The tables show to what extent this is justified for pentane, toluene, and alcohol. In such thermometers, K is practically independent of the kind of glass used.

With the abandonment of the mercury-in-glass thermometer as an instrument of high precision there has been an increasing tendency to use partial immersion thermometers, graduated and standardized for a particular depth of immersion, thus avoiding the necessity of determining and applying the correction for emergent stem.

Table of Emergent Stem Correction Factors

Mercury-in-glass Thermometers

$\frac{t + t_s}{2}$ °C	Verre dur	Jena 16^{III}	Jena 59^{III}	Jena 1565^{III}	Jena combustion
50	0.000158	0.000158	0.000164	0.000172	0.000164
100	158	158	164	172	164
150	158	158	165	173	165
200	159	159	167	175	167
250		161	170	177	171
300		164	174	180	174
350			177	184	178
400			182	188	182
450			187	194	188
500			195	200	195

Liquid-in-glass Thermometers

$\frac{t + t_s}{2}$	Pentane	Toluene	Alcohol
−180	0.0009		
−160	09		
−140	09		
−120	10		
−100	10		
− 80	10	0.0009	0.0010
− 60	11	09	10
− 40	12	10	10
− 20	13	10	10
0	14	10	10
+ 20	15	11	10

LITERATURE

(For a key to the periodicals see end of volume)

Buckingham, *31a*, **8**: 239; 12.

Example: A thermometer of Jena 59^{III} (or Corning borosilicate glass) indicated a temperature, t, of 470° after application of corrections peculiar to the instrument. The thermometer was immersed to the 150° mark, and the *average* temperature t_s of the 320° (n°) of exposed mercury column was found to be 190°. The average of t and t_s is 330° and the value of the factor K for this temperature is 0.000176. Accordingly

$$\text{Correction} = 0.000176(320)(470 - 190) = 15.8°$$

The corrected temperature is therefore 470° + 15.8° = 485.8°. Since the bulb temperature was considerably higher than 470° a second approximation may be tried:

$$\text{Correction} = 0.000176(320)(486 - 190) = 16.7°$$

The second approximation yields a corrected temperature of 470° + 16.7° = 486.7° which in view of the rather large emergent stem correction, may properly be reported as 487°.

Possible short cuts in making the second approximation will be readily apparent.

The example given is purposely somewhat exaggerated by assuming an unusually high temperature (190°) for the emergent stem, in order to show that the factor K may differ appreciably from the conventional value of 0.00016.

For computations in Fahrenheit temperatures, the proper value of K is 5/9 of the tabulated value.

6. THERMOCOUPLES

L. H. Adams

"Standard" Calibration Tables (for Use with Deviation Curve)

Standard tables such as these do not necessarily have any absolute significance; primarily, they are arbitrary reference curves which, although representing fairly well the temperature-emf functions for certain thermocouples, are intended for use with an appropriate deviation-curve. This correction-curve is determined for each couple by calibration at several—preferably three or more—fixed points within the "applicability range of the couple." This curve is constructed by plotting ΔE as ordinate ($\Delta E = E_{obs.} - E_{stand.}$) against $E_{stand.}$ as abscissa. In order to obtain the temperature corresponding to the emf indicated by the couple, the appropriate value of ΔE (as obtained from *its* deviation curve) is subtracted algebraically from the observed value of E before the latter is converted into degrees by means of the table. Example: At a certain temperature a copper-constantan couple gave an emf of 8720 microvolts. From the previously determined deviation curve of the particular couple the value of ΔE at 8720 microvolts is found to be 12 microvolts. The "standard" emf is therefore 8720 − 12 or 8708 microvolts and from the copper-constantan table this may be seen to correspond to 189.0_8°, which is the required temperature.

The fixed (*i.e.*, cold) junction is supposed to be maintained at 0°C.

Temperatures and Temperature Differences for Every 100 Microvolts

Platinum: Platinrhodium (90–10). Standard range, 630°–1083°C. Applicability range, 0–1754°C

E μV	0	1000	2000	3000	4000	5000	6000	7000	8000	9000	E μV
0	0	147.1	265.4	374.3	478.1	578.3	675.3	769.5	861.1	950.4	**0**
	17.8	*12.6*	*11.2*	*10.6*	*10.2*	*9.8*	*9.5*	*9.3*	*9.0*	*8.8*	
100	17.8	159.7	276.6	384.9	488.3	588.1	684.8	778.8	870.1	959.2	**100**
	16.7	*12.4*	*11.1*	*10.5*	*10.1*	*9.8*	*9.5*	*9.2*	*9.0*	*8.8*	
200	34.5	172.1	287.7	395.4	498.4	597.9	694.3	788.0	879.1	968.0	**200**
	15.8	*12.3*	*11.0*	*10.5*	*10.1*	*9.8*	*9.5*	*9.2*	*9.0*	*8.7*	
300	50.3	184.3	298.7	405.9	508.5	607.7	703.8	797.2	888.1	976.7	**300**
	15.1	*12.0*	*11.0*	*10.4*	*10.1*	*9.7*	*9.5*	*9.2*	*9.0*	*8.7*	
400	65.4	196.3	309.7	416.3	518.6	617.4	713.3	806.4	897.1	985.4	**400**
	14.6	*11.8*	*10.9*	*10.4*	*10.0*	*9.7*	*9.4*	*9.2*	*9.0*	*8.7*	
500	80.0	208.1	320.6	426.7	528.6	627.1	722.7	815.6	906.1	994.1	**500**
	14.1	*11.6*	*10.9*	*10.4*	*10.0*	*9.7*	*9.4*	*9.1*	*8.9*	*8.7*	
600	94.1	219.7	331.5	437.1	538.6	636.8	732.1	824.7	915.0	1002.8	**600**
	13.7	*11.5*	*10.8*	*10.3*	*10.0*	*9.7*	*9.4*	*9.1*	*8.9*	*8.7*	
700	107.8	231.2	342.3	447.4	548.6	646.5	741.5	833.8	923.9	1011.5	**700**
	13.4	*11.5*	*10.7*	*10.3*	*9.9*	*9.6*	*9.4*	*9.1*	*8.9*	*8.6*	
800	121.2	242.7	353.0	457.7	558.5	656.1	750.9	842.9	932.8	1020.1	**800**
	13.1	*11.4*	*10.7*	*10.2*	*9.9*	*9.6*	*9.3*	*9.1*	*8.8*	*8.6*	
900	134.3	254.1	363.7	467.9	568.4	665.7	760.2	852.0	941.6	1028.7	**900**
	12.8	*11.3*	*10.6*	*10.2*	*9.9*	*9.6*	*9.3*	*9.1*	*8.8*	*8.6*	
1000	147.1	265.4	374.3	478.1	578.3	675.3	769.5	861.1	950.4	1037.3	**1000**

E μV	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000		E μV
0	1037.3	1122.2	1205.9	1289.3	1372.4	1454.8	1537.5	1620.9	1704.3	......	**0**
	8.6	*8.4*	*8.3*	*8.4*	*8.3*	*8.2*	*8.3*	*8.3*	*8.3*	....	
100	1045.9	1130.6	1214.2	1297.7	1380.7	1463.0	1545.8	1629.2	1712.6	......	**100**
	8.5	*8.4*	*8.4*	*8.3*	*8.3*	*8.2*	*8.3*	*8.4*	*8.4*	....	
200	1054.4	1139.0	1222.6	1306.0	1389.0	1471.2	1554.1	1637.6	1721.0	......	**200**
	8.5	*8.4*	*8.3*	*8.3*	*8.3*	*8.2*	*8.3*	*8.3*	*8.3*	....	
300	1062.9	1147.4	1230.9	1314.3	1397.3	1479.4	1562.4	1645.9	1729.3	......	**300**
	8.5	*8.4*	*8.4*	*8.3*	*8.3*	*8.3*	*8.4*	*8.4*	*8.4*	....	
400	1071.4	1155.8	1239.3	1322.6	1405.6	1487.7	1570.8	1654.3	1737.7	......	**400**
	8.5	*8.4*	*8.3*	*8.3*	*8.2*	*8.3*	*8.3*	*8.3*	*8.3*	....	
500	1079.9	1164.2	1247.6	1330.9	1413.8	1496.0	1579.1	1662.6	1746.0	......	**500**
	8.5	*8.3*	*8.3*	*8.3*	*8.2*	*8.3*	*8.4*	*8.3*	*8.3*	....	
600	1088.4	1172.5	1255.9	1339.2	1422.0	1504.3	1587.5	1670.9	1754.3	......	**600**
	8.5	*8.4*	*8.4*	*8.3*	*8.2*	*8.3*	*8.3*	*8.4*	....	....	
700	1096.9	1180.9	1264.3	1347.5	1430.2	1512.6	1595.8	1679.3	......	......	**700**
	8.5	*8.3*	*8.3*	*8.3*	*8.2*	*8.3*	*8.4*	*8.3*	....	....	
800	1105.4	1189.2	1272.6	1355.8	1438.4	1520.9	1604.2	1687.6	......	......	**800**
	8.4	*8.4*	*8.4*	*8.3*	*8.2*	*8.3*	*8.3*	*8.4*	....	....	
900	1113.8	1197.6	1281.0	1364.1	1446.6	1529.2	1612.5	1696.0	......	......	**900**
	8.4	*8.3*	*8.3*	*8.3*	*8.2*	*8.3*	*8.4*	*8.3*	....	....	
1000	1122.2	1205.9	1289.3	1372.4	1454.8	1537.5	1620.9	1704.3	......	......	**1000**

TEMPERATURES AND TEMPERATURE DIFFERENCES FOR EVERY 100 MICROVOLTS

Copper: Constantan

E µV	−5000	−4000	−3000	−2000	−1000	−0	0	1000	2000	3000	4000	5000	6000
0	−169.14	−124.46	− 87.86	−55.81	−26.82	0	0	25.27	49.20	72.08	94.07	115.31	135.91
	5.20	*4.01*	*3.42*	*3.05*	*2.79*	*2.60*	*2.59*	*2.45*	*2.33*	*2.23*	*2.16*	*2.09*	*2.03*
100	−174.34	−128.47	− 91.28	−58.86	−29.61	− 2.60	2.59	27.72	51.53	74.31	96.23	117.40	137.94
	5.40	*4.09*	*3.46*	*3.08*	*2.81*	*2.62*	*2.57*	*2.43*	*2.32*	*2.23*	*2.15*	*2.08*	*2.02*
200	−179.74	−132.56	− 94.74	−61.94	−32.42	− 5.22	5.16	30.15	53.85	76.54	98.38	119.48	139.96
	5.64	*4.18*	*3.51*	*3.11*	*2.84*	*2.63*	*2.56*	*2.42*	*2.31*	*2.22*	*2.14*	*2.08*	*2.02*
300	−185.38	−136.74	− 98.25	−65.05	−35.26	− 7.85	7.72	32.57	56.16	78.76	100.52	121.56	141.98
	5.89	*4.28*	*3.57*	*3.15*	*2.86*	*2.65*	*2.55*	*2.41*	*2.30*	*2.21*	*2.14*	*2.07*	*2.01*
400	−191.27	−141.02	−101.82	−68.20	−38.12	−10.50	10.27	34.98	58.46	80.97	102.66	123.63	143.99
	6.17	*4.39*	*3.63*	*3.19*	*2.89*	*2.67*	*2.53*	*2.40*	*2.30*	*2.20*	*2.13*	*2.06*	*2.01*
500	−197.44	−145.41	−105.45	−71.39	−41.01	−13.17	12.80	37.38	60.76	83.17	104.79	125.69	146.00
	6.51	*4.50*	*3.68*	*3.22*	*2.90*	*2.69*	*2.52*	*2.39*	*2.28*	*2.20*	*2.12*	*2.06*	*2.00*
600	−203.95	−149.91	−109.13	−74.61	−43.91	−15.86	15.32	39.77	63.04	85.37	106.91	127.75	148.00
	6.97	*4.61*	*3.74*	*3.26*	*2.93*	*2.71*	*2.51*	*2.38*	*2.27*	*2.19*	*2.11*	*2.05*	*2.00*
700	−210.92	−154.52	−112.87	−77.87	−46.84	−18.57	17.83	42.15	65.31	87.56	109.02	129.80	150.00
	7.55	*4.73*	*3.30*	*3.29*	*2.96*	*2.73*	*2.49*	*2.36*	*2.27*	*2.18*	*2.10*	*2.04*	*1.99*
800	−218.47	−159.25	−116.67	−81.16	−49.80	−21.30	20.32	44.51	67.58	89.74	111.12	131.84	151.99
		4.87	*3.86*	*3.33*	*2.99*	*2.75*	*2.48*	*2.35*	*2.25*	*2.17*	*2.10*	*2.04*	*1.99*
900		−164.12	−120.53	−84.49	−52.79	−24.05	22.80	46.86	69.83	91.91	113.22	133.88	153.97
		5.02	*3.93*	*3.37*	*3.02*	*2.77*	*2.47*	*2.34*	*2.25*	*2.16*	*2.09*	*2.03*	*1.98*
1000		−169.14	−124.46	−87.86	−55.81	−26.82	25.27	49.20	72.08	94.07	115.31	135.91	155.95

E µV	7000	8000	9000	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000
0	155.95	175.50	194.62	213.36	231.74	249.82	267.60	285.13	302.42	319.49	336.36	353.08	369.61
	1.97	*1.93*	*1.89*	*1.85*	*1.82*	*1.79*	*1.76*	*1.74*	*1.72*	*1.70*	*1.68*	*1.66*	*1.64*
100	157.92	177.43	196.51	215.21	233.56	251.61	269.36	286.87	304.14	321.19	338.04	354.74	371.25
	1.97	*1.93*	*1.89*	*1.85*	*1.82*	*1.79*	*1.76*	*1.74*	*1.71*	*1.69*	*1.68*	*1.66*	*1.64*
200	159.89	179.36	198.40	217.06	235.38	253.40	271.12	288.61	305.85	322.88	339.72	356.40	372.89
	1.97	*1.92*	*1.88*	*1.85*	*1.82*	*1.78*	*1.76*	*1.74*	*1.71*	*1.69*	*1.68*	*1.66*	*1.64*
300	161.86	181.28	200.28	218.91	237.20	255.18	272.88	290.35	307.56	324.57	341.40	358.06	374.53
	1.96	*1.92*	*1.88*	*1.84*	*1.81*	*1.78*	*1.76*	*1.73*	*1.71*	*1.69*	*1.67*	*1.66*	*1.64*
400	163.82	183.20	202.16	220.75	239.01	256.96	274.64	292.08	309.27	326.26	343.07	359.72	376.17
	1.96	*1.91*	*1.88*	*1.84*	*1.81*	*1.78*	*1.76*	*1.73*	*1.71*	*1.69*	*1.67*	*1.65*	*1.63*
500	165.78	185.11	204.04	222.59	240.82	258.74	276.40	293.81	310.98	327.95	344.74	361.37	377.80
	1.95	*1.91*	*1.87*	*1.84*	*1.81*	*1.78*	*1.75*	*1.73*	*1.71*	*1.69*	*1.67*	*1.65*	*1.63*
600	167.73	187.02	205.91	224.43	242.63	260.52	278.15	295.54	312.69	329.64	346.41	363.02	379.43
	1.95	*1.91*	*1.87*	*1.83*	*1.80*	*1.77*	*1.75*	*1.72*	*1.70*	*1.68*	*1.67*	*1.65*	*1.63*
700	169.68	188.93	207.78	226.26	244.43	262.29	279.90	297.26	314.39	331.32	348.08	364.67	381.06
	1.94	*1.90*	*1.86*	*1.83*	*1.80*	*1.77*	*1.75*	*1.72*	*1.70*	*1.68*	*1.67*	*1.65*	*1.63*
800	171.62	190.83	209.64	228.09	246.23	264.06	281.65	298.98	316.09	333.00	349.75	366.32	382.69
	1.94	*1.90*	*1.86*	*1.83*	*1.80*	*1.77*	*1.74*	*1.72*	*1.70*	*1.68*	*1.67*	*1.65*	*1.63*
900	173.56	192.73	211.50	229.92	248.03	265.83	283.39	300.70	317.79	334.68	351.42	367.97	384.32
	1.94	*1.89*	*1.86*	*1.82*	*1.79*	*1.77*	*1.74*	*1.72*	*1.70*	*1.68*	*1.66*	*1.64*	*1.63*
1000	175.50	194.62	213.36	231.74	249.82	267.60	285.13	302.42	319.49	336.36	353.08	369.61	385.95

TEMPERATURES AND TEMPERATURE DIFFERENCES FOR EVERY 0.5 MILLIVOLT

Chromel-alumel

E mv	0	10	20	30	40
0	0.0	244.5	482.8	719.2	970.4
	12.3	*12.2*	*11.7*	*12.2*	*13.0*
0.5	12.3	256.7	494.5	731.4	983.4
	12.1	*12.2*	*11.7*	*12.3*	*13.1*
1.0	24.4	268.9	506.2	743.7	996.5
	12.0	*12.1*	*11.7*	*12.3*	*13.2*
1.5	36.4	281.0	517.9	756.0	1009.7
	12.0	*12.1*	*11.7*	*12.3*	*13.3*
2.0	48.4	293.1	529.6	768.3	1023.0
	12.0	*12.0*	*11.7*	*12.4*	*13.3*
2.5	60.4	305.1	541.3	780.7	1036.3
	12.0	*12.0*	*11.7*	*12.4*	*13.4*
3.0	72.4	317.1	553.0	793.1	1049.7
	12.0	*12.0*	*11.7*	*12.5*	*13.5*
3.5	84.4	329.1	564.7	805.6	1063.2
	12.0	*11.9*	*11.7*	*12.5*	*13.6*
4.0	96.4	341.0	576.4	818.1	1076.8
	12.1	*11.9*	*11.8*	*12.5*	*13.7*
4.5	108.5	352.9	588.2	830.6	1090.5
	12.1	*11.9*	*11.8*	*12.6*	*13.7*
5.0	120.6	364.9	600.0	843.2	1104.2
	12.2	*11.9*	*11.8*	*12.6*	*13.8*
5.5	132.8	376.8	611.8	855.8	1118.0
	12.4	*11.9*	*11.8*	*12.6*	*13.8*
6.0	145.2	388.6	623.6	868.4	1131.8
	12.5	*11.8*	*11.8*	*12.6*	*13.9*
6.5	157.7	400.4	635.4	881.0	1145.7
	12.6	*11.8*	*11.8*	*12.7*	*13.9*
7.0	170.2	412.2	647.2	893.7	1159.6
	12.5	*11.8*	*11.9*	*12.7*	*14.*
7.5	182.7	424.0	659.1	906.4	(1174.)
	12.5	*11.8*	*11.9*	*12.7*	*14.*
8.0	195.2	435.8	671.0	919.1	(1188.)
	12.4	*11.8*	*12.0*	*12.8*	*14.*
8.5	207.7	447.6	683.0	931.9	(1202.)
	12.3	*11.8*	*12.0*	*12.8*	
9.0	220.0	459.4	695.0	944.7	
	12.3	*11.7*	*12.1*	*12.8*	
9.5	232.3	471.1	707.1	957.5	
	12.2	*11.7*	*12.1*	*12.9*	
10.0	244.5	482.8	719.2	970.4	

Fixed-junction Corrections

If the fixed or "cold" junction be not maintained at 0°C, a correction must be applied. This may be done by any one of several methods, of which the following are suggested:

A. Let the temperature of the fixed junction be t_c and that of the variable or "hot" junction be t. Then to the emf as read E_{t-t_c}, add the emf corresponding to t_c. This gives E_t which may at once be converted into degrees by means of the proper table.

B. Multiply the fixed-junction temperature by the factor, $f = (dE/dt)_0/(dE/dt)$, which is the ratio of the mean emf-temperature gradient between 0° and t_c to the gradient at t, and add the product to t', the uncorrected temperature. That is, $t = t' + ft_c$. These emf-temperature gradients may be obtained by taking the reciprocals of the numbers appearing in the difference columns of the calibration tables.

COMPARISON OF THE MORE COMMON THERMOCOUPLES

E mv	Temperature, °C				*E* mv	Temperature, °C		
	Iron: constantan	Chromel (X): copel	Chromel (P): alumel	Platinrhodium:* gold-palladium		Platinum: platinrhodium (Heraeus)	Platinum: Platinrhodium (Johnston-Matthey)	Copper: constantan
0	0	0	0	0	0	0	0	0
5	95	105	121	131	1	147	146	25
10	186	195	244	237	2	265	260	49
15	277	277	365	335	3	374	364	72
20	367	353	483	429	4	478	461	94
25	457	425	600	513	5	578	553	115
30	546	495	719	607	6	675	641	136
35	632		843	694	7	769	725	156
40	713		970	779	8	861	806	176
45	792		1104	866	9	950	884	195
50	871			954	10	1037	959	213
55	950			1044	11	1122	1032	232
60				1136	12	1206	1103	250
					13	1289	1173	268
					14	1372	1242	285
					15	1455	1311	302
					16	1537	1379	320
					17	1620	1447	336
					18	1704	1515	353

* 10 % Rh; 40 % Pd.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Adams, *128*, **3**: 469; 13. *1*, **36**: 65; 14. *255*, **1919**: 2111. (2) Adams, *O.* (3) Adams and Johnston, *12*, **32**: 534; 12. (4) Foote, Fairchild and Harrison, *32*, No. **170**; 21. (5) Hoskins Mfg. Co., Catalog D; 24. (6) Roberts, *O.* (7) Sosman, *12*, **30**: 7; 10.

OPTICAL PYROMETRY

C. O. FAIRCHILD AND H. T. WENSEL

The temperature scale above the melting point of gold is based upon Wien's Law, $J_\lambda = c_1\lambda^{-5}e^{\frac{-C_2}{\lambda T}}$, in which the constant C_2 (1.433 cm deg) and the value 1336°K for the melting point of gold determine the scale. In optical pyrometry temperatures are usually measured by comparing the brightness of a glowing object with that of the filament of a lamp mounted in the image plane of a simple telescope. For highest accuracy the current through the lamp is kept at or near the value corresponding to 1336°K and higher temperatures are measured by reducing the brightness of the image of the object to match that of the filament by means of a suitable screen such as a rotating sector or an absorption glass of known transmission. The temperature is then found from the following formula derived from Wien's Law:

$$\frac{1}{T} = \frac{1}{1336} + \lambda_e \cdot \frac{\log_{10} R}{6222},$$

in which R is the transmission of the absorption device and λ_e is the "mean effective wave-length" of a color filter in the pyrometer for the temperature interval 1336° to T. Values of λ_e can be obtained in some cases by the use of Table 2.

For practical purposes the pyrometer is ordinarily calibrated in the range 700° to 1400°C (occasionally to 1550°C) in terms of filament current. A satisfactory empirical relation between the current I through the lamp filament and temperature t°C is:

$I = a + bt + ct^2 + dt^3$. For tungsten lamps with short 3 mil filaments dI/dt varies from about 0.00015 ampere per degree at 700°C ($I = 0.3$) to 0.0003 ampere per degree at 1400° ($I = 0.5$). For measurements above 1400° an absorption glass of such type is employed that $A(= \lambda_e \log_{10} R/6223)$ is a constant or varies slightly with temperature. If the spectral transmission, Tr, of the absorption device is of the form $Tr_\lambda = e^{\frac{K}{\lambda}}$, A will be a constant and equal to K/c_2. For sector discs $A = \text{constant} \cdot \lambda_e$.

TABLE I

Temperatures extrapolated from 1336°K, using Wien's Law, compared with those obtained using Planck's Law. The values in this table were computed from the relation:

$$T_p = \frac{C_2}{\lambda \log_e\left[1 + e^{\frac{c_2}{\lambda T_w}}\right]}$$

taking $\lambda = 0.65\mu$.

T_w	T_p	$T_w - T_p$	T_w	T_p	$T_w - T_p$
1336	1336.000	.....	4500	4493	7
2000	1999.997	0.003	5000	4986	14
2500	2499.958	.042	6000	5959	41
3000	2999.74	.26	8000	7825	175
3500	3499.0	1.0	10 000	9550	450
4000	3997	3	∞	31 800	∞

TABLE 2

Effective wave-length and mean effective wave-length of optical pyrometer red glass filters. The effective wave-length λ_T is found from the formula

$$\frac{1}{\lambda_T} = a - \frac{b}{T}.$$

Equation*	Corning H. T. red glasses				Visibility
	A	B	C	D	
a	1.5509	1.5415	1.5369	1.5319	
b	29.6	28.2	28.0	26.8	
Wave-length microns	Transmission				
0.615	0.000	0.000	0.000	0.000	0.442
.625	.085	.007	.000	.000	.323
.635	.520	.270	.141	.080	.220
.645	.730	.533	.389	.350	.141
.655	.798	.637	.508	.520	.084
.665	.815	.664	.541	.580	.046
.675	.823	.677	.557	.605	.024
.685	.828	.686	.567	.605	.0126
.695	.830	.689	.572	.603	.0061
.705	.830	.689	.572	.598	.0031
.715	.826	.682	.564	.590	.00158
.725	.824	.679	.559	.580	.00078
.735	.822	.676	.555	.572	.00038
.745	.820	.672	.551	.567	.00018
.755	.818	.669	.547	.550	.00009
.765	.815	.664	.541	.535	.00003
.775	.813	.661	.537	.510	.00000

* The constants a and b are given for four typical red glasses of the transmissions indicated. The change in effective wave-length with temperature of glass filter itself is closely 0.00009μ per deg C at ordinary room temperatures.

Angular apertures required in the telescope of the disappearing filament type of optical pyrometer for a balance between reflection and diffraction at the filament. Under such conditions disappearance of the filament is obtained without resorting to low magnification or very low resolving power.

TABLE 3.—TUNGSTEN FILAMENT OF CIRCULAR CROSS-SECTION

Exit aperture radians	Entrance aperture, radians	
	Filament diameter 0.04 to 0.06 mm	Filament diameter 0.1 mm
0.005	very low resolving power	
.01	0.04 and larger	0.04 and larger
.02	.06 to .16	.055 to .07
.04	.08 to .13	
.06	non-disappearance	

TABLE 4.—BRIGHTNESS TEMPERATURE VERSUS TRUE TEMPERATURE FOR RED LIGHT($\gamma = 0.65\mu$)

Observed brightness temperature	True temperature						
	Platinum(1)	Iron(2)	Iron oxide(3)	Nickel oxide(4)	Copper(5)	Copper oxide(5)	Nichrome or chromel(6)
700	745		700	701			702
800	857		801	802			804
900	972		902	904		903	906
950					1083	958	
975					1181		
1000	1090		1004	1007	1156	1020	1010
1025					1193		
1050					1231	1087	
1100	1210	1183	1106	1110		1159	1116
1150						1233	
1200	1332	1296	1210	1215			1224
1300	1455	1410		1320			
1400		1525					
1500		1641					
1600		1758					
1700		1877					
1750		1936					

LITERATURE

(For a key to periodical see end of volume)

(1) Waidner and Burgess, *31a*, **3**: 163; 07. (2) Computed for an emissivity of 0.4; *cf.* Burgess, *32*, No. **91**: 17. (3) Burgess and Foote, *31a*, **12**: 83; 15. (4) Burgess and Foote, *31a*, **11**: 41; 15. (5) Burgess, *31a*, **6**: 111; 09. (6) Foote, Bureau of Standards, *O*. For data on C, Ta, W and other substances see sections on emissivity, color temperature, etc.

GENERAL REFERENCES

Burgess and Le Chatelier, Measurement of High Temperature, 1912. Pyrometry: Symposium of American Institute of Mining and Metallurgical Engineers, 1919. Foote, Fairchild and Harrison, *32*, No. **170**: 21. Foote, Mohler and Fairchild, *128*, **7**: 18; 17. Foote, *83*, **13**: 3; 18. Forsythe, *83*, **15**: 3; 20. Fairchild and Hoover, *48*, **7**: 7; 23.

ARRANGEMENT OF CHEMICAL SUBSTANCES

Throughout I. C. T., except when otherwise indicated, the tabular arrangement of all chemical substances and of all systems capable of representation by formula is in accordance with a system called the "Standard Arrangement," which will now be explained and which should be learned by every user of I. C. T.

ARRANGEMENT DES SUBSTANCES CHIMIQUES

L'arrangement tabulaire de toutes les substances chimiques et de tous les systèmes susceptibles d'une représentation par formule est, dans les T. C. I., excepté lorsqu'il y a une autre indication, en accord avec un système appelé "arrangement type," (standard arrangement) expliqué ci-dessous, qui devra être appris par chaque personne qui veut utiliser les T. C. I.

Elementary Substances

All tables containing *only* elementary substances (𝔄-Tables) are arranged in alphabetical order of the symbols of the elements. In tables containing both elements and compounds (𝔄𝔅-Tables) the elements follow the "standard arrangement," *v. infra.*

Substances Élémentaires

Toutes les tables ne contenant que les substances élémentaires (Tables 𝔄) sont arrangées dans l'ordre alphabétique des symboles des éléments. Dans les tables contenant les éléments et les corps composés (Tables 𝔄𝔅) les éléments se trouvent suivant l' "arrangement type" voir *infra.*

Chemical Compounds and Other Systems Represented by Formula

The arrangement is based upon the following table of "Key-numbers" of the elements:

Composés Chimiques et Autres Systèmes Représentés Par Formule

L'arrangement est basé sur la table suivante des "nombres clés" des éléments:

KEY-NUMBERS OF THE ELEMENTS — NOMBRES CLÉS DES ÉLEMENTS

−6	−5	−4	−3	−2	−1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
(He	Ne	A	Kr	Xe	Rn)	O	H	F	Cl	Br	I	(85)	S	Se	Te	N	P	As	Sb	Bi	C	Po	Si	Ti	Ge
						46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65
						Cr´	Mo	W	U	V	Cb(Nb)	Ta	Pa	B	Al	Sc	Y	La	Ce	Pr	Nd	(61)	Sa	Eu	Gd

Ac	Ag	Al	As	Au	B	Ba	Be	Bi	Br	C	Ca	Cb	Cd	Ce	Cl	Co	Cr	Cs	Cu	Dy	Er	Eu	F	Fe
74	32	55	13	33	54	79	75	15	5	16	77	51	29	59	4	44	46	85	31	67	69	64	3	43
					Os	P	Pa	Pb	Pd	Po	Pr	Pt	Ra	Rb	Re	Rh	Ru	S	Sa	Sb	Sc	Se	Si	Sn
					35	12	53	23	41	17	60	37	80	84	34	40	39	8	63	14	56	9	18	22

To locate a given compound, first write its "key-formula," neglecting water of crystallization, thus:

Afin de situer un composé donné, il faut d'abord écrire sa "formule-clé," en négligeant l'eau de cristallisation, ainsi:

Compound	Composé	Na_2SO_4	$HClO_4.3H_2O$	$Hg(C_{18}H_{33}O_2)_2$	$2Fe_2O_3.P_2O_5.12H_2O$	$Ni_3Pr_2(NO_3)_{12}.24H_2O$	$I_2C_6H_3SO_3H$	$(NH_4)_2CO_3$
Key formula	Formule-clé	82–8–1	4–2–1	30–16–2–1	43–12–1	60–45–11–1	16–8–6–2–1	16–11–2–1

In writing a key-formula the key-numbers must be written *in descending order.*

All chemical compounds (𝔅-Tables) are arranged in the inverse numerical order of their key-formulae. *Example:* to find the compound $Hg(C_{18}H_{33}O_2)_2$ = 30 − 16 − 2 − 1; First, turn to section 30 of the table. Then follow down the column of chemical formulae until element 16 (C) is first encountered. From this point continue until element 2 (H) is found, and then on until element 1 (O) is reached. At this point will be found all the compounds composed of the four elements Hg, C, H, and O and these compounds are arranged in an obvious manner according to the subscripts in the chemical formula. To facilitate the use of the tables, key-numbers are inserted at frequent intervals either along the top of the page or down the left hand column or both.

In looking for a chemical compound *always consult the 𝔅-Table,* the scope of which provides for *all* chemical compounds except those of the radioactive elements, of which only compounds of U, Th and Ra are given in the 𝔅-Table. For the others see p. 364. In certain of the 𝔅-Tables, at the point where key-formulae beginning with 16 occur, there will be found frequently only a few of the simpler compounds, and the reader will be referred to a

Lorsqu' on écrit une formule-clé, les nombres clés doivent être écrits *dans l'ordre des valeurs décroissantes.*

Tous les composés chimiques dans toutes les tables (Tables 𝔅.) sont arrangés d'après l'ordre numérique inverse de leurs formules-clés. *Exemple:* pour trouver le composé Hg $(C_{18}H_{33}O_2)_2$ = 30–16–2–1; il s'agit premièrement de chercher la section 30 de la table; ensuite de suivre en descendant la colonne des formules chimiques jusqu'à ce qu'on trouve l'élément 16 (C). De ce point, on continue jusqu'à ce qu'on rencontre l'élément 2 (H), et ensuite jusqu'à ce que l'élément 1 (O) soit atteint. On trouvera alors à ce point tous les composés renfermant les quatre éléments Hg, C, H et O et ces composés sont arrangés d'une manière apparante en relation avec les indices de leurs formules chimiques. Afin de faciliter l'usage des tables, les nombres-clés sont inscrits, à de fréquents intervalles, ou au haut de la page ou le long de la colonne gauche, ou aux deux places.

Pour la recherche d'un composé chimique, il s'agit de *consulter toujours la Table* 𝔅 dont le but est de renseigner sur *tous* les composés chimiques, à l'exception des éléments radio-actifs, dont seuls ceux de U, Th et Ra sont donnés dans la Table 𝔅. Pour les autres, voir p. 364. Dans certaines des Tables 𝔅, au point où les

STANCES AND SYSTEMS IN I. C. T.

DIE ANORDNUNG DER CHEMISCHEN VERBINDUNGEN

Durch die ganzen I. C. T., ausgenommen es ist etwas anderes angegeben, ist die tabellarische Anordnung aller chemischen Verbindungen und aller durch chemische Zeichen oder Formeln darstellbarer Systeme, nach der "Normal-Anordnung" (standard arrangement), durchgeführt. Sie ist im folgenden dargelegt und soll von jedem Leser der I. C. T. erlernt werden.

Elementare Stoffe

Alle Tafeln, welche *nur* elementare Stoffe (𝔄-Tabellen) enthalten, sind in alphabetischer Reihenfolge nach den Symbolen der Elemente angeordnet. In den Tafeln, welche beides, Elemente und Verbindungen (𝔄𝔅-Tabellen), enthalten, folgen die Elemente der "Normal-Anordnung." Siehe weiter unten.

Die chemischen Verbindungen und andere durch Formeln darstellbare Systeme

Die Anordnung ist auf der folgenden Tafel begründet, welche die "Schlüsselnummern" der Elemente enthält:

ORDINE DI ELENCAZIONE DELLE SOSTANZE

In tutti i volumi delle T. C. I. l'ordine in cui le sostanze ed i sistemi rappresentabili con formule sono disposti nelle tabelle è (tranne che non sia diversamente indicato) quello "standard" illustrato più avanti. Chiunque voglia servirsi delle T. C. I. deve anzitutto apprendere in che consiste questo sistema "standard."

Sostanze Elementari

Tutte le Tabelle contenenti soltanto sostanze elementari (tabelle 𝔄) sono disposte secondo l'ordine alfabetico dei simboli degli elementi. Nelle tabelle che comprendono elementi e composti (tabelle 𝔄-𝔅) gli elementi sono ordinati secondo la disposizione "Standard." *v. infra.*

Composti Chimici ed Altri Sistemi Rappresentati da Formule

La disposizione è basata sul quadro seguente di "numeri chiave" degli elementi.

Schlüsselnummern der Elemente

Numeri chiave degli elementi

21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Zr	Sn	Pb	Th	Ga	In	Tl	Zn	Cd	Hg	Cu	Ag	Au	Re	Os	Ir	Pt	Ma	Ru	Rh	Pd	Mn	Fe	Co	Ni
66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86				
Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ac	Be(Gl)	Mg	Ca	Sr	Ba	Ra	Li	Na	K	Rb	Cs	(87)				

Ga	Gd	Ge	Gl	H	Hf	Hg	Ho	I	In	Ir	K	La	Li	Lu	Ma	Mg	Mn	Mo	N	Na	Nb	Nd	Ni	O
25	65	20	75	2	73	30	68	6	26	36	83	58	81	72	38	76	42	47	11	82	51	61	45	1
Sr	Ta	Tb	Te	Th	Ti	Tl	Tm	U	V	W	Y	Yb	Zn	Zr	(61)	(75)	(85)	(87)						
78	52	66	10	24	19	27	70	49	50	48	57	71	28	21	62	34	7	86						

Um eine gegebene Verbindung aufzufinden, hat man zuerst seine Schlüsselformel aufzuschreiben, wobei man das Kristallwasser auslässt. z.B.:

Per trovare il posto di un dato composto bisogna prima scrivere la formula chiave trascurando l'acqua di cristallizzazione, p. es.:

Verbindungen	Composto	Na_2SO_4	$HClO_4.3H_2O$	$Hg(C_{18}H_{33}O_2)_2$	$2Fe_2O_3.P_2O_5.12H_2O$	$Ni_3Pr_2(NO_3)_{12}.24H_2O$	$I_2C_6H_3SO_3H$	$(NH_4)_2CO_3$
Schlüsselformel	Formula chiave	82–8–1	4–2–1	30–16–2–1	43–12–1	60–45–11–1	16–8–6–2–1	16–11–2–1

In die Schlüssselformel müssen die Schlüsselnummern in *absteigender* Reihenfolge geschrieben werden.

Alle chemischen Verbindungen (𝔅-Tabellen) sind in der umgekehrten Reihenfolge der Schlüsselformeln angeordnet. Z. B.: Um die Verbindung $Hg(C_{18}H_{33}O_2)_2$ = 30–16–2–1 zu finden, hat man zuerst den Abschnitt 30 aufzusuchen. Dann hat man den Kolonnen der chemischen Verbindungen abwärts zu folgen, bis man zuerst das Element 16 (C) antrifft, von da an setzt man weiter fort, bis das Element 2 (H) gefunden ist und dann weiter, bis das Element 1 (O) erreicht ist. Bei dieser Stelle werden alle Verbindungen gefunden werden, welche sich aus den 4 Elementen Hg, C, H, und O zusammensetzen. Diese Verbindungen sind in deutlicher Art, entsprechend der Bezeichnungsweise chemischer Formeln, angeordnet. Um den Gebrauch der Tafeln möglichst zu erleichtern, sind die Schlüsselnummern häufig an verschiedenen Stellen eingefügt. Sie befinden sich entweder am Kopf der Seiten, oder auf der linken Seite unten, oder an beiden Stellen.

Um eine chemische Verbindung zu suchen, *benütze man immer die 𝔅-Tabellen:* die *alle* chemischen Verbindungen enthalten, ausgenommen jene der radioaktiven Elemente. Von diesen sind

Nella formula chiave, i numeri chiave devono essere scritti *in ordine decrescente.*

Tutti i composti in tutte le tabelle (Tabelle 𝔅) sono disposti nell'ordine numerico inverso delle loro formule chiavi.

Supponiamo ad es. di voler trovare il composto Hg $(C_{18}H_{32}O_2)_2$ = 30–16–2–1. Prima si cerca la sezione 30 della Tabella, poi si scorre la colonna delle formule fino ad incontrare l'elments 16 (C). Da questo punto si continua finchè si trova l'elemento 2 (H), e quindi fino a raggiungere l'elemento 1 (O). Qui si trovano tutti i composti risultanti dai quattro elementi Hg, C, H e O ordinati secondo gli indici delle formule. Per facilitare l'uso delle tabelle i numeri chiave sono inseriti ad intervalli frequenti nella testata o lungo il margine sinistro della pagina, o nell'una e nell'altro.

Per cercare un composto bisogna *sempre consultare la tabella 𝔅* che contiene *tutti* i composti tranne quelli degli elementi radioattivi; di questi sono riportati nella tabella 𝔅 soltanto i composti di U, Th, Ra. Per gli altri vedi p. 364. In alcune tabelle 𝔅, laddove si trovano formule chiave che cominciano con 16, si troveranno spesso soltanto pochi composti fra i più semplici e il lettore

ℭ-Table where the remainder of such compounds will be found listed under a different arrangement known as

The ℭ-Arrangement

In this arrangement the compounds are arranged according to their empirical formulae (*including* water of crystallization), in the order C, H, with the remaining symbols alphabetical, *e.g.*, $C_6H_4I_2O_3S$. The ℭ-Tables, however, will not contain any carbon compound whose key-formula contains a number greater than 16.

SYSTEMS OF MORE THAN ONE COMPONENT

The components of each system are first arranged according to the standard arrangement, giving the order A, B, C, etc. The systems are then arranged, according to the standard arrangement, in the order of their A-components. All systems having the same A-component will be found (under that component) in the order of their B-components, etc.

In certain tables, the above plan will be based upon the ℭ-arrangement instead of the standard arrangement. Such cases will always be so indicated.

Name Indices

The chemical formulae of nearly all of the organic compounds and minerals whose properties are given in I. C. T. can be found with the aid of the extensive indices of names given on p. 174 and 280. If the name is not found there, other works of reference must be consulted for the formula. It should be noted, however, that the exact formula is not required. The compound can be readily located if only the elements composing it are known (in the case of inorganic compounds) or if only the number of carbon atoms are known (in the case of organic compounds) provided only that the user can recognize either name or formula when he sees it.

formules-clés commençant par 16 se présentent, on ne trouvera fréquemment qu'un petit nombre de composés plus simples, et le lecteur sera alors renvoyé à une Table ℭ, où le reste de ces composés se trouvera disposé d'une façon différente nommé

L'Arrangement ℭ

Dans cet arrangement, les composés sont disposés en relation avec leurs formules empiriques (l'eau de cristallisation inclusivement) dans l'ordre C, H, les symboles restants venant ensuite dans l'ordre alphabétique; par ex: $C_6H_4I_2O_3S$. Cependant les Tables ℭ ne contiendront aucun composé dont la formule-clé renferme un nombre supérieur à 16.

SYSTÈMES DE PLUS D'UN COMPOSANT

Les *composants* de chaque système sont premièrement disposés d'après l'arrangement type suivant l'ordre A, B, C, etc. Les *systèmes* sont alors arrangés, en accord avec l'arrangement type, dans l'ordre de leurs composants A. Tous les systèmes ayant le même composant A seront trouvés sous ce composant dans l'ordre de leurs composants B, etc.

Dans certaines tables, le plan sera basé sur l'arrangement ℭ au lieu de l'arrangement type. De tels cas seront toujours mentionnés.

Noms Indices (Anglais)

Les formules chimiques de presque tous les composés organiques et les minéraux dont les propriétés sont données dans les T. C. I. peuvent être trouvées au moyen des indices extensifs des noms donnés aux p. 174 et 280.

Si l'on ne trouve pas le nom à cette place, il faudra consulter d'autres ouvrages de références pour la formule. Il faut noter, cependant, que la formule exacte n'est pas nécessaire. Le composé peut être immédiatement situé si l'on ne connait que les éléments qui le composent (dans le cas des composés inorganiques), ou que les nombres des atomes de C (dans le cas des composés organiques); à la seule condition que le lecteur puisse reconnaître ou le nom ou la formule lorsqu'il la voit.

PHYSICAL PROPERTIES OF CHEMICAL SUBSTANCES

INTRODUCTION

The following tables (p. 96 to 314) are intended to serve as a source of ready reference for the *approximate* values of certain properties of chemical substances, displayed in such a manner as to be of the greatest utility. The values given may be uncertain by one or more units in the last significant figure. Non-significant figures are given in small type. Thus, 2300 indicates that the correct value lies between 1800 and 2800, with 2300 as most probable value.

More accurate values for these properties, if known, will be found in subsequent sections of I. C. T., together with their literature references.

𝔄. ELEMENTARY SUBSTANCES AND ATMOSPHERIC AIR

𝔄-Tables, p. 102. Values in parentheses are estimated, usually with the aid of the Periodic Law.

𝔅. CHEMICAL COMPOUNDS. STANDARD ARRANGEMENT (*v.* p. 96)

𝔅-Tables, p. 106

1. Formula or formula and name.
2. Gram-formula-weight. (I. C. T. atomic weights, *v.* p. 43.)
3. Crystal system.
   𝔅-Table.
   Special tables.

PROPRIÈTÈS PHYSIQUES DES SUBSTANCES CHIMIQUES

INTRODUCTION

Les tables suivantes (p. 96 à 314) ont été établies dans le but de servir de source de référence rapide pour les valeurs *approximatives* de certaines propriétés des substances chimiques, et sont disposées de manière à être de la plus grande utilité possible. Les valeurs données puivent être incertaines par une ou plusieurs unités de leur dernier chiffre significatif. Les chiffres non signicatifs sont donnés en petits caractères. Ainsi, 2300 indique que la valeur correcte se trouve entre 1800 et 2800, avec 2300 comme valeur la plus probable. Si l'on connait des valeurs plus précises pour ces propriétés, on les trouvera dans les sections suivantes des T. C. I., accompagnées de leurs références bibliographiques.

𝔄. SUBSTANCES ÉLÉMENTAIRES ET AIR ATMOSPHÉRIQUE

Tables 𝔄, p. 102. Les valeurs entre parenthèses sont estimées ordinairement à l'aide de la Loi périodique.

𝔅. COMPOSES CHIMIQUES. ARRANGEMENT TYPE (*v.* p. 96)

Tables 𝔅, (p. 106)

1. Formule ou formule et nom.
2. Poids moléculaire en grammes (Poids atomiques des T. C. I., *v.* p. 43.)

in den 𝔅-Tabellen nur die Verbindungen des U, Th und Ra enthalten. Für die anderen siehe Seite 364. In einigen 𝔅-Tabellen, dort wo die Schlüsselnummern mit 16 beginnen, findet man häufig nur einige wenige einfache Verbindungen. Der Leser wird dann auf die ℭ-Tabellen verwiesen, wo die restlichen derartigen Verbindungen gefunden werden können. Diese Tabellen sind nach anderen Gesichtspunkten zusammengestellt. Es ist das die

ℭ-Anordnung (ℭ-Arrangement)

Bei dieser Anordnung sind die Verbindungen nach ihrer empirischen Formel gegeben (einschliesslich Kristallwasser) und zwar in der Ordnung C, H, die restlichen Zeichen dann in alphabetischer Ordnung, z.B. $C_6H_4I_2O_3S$. Die ℭ-Tabellen enthalten jedoch keine Kohlenstoffverbindung, in deren Schlüsselformel eine Zahl grösser als 16 vorkommt.

SYSTEME MIT MEHR ALS EINER KOMPONENTE

Die Komponenten jedes einzeln Systemes sind zuerst in der Reihenfolge A, B, C, u. s. w., entsprechend des "Standard-Arrangement" anzuordnen. Die Systeme sind dann, entsprechend des "Standard-Arrangement," in der Reihenfolge ihrer A-Komponenten angegeben. Alle Systeme, welche dieselbe A-Komponente haben, werden unter dieser Komponente in der Reihenfolge ihrer B-Komponenten gefunden.

In gewissen Tabellen wird dieser Plan entsprechend der ℭ-Anordnung, an Stelle des "Standard Arrangement," gewahlt. Solche Fälle werden immer entsprechend bemerkt.

Namenverzeichnis (Englisch)

Die chemischen Formeln von so ziemlich allen organischen Verbindungen und Mineralien, deren Eigenschaften in den I. C. T. enthalten sind, können mit Hilfe des ausgedehnten Namenverzeichnisses auf Seite 174 und 280 gefunden werden. Ist der Name hier nicht auffindbar, so müssten andere Quellen für die Formel nachgesehen werden. Es soll aber bemerkt werden, dass eine genaue Formel nicht nötig ist. Die Verbindung kann bei anorganischen Verbindungen leicht aufgefunden werden, wenn nur die Elemente, die sie zusammensetzen, bekannt sind, bei organischen Verbindungen, wenn nur die Zahl der Kohlenstoffatome bekannt ist. Nötig ist es, dass der Leser entweder den Namen oder die Formel beim Ansehen erkennt.

DIE PHYSIKALISCHEN EIGENSCHAFTEN CHEMISCHER STOFFE

EINFÜHRUNG

Die folgenden Tafeln (s. 96 bis 314) sollen zur raschen Orientierung über angenäherte Werte gewisser Eigenschaften chemischer Verbindungen dienen. Sie sind in einer solchen Art angeordnet, um vom grösstmöglichem Nutzen zu sein. Die angegebenen Werte können auf einer und mehreren Stellen der letzten grossgeschriebenen Ziffer unsicher sein. Z.B. sagt die Zahl 2300 aus, dass der zwischen 1800 und 2800 liegende Wert am wahrscheinlichsten 2300 sein wird.

Genauere Werte für diese Eigenschaften können, wenn sie bekannt sind, in den weiter unten vorhandenen Abschnitten der I. C. T. zusammen mit der Literatur gefunden werden.

𝔄. ELEMENTARE STOFFE UND DIE ATMOSPHÄRISCHE LUFT

𝔄-Tabellen, Seite 102. Werte, die in den Klammern sich befinden, sind geschätzt gewöhnlich nach dem periodischem System der Elemente.

𝔅. CHEMISCHE VERBINDUNGEN. NORMAL-ANORDNUNG [STANDARD-ARRANGEMENT] (siehe S. 97)

𝔅-Tabellen, Seite 106

1. Formel oder Formel und Name.
2. Gramm-Formel-Gewicht (Atomgewichte der I. C. T. siehe S. 43.)

sarà rimandato a una tabella ℭ dove si troveranno gli altri disposti con criterio differente che viene chiamato

La Disposizione ℭ

Secondo questa i composti sono disposti in base alle formule empiriche (*compresa* l'acqua di cristallizzazione) nell'ordine C, H e con i rimanenti simboli ordinati alfabeticamente P. es. $C_6H_4I_2O_3S$. Le tabelle ℭ non comprendono però composti del carbonio che hanno un numero chiave piu grande di 16.

SISTEMI DI PIU' D'UN COMPONENTE

I *componenti* di ciascun sistema sono dapprima disposti secondo la disposizione tipo, nell'ordine A, B, C, etc. I *sistemi* sono quindi disposti, secondo la disposizione tipo, nell'ordine dei loro componenti A. Tutti i sistemi aventi lo stesso componente A verranno trovati, sotto questo componente, nell'ordine dei loro componenti B, etc.

In alcune tavole il piano sara' basato sulla disposizione ℭ in luogo della disposizione tipo. Di cio' verra' sempre fatta menzione.

Indici Per Nome (Inglese)

Le formule chimiche di quasi tutti i composti organici e minerali di cui sono riportate le proprietà nelle T. C. I. si possono trovare con l'aiuto di estesi indici di nomi dati a p. 174, e 280. Se negli indici non si trova il nome bisogna consultare altre opere per trovare la formula. Deve tuttavia notarsi che non è necessaria la formula esatta. Il composto può essere facilmente ritrovato se si conoscono solo gli elementi componenti (nel caso di composti inorganici) o se si conosce solo il numero di atomi di carbonio (nel caso di composti organici) purchè il lettore sia in grado di riconoscerne il nome o la formula quando li vede.

PROPRIETA' FISICHE DELLE SOSTANZE

INTRODUZIONE

Le tabelle seguenti (p. 96 a 314) hanno lo scopo di fornire per una serie di sostanze valori *approssimati* di certe proprietà disposti in modo da essere della più grande utilità. I valori riportati pòs sono essere incerti per una o più unità nelle ultime cifre significative. Le cifre non significative sono indicate in caratteri piccolli. Così 2300 indica che il valore esatto si trova fra 1800 e 2800, e che 2300 è il valore più probabile.

Valori più precisi di queste proprietà quando sono conosciuti, sono riportati nelle sezioni successive delle T. C. I. insieme con le relative indicazioni bibliografiche.

𝔄. SOSTANZE ELEMENTARI ED ARIA ATMOSFERICA

Tabelle 𝔄, p. 102. I valori fra parentesi sono calcolati generalmente con l'aiuto della legge periodica.

𝔅. COMPOSTI, DISPOSIZIONE STANDARD (*v.* p. 97)

Tabelle 𝔅, p. 106

1. Formula oppure formula e nome.
2. Peso della formula in grammi. (T. C. I. pesi atomici *v.* p. 43.)
3. Sistema cristallino.
   Tabella 𝔅.
   Tabelle speciali.
4. Punto di fusione. (Alla pressione di una atmosfera, tranne che non sia diversamente indicato dalla soprascritta; così $125^{17\text{atm.}}$ = fonde a 125° alla pressione di 17 atmosfere.)
   Tabella 𝔅

4. Melting point. (Under 1 atm. unless otherwise indicated by superscript, thus $125^{17\text{atm.}}$ melts at 125° under 17 atm.)
𝔅-Table.

5. Boiling point. (Under 760 mm Hg unless otherwise indicated by superscript, thus 321^{125} = boils at 321° under 125 mm Hg.)
𝔅-Table.

6. Density, g cm^{-3}. (At 20° unless otherwise indicated by superscript, thus 1.853^{40} = 1.853 g cm^{-3} at 40°C,)
𝔅-Table.

7. Refractive index and dispersion, (n_D and $H_\beta - H_\alpha$) for 20° unless otherwise indicated.

ABBREVIATIONS AND CONVENTIONS

at. or atm.	atmosphere
C.	cubic or regular
d.	decomposes, *e.g.*, d. 335 = decomposes at *ca.* 335°; 335 d. = melts (resp. boils) at 335° with decomposition
diss.	a dissociation temperature
exp.	explodes
l.	liquid
H.	hexagonal
M.	monoclinic
P.	under pressure
s.	sublimation
s. d.	slight decomposition
R.	rhombic or orthorhombic
Tet.	tetragonal
Tr.	transition temperature
Tri.	triclinic
Trig.	trigonal
vac.	*in vacuo*
var.	variable

THE PROPERTY-SUBSTANCE TABLES

Following the General Tables will be found (p. 306) the Property-substance Tables, in each of which the substances, identified by Index Number, are arranged in ascending order of the values of the property, the intervals on the scale of values of the property being given in black-face type.

To Identify a Substance by Means of Its Properties.—*Example:* A liquid is found to have the following properties: B. P. = 81.1° at 745 mm, $d = 0.783$, $n_D = 1.347$. What is the substance ? With the aid of Craft's rule, first correct the boiling point to 760 mm. If the general nature of the substance is unknown, put $c = 10^{-4}$ in the Craft's equation, $\Delta t = cT_B(760 - P)$. Thus in the present instance, we should have $\Delta t = 10^{-4} \times (81.1 + 273)\ (760 - 745) = 0.3°$, and $t_B = 81.1 + 0.3° = 81.4°$. Next turn to the special B. P. (p. 310), d (p. 313), and n (p. 276) tables and read off from these tables the index numbers of substances having values of the above properties in the neighborhood of those for the unknown substance. Thus, for the present example, the following index numbers will be obtained: For B. P., 130, 758, 727, 1612, 168, 277, 1535, 506, 792; for d, 208, 168, 395, 506, 3320, 1049, 262, 792, 5156; for n_D, 141, 168, 213. The only index number common to each of these properties is 168; and on turning to this index number in the General ℭ-Table, we can readily identify our substance as acetonitrile. The identification can then be further checked by appropriate chemical tests, if desired.

3. Système cristallin.
Table 𝔅.
Tables spéciales.

4. Point de fusion. (Sous 1 atm. à moins d'une indication par exposant, ainsi $125^{17\text{atm.}}$ = fond à 125° sous 17 atm.)
Table 𝔅.

5. Point d'ebullition. (Sous 760 mm Hg à moins d'une indication par exposant, ainsi 321^{125} = boût à 321° sous 125 mm Hg.)
Table 𝔅.

6. Densité, g cm^{-3}. (A 20° à moins d'une indication par exposant, ainsi $1{,}853^{40}$ = g cm^{-3} à 40°C.)
Table 𝔅.

7. Indice de réfraction, et dispersion (n_D et $H_\beta - H_\alpha$) à 20° à moins d'une indication.

ABRÉVIATIONS ET CONVENTIONS

at. ou atm.	atmosphère
C.	cubique ou régulier
d.	Se décompose, par ex., d. 335 = se décompose à *environ* 335°; 335 d. = fond (resp. bout) à 335° avec décomposition
diss.	une température de dissociation
exp.	exploser
l.	liquide
H.	hexagonal
M.	monoclinique
P.	sous pression
s.	sublimation
s.d.	légère décomposition
R.	rhombique ou orthorhombique
Tet.	tétragonal ou quadratique
Tr.	température de transition
Tri.	triclinique
Trig.	trigonal
vac.	dans le vide
var.	variable

TABLES DES PROPRIÉTÉS DES SUBSTANCES

On trouvera (p. 306) à la suite des Tables générales, les Tables des Propriétés des Substances, dans chacune desquelles, les substances identifiées par leur Nombre-Index, sont arrangées dans l'ordre ascendant des valeurs de la propriété; les intervalles de l'échelle des valeurs de la propriété sont donnés en caractères gras.

Pour identifier une substance au moyen de ses propriétés.—*Exemple*: On a trouvé qu'un liquide a les propriétés suivantes: P.E. = 81.1° à 745 mm, $d = 0.783$, $n_D = 1{,}344$. Quelle est la substance? Au moyen de la règle de Craft, on corrige premièrement le point d'ébullition à 760 mm. Si la nature générale de la substance est inconnue, on pose $c = 10^{-4}$ dans l'équation de Craft, $\Delta t = cT_E$ $(760 - P)$. Ainsi dans le cas présent, nous aurions $\Delta t = 10^{-4} \times (81.1 + 273)(760 - 745) = 0.3°$, et $t_E = 81.1° + 0.3° = 81.4°$. Ensuite on cherche dans les tables spéciales des P.E. (p. 310), des d (p. 313) et des n (p. 276) et on note les nombres-index des substances ayant les valeurs des propriétés ci-dessus dans le voisinage de celles de la substance inconnue. Ainsi, pour l'exemple présent, les nombres-index suivants seront obtenus; Pour le P.E., 130, 758, 727, 1612, 168, 277, 1535, 506, 792; pour d, 208, 168, 395, 506, 3320, 1049, 262, 792, 5156; pour n_D, 141, 168, 213. Le seul nombre-index commun à chacune de ces propriétés est 168; en revenant à ce nombre-index dans la Table générale ℭ, et en notant les autres propriétés, on peut rapidement identifier notre substance comme étant acétonitrile. L'identification peut être alors poussée plus loin au moyen d'essais chimiques appropriés, si on le désire.

3. Kristall-System
𝔅-Tabellen.
Besondere Tabellen.

4. Schmelzpunkt. (Bei 1 Atmosphäre: wird dem Werte eine Zahl rechts hinaufgesetzt, so bedeutet diese den Druck unter welchem der Schmelzpunkt angegeben ist. Es bedeutet $125^{17\text{atm.}}$: der Schmelzpunkt ist bei einem Druck von 17 Atm. bei 125°.)
𝔅-Tabellen.

5. Siedepunkt. (Unter 760 mm Quecksilber: wird dem Werte eine Zahl rechts hinaufgesetzt, so bedeutet diese Zahl den Druck, unter welchem der Siedepunkt angegeben ist. Es bedeutet 321^{125}; der Siedepunkt liegt bei einem Druck von 125 mm Hg bei 321°.)
𝔅-Tabellen.

6. Dichte, g cm^{-3}. (Bei 20°C: wird dem Wert eine Zahl rechts hinaufgesetzt, so bedeutet diese Zahl die Temperatur, für welche die Dichte angegeben ist. Es bedeutet 1.853^{40}: die Dichte bei 40° beträgt 1.853).
𝔅-Tabellen.

7. Brechungs-Index und Dispersion, (n_D und $H_\beta - H_\alpha$) für 20°, wenn nichts anderes angegeben ist.

ABKÜRZUNGEN UND ZEICHEN

at. oder atm.	Atmosphäre
C.	kubisch oder regulär
d.	zersetzt sich, z. B. d335 bedeutet, zersetzt sich bei *ungefähr* 335°; 335d bedeutet, schmilzt (oder siedet) bei *ungefähr* 335° unter Zersetzung
diss.	Dissoziations Temperatur
exp.	explodiert
l.	flüssig
H.	hexagonal
M.	monoklin
P.	unter Druck
s.	Sublimation
s.d.	schwache Zersetzung
R.	rhombisch oder orthorhombisch
Tet.	tetragonal
Tr.	Umwandlungstemperatur
Tri.	triklin
vac.	im Vacuum
var.	variabel

STOFF-EIGENSCHAFTS TAFELN

Den Haupttabellen folgend, findet man Seite 306 Stoff-Eigenschafts Tafeln. In jeder dieser Tafeln, in welcher die Stoffe durch ihre Indexzahlen bezeichnet sind, werden die Stoffe in aufsteigender Ordnung der Werte dieser Eigenschaften dargestellt. Die Intervalle an der Scala der Eigenschaftswerte sind in fettgedruckten Ziffern angegeben.

Die Erkennung eines Stoffes mit Hilfe seiner Eigenschaften.—*Beispiel:* Es ist eine Flüssigkeit gefunden, welche folgende Eigenschaften hat: Siede-Punkt 81.1° bei 745 mm, $d = 0.783$, $n_D = 1.344$. Welcher Stoff ist das? Mit Hilfe der Regel von Craft corrigiere man zuerst den Siede-Punkt auf 760 mm. Ist die allgemeine Natur des Stoffes nicht bekannt, setze man $c = 10^{-4}$ in die Gleichung von Craft ein: $\Delta t = cT_B(760 - P)$. Im gegenwärtigen Falle ist also $\Delta t = 10^{-4} \times (81.1 + 275)(760 - 745) = 0.3°$, wonach dann der Siede-Punkt $t_B = 81.1° + 0.3° = 81.4°$ sich ergibt. Dann verwende man die Sd.P. Tabellen (Seite 310), die *d*-Tabellen (Seite 313) und die *n*-Tabellen (Seite 276), suche in diesen die Indexzahlen jener Stoffe heraus, deren oben genannte Eigenschaften solche Werte haben, die in der Nähe der Eigenschafts Zahlen des unbekannten Stoffes liegen. So erhält man für das gewählte Beispiel, folgende Indexnummern: für Sd. P. 130, 758, 727, 1612, 168, 277, 1535, 506, 792, für *d*, 208, 168, 395, 506, 3320, 1049, 262, 792, 5156; für n_D 141, 168, 213. Die einzige Index-Nummer, die alle drei Eigenschaften vereinigt, ist 168. Diese Index-Nummer wird in der Haupt ℭ-Tabelle aufgesucht; mit Beachtung noch anderer Eigenschaften kann man leicht die Flüssigkeit als Azetonitril erkennen. Die Identifizierung kann dann noch weiter durch

5. Punto di ebollizione. (Alla pressione di 760 mm Hg tranne che non sia altrimenti indicato dalla soprascritta; così 321^{125} = bolle a 321° alla pressione di 125 mm Hg.)
Tabella 𝔅.

6. Densità, g cm^{-3}. (A 20°, tranne che non sia altrimenti indicato dalla soprascritta; così $1.853^{40} = 1.853$ g cm^{-3} a 40°C.)
Tabella 𝔅.

7. Indice di rifrazione e dispersione (n_D e $H_\beta - H_\alpha$) per 20° tranne che non sia altrimenti indicato.

ABBREVIAZIONI E CONVENZIONI

at. oppure atm.	atmosfera
C.	cubico o regolare
d.	si decompone; per es. d335 = si decompone a *ca.* 335°; 355d = fonde (o bolle) a 335° con decomposizione
diss.	una temperatura di dissociazione
exp.	esplode
l.	liquido
H.	esagonale
M.	monoclino
P.	sotto pressione
s.	sublimazione
s.d.	leggera decomposizione
R.	rombico od ortorombico
Tet.	tetragonale
Tr.	temperatura di trasformazione
Tri.	triclino
Trig.	trigonale
vac.	nel vuoto
var.	variable

LE TABELLE DELLE PROPRIETA' DELLE SOSTANZE

Seguendo le tabelle generali si troveranno (p. 306) le tabelle delle proprietà in ciascuna delle quali le sostanze, indicate col numero indice, sono disposte secondo l'ordine ascendente dei valori della proprietà. Gli intervalli nella scala dei valori della proprietà sono indicati in grassetto.

Identificazione di una sostanza a mezzo delle sue proprietà.—*Esempio:* si supponga che un liquido abbia le seguenti proprietà: B.P. = 81.1° a 745 mm, $d = 0.783$, $n_D = 1.344$. Che sostanza è?

Con l'aiuto della regola di Craft, bisogna anzitutto ridurre il punto di ebollizione a 760 mm. Se non si conosce la natura della sostanza bisogna mettere, nella equazione di Craft, $c = 10^{-4}$, $t = cT_B(760 - P)$. Così, nel caso nostro, si avrebbe $t = 10^{-4} \times (81.1 + 273)\ (760 - 745) = 0.3°$, e $t_B = 81.1° + 0.3° = 81.4°$. Dopo bisogna guardare alle tabelle speciali per il B. P. (p. 310), per *d* (p. 313) e per *n* (p. 276), e ricavare da queste tabelle i numeri indici delle sostanze aventi valori delle suddette proprietà vicini a quelli della sostanza sconosciuta. Così, per il nostro esempio, si otterranno i seguenti numeri indici: per B.P., 130, 758, 727, 1612, 168, 277, 1535, 506, 792; per *d*, 208, 168, 395, 506, 3320, 1049, 262, 792, 5156; per n_D 141, 168, 213. L'unico numero indice comune a ciascuna di queste proprietà è 168; tornando a questo numero indice nella Tabella Generale ℭ, e osservando le altre proprietà, si può prontamente identificare la sostanza nel acetonitrile.

La identificazione può quindi essere ulteriormente comprovata da appropriati saggi chimici, se si desidera.

ELEMENTARY SUBSTANCES AND ATMOSPHERIC AIR. A-TABLE

THE GASEOUS STATE

Chem. symb.	Standard density 0°, 1 A_n g l^{-1}	Density of the saturated vapor at the normal boiling point g l^{-1}	Critical constants			Specific heat joules per gram atom at 15°	Viscosity $\eta = A \times 10^{-6}$ poises	
	d_g	d_v	t_c °C	p_c atm.	d_c g cm^{-3}	C_p	A	t
A	1.7824	5.89	−122.4	48.0	0.531	20.2	221	20
As			>1400.					
Br			302.		1.18		155	20
Cl	3.214		144.	76.	0.573	17.2	132	20
F	1.695							
H	0.08987	1.33	−239.9	12.8	0.0310	14.55	88.7	20
He	0.1785	(11.2)	−267.9	2.26	0.069	20.9	197	20
Hg		0.020 at 320°	1650	3500	5.		494	273
I			553.				184	124
Kr	3.708	(8.3)	− 62.6	54.2			248	20
N	1.2506	4.61	−147.1	33.5	0.311	14.56	176.5	23
Ne	0.9002	9.46	−228.7	26.9	0.484		312	20
O	1.4290	4.74	−118.8	49.7	0.430	14.60	203.9	23
O_3	3.03 at −80°		− 5.0	(67.)	0.54			
P			721.	100.				
Rn	9.73	(12.6)	104.4	62.4			229	20
S			1040.					
Tl		14.8						
Xe	5.851	(9.7)	16.6	58.2	1.15		225	20
Air	1.2930						284.2	20

THE LIQUID STATE

Chem. symb.	Density g cm^{-3}		Thermal expansion $\frac{1}{v}\frac{dv}{dt} = A \times 10^{-6}$		Normal boiling point (s = "solid")	Latent heat of vaporization at t_B. Kilo-joules per gram atom (s = "solid")
	d	t	A	at t^0	t_B	L_V
A	1.402	−185.7	4500.	−183	−185.7	6.3
Ac					(>1700.)	
Ag	9.4	960.	110.	960–1200	1950.	249.
Al	2.40	658.	113.	658–1100	1800.	225.
As					615.s	139.s
Au	17.	1063.			2600.	368.
B					(2550.)	
Ba					1140.	361.
Be					(1500.)	
Bi	10.1	270.	122.	270–630	1450.	193.
Br	3.119	20.	1100.	0–30	58.78	15.0
C					4200.	600.
Ca					1170.	399.
Cb					(>3300.)	
Cd	8.0	320.	150.	320–540	767.	107.
Ce					1400.	
Cl	1.557	− 33.6	1500.	−34	−34.6	10.0
Co					2900.	380.
Cr					2200.	320.
Cs	1.84	26.	370.	27–123	670.	73.
Cu	8.3	1083.	190.	1083–1295	2300.	467.

THE LIQUID STATE.—(*Continued*)

Chem. symb.	d	t	A	at t^0	t_B	L_V
F	1.11	−187.	3000.	−200	−187.	(6.)
Fe	6.9	1530.			3000.	380.
Ga	6.095	29.7			>1600.	
Ge					(2700.)	(500.)
H	0.0709	−252.7	13000.	−255	−252.7	0.450
He	0.126 0.147 d_{max}	−268.9 −270.8			−268.9	0.10
Hf					(>3200.)	
Hg	13.546	20.	182.	20	356.90	59.3
I	4.00	107.	800.	107–150	184.35	22.0
In					>1450.	
Ir					(>4800.)	
K	0.83	62.	290.	62–150	760.	84.
Kr	2.6	146.			−151.8	(9.4)
La					1800.	
Li			180.	186–230	>1200.	(170.)
Mg	1.57	650.	380.	650–800	1110.	262.
Mn					1900.	240.
Mo					3700.	710.
N	0.808	−195.8	6000.	−195	−195.8	2.80
Na	0.93	97.5	280.	100–200	880.	105.
Ne	1.204	−245.9			−245.9	1.74
Ni					2900.	380.
O	1.14	−183.	4100.	−195	−183.00	3.415
O_3	1.71	−183.	2000.	−183	−112.	4.88
Os					(>5300.)	
P	1.745	44.5	520.	50–60	280.	
Pa					(6200.)	
Pb	10.3	327.	120.	327–825	1620.	193.
Pd	11.	1550.			2200.	
Pt	19.	1755.			4300.	520.
Ra					(1140.)	
Rb	1.475	38.5	340.	40–140	700.	74.
Rh					(>2500.)	
Rn	4.4	−62.			−61.8	(18.1)
Ru					(>2700.)	
S	1.808	115.	430.	115	444.6	8.98
Sb	6.55	631.	100.	630–1050	1380.	190.
Sc					(2400.)	
Se					688.	31.
Si					2600.	170?
Sn	6.98	232.	100.	232–1600	2260.	325.
Sr					1150.	383.
Ta					(>4100.)	
Te					1390.	85.
Th					(>3000.)	
Ti					(>3000.)	
Tl	11.0	300.	140.	300–350	1650.	120? 256?
V					(3000.)	
W					5900.	910.
Xe	3.06	−109.1			−109.1	(13.4)
Yt					(2500.)	
Zn	6.7	463.	150.	419–543	907.	99.2
Zr					(>2900.)	
87					(620.)	(69.6)
85					(520.)	(83.7)

AIR

Mole % O_2 in liquid	d	t	A at $t°$		t_B	L_V
10	0.831	−195.0			−195.0	
20	.856	−194.3			−194.3	
20.94	.861	−194.2			−194.2	0.185 (pergram)
30	.893	−193.5			−193.5	
40	.932	−192.6			−192.6	
50	.974	−191.5			−191.5	

Chem. symb.	Specific heat joules per gram atom		Electrical resistivity ohm-cm $R = A \times 10^n$		
	C_p	t	A	n	t
A	22.4	−100.			
Ag	33.8	907–1100	17.0	− 6	1000.
Al	28.	660	20.1	− 6	657.
Au	27.	1100	30.8	− 6	1063.
Bi	31.	400	127.		269.
Br	36.	13–45	7.8	12	17.
Cd	36.	321	34.	− 6	400.
Cl	33.5	0–24	>10.	15	−70.
Cs	32.	50	36.6	− 6	28.
Cu	27.	1084	21.3	− 6	1083.
Ga	23.	119	27.	− 6	30.
H	0.975	−252			
Hg	27.9	20	95.8	− 6	20.
I	8.01	114–185	78.	6	110.5
In			29.	− 6	155.
K	30.	63	13.	− 6	62.
Li			45.	− 6	230.
N	27.8	−200			
Na	32.	100	9.7	− 6	100.
Ni	33.	1452	109.		1500.
O	26.4	−200			

Chem. symb.	C_p	t	A	n	t
P			2.3	6	25.
Pb			98.	− 6	400.
Rb	32.	50	23.5	− 6	50.
S	30.4	100	95.	10	115.
Sb	28	630	12.	− 6	860.
Se			76.6	− 9	390.
Sn	31.	232	49.	− 6	300.
Tl			74.	− 6	300.
Zn			43.	− 6	440.
Air	1.91*	−200.			

* Per gram, for liquid containing 20.94 mole % O_2.

SURFACE TENSION

Chem. symb.	γ dyne cm^{-1}	t	Chem. symb.	γ dyne cm^{-1}	t
A	12.5	−185.8	N	8.85	−195.8
Al	520.	750.	O	13.2	−183.
Bi	376.	300.	Pb	442.	350.
Br	36.	58.6	S	60.	120.
Cd	628.	350.	Se	72.	217.
Cl	27.	− 34.5			
Ga	358.	30(CO_2)	Air, with 50 mole % O_2	11.6	−190.3
H	1.91	−252.7			
Hg	476.	20.			

REFRACTIVE INDEX

Chem. symb.	n_D	t	Chem. symb.	n_D	t
B	2.5*		N	1.2053	−190.
Br	1.661	15.	Na	0.0045	
Cd	0.82*		O	1.221	−181.
Cl	1.385	20.	Pb	2.6*	
H	1.097*	−252.8	S	1.929	110.
Hg	1.6–1.9	20.	Se	2.9	220.
N	1.1975*	−195.8	Sn	2.1	

* These values are for the Hg line 5790 Å.

THE CRYSTALLINE STATE

Chem. symb. (At. wt. *v.* p. 43)	Crystal system or form	Density, g cm^{-3}		Thermal expansion $\frac{1}{l}\frac{dl}{dt} = A \times 10^{-6}$		Melting point °C	Specific heat joules per gram atom 1 joule = 4.185 cal.		Latent heat of fusion at t_F Kilo-joules per gram atom	Electrical resistivity ohm–cm $R = A \times 10^{-6}$	
		d	t	A at $t°$		t_F	C_p at $t°$		L_F	A	t
A	C.	1.65	−233			−189.2	25.9	−223	1.12		
Ac						(1800.)					
Ag	C.	10.5	20	18.9	20	960.5	25.2	20	11.	1.62	20
Al	C.	2.702	20	23.03	20	660.0	24.2	20	8.0	2.62	20
As	Met.H.	5.7		4.7	20	$814^{36\text{atm}}$	25.8	0–100		35	0
	Black	4.7	20				27.0	0–100			
	Yel. C.	2.0	20								
Au	C.	19.3	20	14.2	20	1063.0	25.7	18	13.3	2.4	20
B		2.		2		2300.	14.	0–100		1.8×10^{12}	0
Ba		3.5	20			850.					
Be	H.	1.8	20			1350.	16.1	0 – 100	12.	18.5	20
Bi	H.	9.80	20	13.3	20	271.	25.6	20	10.9	115	20
Br	R.	(3.4)				−7.2	23.5	−192 to −108	5.4	$>10^{14}$	
C	Dia. C.	3.51	20	0.9	20		6.1	20		5×10^{20}	15
Graphite	C.	2.255	20	3	20	3500.	8.5	20		1400.	20
Graphite	Single crystal									39–60	20

THE CRYSTALLINE STATE.—(*Continued*)

Chem. symb.	Crystal system	d	t	A at $t°$		t_F	C_p at $t°$		L_F	A	t
Ca	C.	1.55	20	25.	0–21	810.	26.0	20		4.6	20
Cb		8.4	20			1950.					
Cd	H.	8.6	20	29.8	20	320.9	28	20	6.2	7.5	20
Ce	C.	6.90	20			640.	24.8	0–100		78	20
	H.	(6.7)									
Cl	R.	(1.9)				−101.6	28.	−113	3.40		
Co	C.	8.9	20	12.3	20	1480.	24.8	20	14.4	9.7	20
Cr	C.	7.1		8.2	20	1615.	23.	20	6.9	2.6	0
Cs		1.90	20	97.	0–26	26.	29.	20	2.1	20.	20
Cu	C.	8.92	20	16.6	20	1083.	24.5	20	11.5	1.69	20
F		(1.3)				−223.			(0.8)		
Fe	C.	7.86	20	11.7	20	1535.	24.9	20	11.2	10.0	20
Ga	Tet.	5.91	20	18	0–30	29.75	23	12–23	5.55	53	0
Ge	C.	5.36	20			958.5	22.3	0–100		89×10^3	0
H	C.	0.0808	−262			−259.14	2.4	−260.6	0.059		
He						< -272.2					
Hf						(1700)					
Hg	H.?	14.19	−38.9	90	−190 to −40	−38.87	28.0	−40	2.33	21.3	−50
I	R.	4.93	20	93	20–100	113.5	27.8	20	8.38	1.3×10^{15}	20
In	Tet.	7.3	20	33	20	155	27.3	0–100		9	20
Ir	C.	22.4	20	6.5	20	2350.	26.1	0–100		6.	20
K	C.	0.86	20	83.	20	62.3	29	14	2.38	7.0	20
Kr		(2)				−169			(1.5)		
La		6.15	20			826	26	0–100		59	18
Li	C.	0.53	20	56.	20	186	23	0	(3.5)	9.3	20
Ma						(2300)					
Mg	H.	1.74	20	25.6	20	651	25	20	7.13	4.46	20
Mn		7.2	20	23.	20	1260	24.6	0	8.4	5	
Mo	C.	10.2		4	20	2620 ±10	26	20–100		4.77	20
N	C.	1.026	−252.5			−209.86	23	−212	0.356		
Na	C.	0.97	20	71	20	97.5	28.4	20	2.65	4.6	20
Nd		6.9	20			840	27	0–100		79.	20
Ne		(1.0)				−248.67			(0.24)		
Ni	C.	8.90	20	12.8	20	1452	25.8	20	18.17	6.9	20
O	H.	1.426	−252.5			−218.4	22.5	−221.8	0.22		
O_3	Ozone					−251.					
Os	H.	22.48	20	6.1	20	2700.	25	20–100		9	20
P	Yel. H.	1.82	20	125.	0–40	44.1	23	9	0.654	10^{17}	11
	Red, C.	2.20	20			$590^{43 \text{atm}}$	24	−21 to +7			
	Black									710×10^3	0
Pb	C.	11.34	20	29.1	20	327.5	26.5	20	4.70	21.9	20
Pd	C.	12.0	20	11.8	20	1555.	26.2	18	16	10.8	20
Po						(1800.)					
Pr		6.5	20			940.	27	0–100		88	18
Pt	C.	21.45	20	8.9	20	1755.	26.5	20	22	10.5	20
Ra		(5.)				(960.)					
Rb		1.53	20	90.	20	38.5	28.7	0	2.18	12.5	20
Re						(3000)					
Rh	C.	12.5	20	8.4	20	1955.	25	0–100		5.1	20
Rn		(4.)				−71.			(3.25)		
Ru	H.	12.2	20	9.1	20	2450.	26	0–100		10.	20
S	R.	2.07	20	64.	40	112.8	23	0– 30		2×10^{23}	20
	M.	1.96	20			119.0	24	0– 30	1.18		
Sa		7.7				>1300.					
Sb	H.	6.684	25	11.4	20	630.5	25	20	19.5	39.	20
Sc		(2.5)				1200.					
Se	Gray, Trig.	4.80	25	37	40	220.	28	0– 41	(2.2).	1.2	20
	Red, H.?	4.50	25								
Si	C.	2.4	20	2.8–7.3	20	1420.	20.7	20		85×10^3	20
Sn	White, Tet.	7.31	20	20.	20	231.85	26.9	18	(7.)	11.4	20
	Gray, C.?	5.750	20	5.	−163 to −18		25.6	20			

THE CRYSTALLINE STATE.—(*Continued*)

Chem. symb.	Crystal system	*d*	*t*	*A* at *t*°		t_F	C_p at *t*°		L_F	*A*	*t*
Sr		2.6				800.				23.	20
Ta	C.	16.6		7	20	2850.	27	20		15	20
Te	α Met. H.?	6.24	20	16.8	40	452.	25	20	3.9	[5.8 − 33 × 10^3]	
	β H.?	6.00	20								
Th	C.	11.2				1845.	26.8	0–100		18.	20
Ti	C.	4.5	20			1800.	29	0–100		3	20
Tl	Tet.	11.85	20	28	20	303.5	26.6	20	6.15	18.1	20
U		18.7				<1850.	28	0–100		60.	20
V	C.	5.96				1710.	24.6	0–100			
W	C.	19.3		4	20	3370.	26	20–100		5.48	20
Xe		(2.7)				−140.			(2.05)		
Yt		5.51				1490.					
Zn	H.	7.140	20	33	20	419.43	25.3	20	7.1	6	20
Zr	C.	6.4	20			1700.	25.2	0–100		170.	0
85						(470.)					
87						(23.)					

𝔅58, 2494, 𝔅129, 𝔅512, 𝔅628, 𝔅59, 757, 𝔅210, 𝔅57, 𝔅100, 221, 2061, 2062. **1.700**: 368, 555, 476, 987, 694, 475, 𝔅62, 693, 𝔅13, 414, 𝔅622, 690. **1.800**: 2064, 689, 1949, 688, 1759, 1333, 𝔅523, 𝔅45, 390, 𝔅1597, 𝔅60, 38, 𝔅1808, 116, 𝔅621. **1.901**: 𝔅163, 600, 𝔅39, 412, 341, 234, 1205, 413, 𝔅619, 83, 339, 340, 183, 𝔅218, 𝔅522. **2.110**: 415, 122, 184, 649, 186, 𝔅488, 123, 𝔅236, 45, 522, 370, 𝔅378, 𝔅76, 𝔅919, 4, 427. **2.529**: 601, 20, 151, 𝔅1815, 𝔅63, 𝔅142, 345, 𝔅64, 101, 5, 127, 18, 235, 128. **3.022**: 𝔅204, 𝔅918, 𝔅497, 𝔅381, 29, 𝔅34, 𝔅206, 87, 𝔅205. **4.49.**

B. Solids

0.760: 846, 5881, 5918, 5967, 5985, 6014, 6080, 𝔅2916, 5244, 2266, 𝔅2601, 1502, 936, 4406, 6010. **0.919**: 𝔅2667, 548, 3016, 𝔅1812, 3257, 4805, 1058, 239, 3756, 481, 3302. **1.008**: 607, 5343.1, 3901, 𝔅2791, 761, 2573, 4322, 1057, 4652, 3307, 760, 2801, 5902, 482, 1077, 2206, 831. **1.051**: 2160, 5847, 5933, 1771, 3140, 289, 571, 𝔅2643, 3853, 3550, 502, 2116, 3494, 5244.1. **1.150**: 5213.1, 238, 4270, 2166, 3498, 4352, 832, 𝔅431, 𝔅430, 𝔅2623, 5887, 4943, 5404, 5284, 4894, 2595. **1.203**: 4225, 𝔅2626, 259, 5818, 3886.1, 𝔅2998, 504, 298, 3867.1, 5428.1, 𝔅5, 𝔅1896, 2701, 4480, 2308.1, 4226. **1.250**: 4467, 4956, 503, 5573, 1705, 𝔅2624, 5435, 2032, 5202, 𝔅2306, 1287, 1992, 308.1, 1581, 55, 5541, 5028.1, 1990, 1414. **1.35**: 6104, 4739, 5647, 𝔅111, 5028, 4656.1, 802, 3697, 𝔅173, 3111, 5704, 𝔅2655, 5522. **1.40**: 498, 2475, 58, 4622, 1929, 947, 𝔅134, 𝔅2170, 𝔅2347, 1398, 6148, 1397, 5659, 𝔅2300, 4620, 2013, 1349, 𝔅3086, 3778. **1.45**: 𝔅2757, 808, 3178, 1419, 𝔅2171, 630, 𝔅2807, 1231, 𝔅2636, 976, 𝔅2149, 𝔅2693, 1351. **1.47**: 𝔅2990, 204, 1464, 1991, 2682.1, 𝔅2814, 1172, 1350, 𝔅1400, 𝔅1809, 𝔅201, 𝔅2855. **5.0**: 𝔅502, 𝔅1328, 𝔅1350, 𝔅1426, 𝔅1428, 𝔅1844, 𝔅1994, 𝔅289, 𝔅1969, 𝔅1260, 𝔅1375, 𝔅2282, 𝔅1712, 𝔅2202, 𝔅1539, 𝔅499. **5.10**: 𝔅311, 𝔅1130, 𝔅2017, 𝔅734, 𝔅1334, 𝔅994, 𝔅2035.1, 𝔅3329, 𝔅1021, 𝔅2030, 𝔅2513, 𝔅456, 𝔅507, 𝔅554, 𝔅1258, 𝔅1441, 𝔅3061, 𝔅829. **5.2**: 𝔅280, 𝔅1096, 𝔅1337, 𝔅1682, 𝔅1711, 𝔅1063, 𝔅1371, 𝔅1590, 𝔅1686, 𝔅2518, 𝔅1990, 𝔅1992, 𝔅2516, 𝔅618, 𝔅462. **5.3**: 𝔅600, 𝔅677, 𝔅716, 𝔅724, 𝔅1154, 𝔅1634, 𝔅313, 𝔅595, 𝔅1423, 𝔅593, 𝔅1049, 𝔅1236, 𝔅1403, 𝔅1767, 𝔅883, 𝔅1457, 𝔅862, 𝔅608, 𝔅745, 𝔅864, 𝔅473, 𝔅1095. **5.50**: 𝔅592, 𝔅1630, 𝔅1671, 𝔅1852, 𝔅1542, 𝔅1065, 𝔅544, 𝔅723, 𝔅956, 𝔅1059, 𝔅708. **5.6**: 𝔅306, 𝔅306.1, 𝔅1304, 𝔅1710, 𝔅1726, 𝔅744, 𝔅601, 𝔅603, 𝔅951, 𝔅971, 𝔅1636, 𝔅1763, 𝔅1123, 𝔅279, 𝔅670, 𝔅1064, 𝔅1996, 𝔅1440, 𝔅1455. **5.7**: 𝔅320, 𝔅322, 𝔅1372, 𝔅1418, 𝔅1614, 𝔅2339, 𝔅714, 𝔅2494, 𝔅473.1, 𝔅1421, 𝔅546, 𝔅2338, 𝔅1632, 𝔅1098, 𝔅1723, 𝔅957, 𝔅582, 𝔅2599. **5.8**: 𝔅568, 𝔅596, 𝔅1117, 𝔅1685, 𝔅1978, 𝔅1391, 𝔅2048, 𝔅529, 𝔅574, 𝔅2571, 𝔅2049, 𝔅1163, 𝔅541. **5.9**: 𝔅602, 𝔅1118, 𝔅1652, 𝔅1703, 𝔅907, 𝔅1071, 𝔅565, 𝔅2507, 𝔅597, 𝔅2538, 𝔅1736, 𝔅1562. **6.0**: 𝔅401, 𝔅936, 𝔅1050, 𝔅1506, 𝔅1781, 𝔅1227, 𝔅540, 𝔅2059, 𝔅894, 𝔅2366, 𝔅1442, 𝔅1105. **6.1**: 𝔅594, 𝔅1022, 𝔅1101, 𝔅1402, 𝔅1666, 𝔅1784, 𝔅402, 𝔅658, 𝔅657, 𝔅548, 𝔅1655, 𝔅501, 𝔅606, 𝔅2483, 𝔅1327. **6.2**: 𝔅553, 𝔅614, 𝔅1124, 𝔅1390, 𝔅1617, 𝔅863, 𝔅539, 𝔅1800, 𝔅898, 𝔅1116, 𝔅897, 𝔅1055. **6.3**: 𝔅604, 𝔅607, 𝔅1100, 𝔅1119, 𝔅1517, 𝔅1570, 𝔅1631, 𝔅1366, 𝔅2580, 𝔅1722, 𝔅559, 𝔅1086. **6.4**: 𝔅335, 𝔅605, 𝔅667, 𝔅934, 𝔅935, 𝔅995, 𝔅1834, 𝔅1025, 𝔅905, 𝔅575, 𝔅616, 𝔅889, 𝔅834, 𝔅672, 𝔅1051, 𝔅1062, 𝔅503, 𝔅833, 𝔅663, 𝔅1121. **6.5**: 𝔅609, 𝔅660, 𝔅1102, 𝔅1501, 𝔅1958, 𝔅1629, 𝔅3118, 𝔅659, 𝔅509, 𝔅598. **6.6**: 𝔅611, 𝔅617, 𝔅1573, 𝔅2827, 𝔅1285, 𝔅824, 𝔅1698, 𝔅543, 𝔅996, 𝔅1143, 𝔅1619. **6.7**: 𝔅1405, 𝔅2007, 𝔅2006, 𝔅545, 𝔅666, 𝔅1374, 𝔅1620, 𝔅1024, 𝔅719, 𝔅1502. **6.8**: 𝔅573, 𝔅671, 𝔅327, 𝔅336, 𝔅551, 𝔅576, 𝔅581, 𝔅1776, 𝔅2005, 𝔅712, 𝔅1700, 𝔅1306. **6.9**: 𝔅610, 𝔅661, 𝔅1040, 𝔅1103, 𝔅1681, 𝔅1688, 𝔅1840, 𝔅2834, 𝔅557, 𝔅612, 𝔅1621, 𝔅484, 𝔅1235. **7.0**: 𝔅485, 𝔅578, 𝔅588, 𝔅613, 𝔅696, 𝔅1386, 𝔅1404, 𝔅1854, 𝔅599, 𝔅2041, 𝔅1807, 𝔅536, 𝔅584. **7.1**: 𝔅586, 𝔅589, 𝔅1565, 𝔅585, 𝔅725, 𝔅3188, 𝔅587, 𝔅334, 𝔅590, 𝔅882, 𝔅1171, 𝔅1842, 𝔅681, 𝔅1734, 𝔅2828. **7.2**: 𝔅1233, 𝔅1697, 𝔅535, 𝔅2023, 𝔅1847, 𝔅615, 𝔅2826, 𝔅2830, 𝔅577, 𝔅1247, 𝔅1977, 𝔅893, 𝔅1705, 𝔅1067, 𝔅1066, 𝔅910, 𝔅325. **7.4**: 𝔅1128, 𝔅1385, 𝔅1393, 𝔅1843, 𝔅1849, 𝔅2062, 𝔅2060, 𝔅2037, 𝔅1057, 𝔅1528. **7.5**: 𝔅305, 𝔅314, 𝔅330, 𝔅552, 𝔅900, 𝔅1833, 𝔅1041, 𝔅700, 𝔅904, 𝔅538, 𝔅1170, 𝔅1464, 𝔅324. **7.7**: 𝔅328, 𝔅896, 𝔅318, 𝔅902, 𝔅2079, 𝔅1384, 𝔅1848, 𝔅1146, 𝔅323, 𝔅891, 𝔅676. **8.0**: 𝔅525, 𝔅704, 𝔅1004, 𝔅1070, 𝔅1732, 𝔅1850, 𝔅580, 𝔅321, 𝔅558, 𝔅901, 𝔅821, 𝔅560, 𝔅822. **8.2**: 𝔅308, 𝔅1695, 𝔅528, 𝔅1326, 𝔅888, 𝔅890, 𝔅1662, 𝔅1701, 𝔅1550, 𝔅888, 𝔅1017, 𝔅309, 𝔅1072, 𝔅1684, 𝔅1780. **8.64**: 𝔅2082, 𝔅887, 𝔅880, 𝔅895, 𝔅1137, 𝔅1806, 𝔅1169, 𝔅307, 𝔅1663, 𝔅881, 𝔅675. **9.04**: 𝔅1139, 𝔅527, 𝔅892, 𝔅2087, 𝔅526, 𝔅524, 𝔅2099, 𝔅668, 𝔅879, 𝔅1152, 𝔅1702, 𝔅1179, 𝔅1855, 𝔅1693. **11.1**: 𝔅878, 𝔅1725, 𝔅1724, 𝔅1224, 𝔅1225, 𝔅1689, 𝔅1690. **16.06.**

LIQUID CRYSTALS

H. W. Foote

The term "transition temperature" refers in the tables to the temperature at which the solid and crystalline-liquid phases are in equilibrium at a pressure of one atmosphere; by "melting point," is meant the corresponding temperature at which the crystalline-liquid and isotropic liquid phases are in equilibrium. In some cases, more than one stable liquid crystal phase exists, giving an additional transition temperature for each additional liquid crystal phase. These transition temperatures between two liquid crystal phases are indicated by *. In most cases, they are only approximate. Melting points which are quite uncertain, usually due to partial decomposition, have "d." written after the value. No attempt has been made to estimate the accuracy of values obtained by a single investigator, as the methods of determination are the same in nearly every case and the result obviously depends on the skill of the investigator and the purity of the compounds.

A series of apparently good determinations by different observers is apt to vary by considerably more than one degree, and it seems unlikely that any transition temperature or melting point of liquid crystals is known with an accuracy much better than one degree. For this reason, the weighted average of a number of different determinations is usually given to the nearest whole degree. When the number of determinations is sufficient, the weighted average deviation, usually to the nearest whole degree, is given also.

The melting points of unstable liquid crystals, in monotropic systems, are not included in the tables, and transition temperatures, in the ordinary sense, do not exist in this case. Many observations on monotropic compounds will be found in nearly all the Halle dissertations and in the publications by Vorländer, which are listed at the end of the tables.

For the effect of pressure on the transition temperature and melting point of liquid crystals, see G. Hulett, *7*, **28**: 629; 99. For approximate data on liquid crystals of alkali salts of higher fatty acids (chiefly) see Vorländer, *25*, **43**: 3120; 10. For similar data regarding compounds which are optically active, see H. Stoltzenberg, Diss., Halle (1911). For qualitative data regarding liquid crystals, see E. Wolferts, Diss., Halle (09), R. Wilke, Diss., Halle (09); K. Mattenklodt, Diss., Halle (11); and Vorländer, *25*, **40**: 1415, 1966; 07.

Index formula	Formula	Name	Trans. temp.	M. P.	Lit.
$C_{10}H_{10}O_3$	$CH_3OC_6H_4CH:CHCOOH$	*p*-Methoxycinnamic acid	170 ± 1	186 ± 1	(7, 11, 30, 33, 34, 42, 43, 45)
$C_{11}H_{12}O_3$	$C_2H_5OC_6H_4CH:CHCOOH$	*p*-Ethoxycinnamic acid	192	197	(43)
$C_{12}H_{14}O_3$	$C_2H_5OC_6H_4CCH_3:CHCOOH$	*p*-Ethoxy-β-methylcinnamic acid	122.5.	159	(37)
$C_{14}H_{10}BrNO_2$	$BrC_6H_4CH:NC_6H_4COOH$	*p*-Bromobenzal-*p*-aminobenzoic acid	272	274	(12)
$C_{14}H_{10}ClNO_2$	$ClC_6H_4CH:NC_6H_4COOH$	*p*-Chlorobenzal-*p*-aminobenzoic acid	260	263	(12)
$C_{14}H_{10}INO_2$	$IC_6H_4CH:NC_6H_4COOH$	*p*-Iodobenzal-*p*-aminobenzoic acid	279	287	(12)
$C_{14}H_{10}O_5$	$HOC_6H_4COOC_6H_4COOH$	*p*-(*p*-Hydroxybenzoxy)-benzoic acid	258	266 ±	(45)
$C_{14}H_{11}NO_2$	$C_6H_5CH:NC_6H_4COOH$	Benzal-*p*-aminobenzoic acid	183	191	(26)
$C_{14}H_{12}N_2O_3$	$O_2NC_6H_4CH:NC_6H_4OCH_3$	*p*-Nitrobenzalanisidine	135		(26)
$C_{14}H_{14}N_2O_3$	$CH_3OC_6H_4NONC_6H_4OCH_3$	*p*-Azoxyanisol	116 ± 1	135 ± 1	(1, 3, 6, 7, 9, 11, 14, 19, 23, 30, 32, 35, 36, 42, 45)
$C_{14}H_{15}N_3$	$CH_3NHC_6H_4CH:NNHC_6H_5$	*p*-Methylaminobenzalphenylhydrazone	170	190	(34)
$C_{15}H_{10}N_2O_2$	$CNC_6H_4CH:NC_6H_4COOH$	*p*-(*p*-Cyanobenzalamino)-benzoic acid	247	>320	(17)
$C_{15}H_{12}N_2O$	$CNC_6H_4CH:NC_6H_4OCH_3$	*p*-Cyanobenzalanisidine	115	125	(17)
$C_{15}H_{12}N_2O$	$CH_3OC_6H_4CH:NC_6H_4CN$	Anisal-*p*-cyanoaniline	103	113.5	(12)
$C_{15}H_{12}N_2O_4$	$CH_3COOC_6H_4N:NC_6H_4COOH$	*p*-Acetoxyazobenzoic acid	254	d.	(31)
$C_{15}H_{12}O_2$	$C_6H_5C_6H_4CH:CHCOOH$	*p*-Phenylcinnamic acid	221	236	(2)
$C_{15}H_{12}O_5$	$CH_3OC_6H_4COOC_6H_4COOH$	*p*-(*p*-Methoxybenzoxy)-benzoic acid	223	272	(45)
$C_{15}H_{13}NO_2$	$CH_3C_6H_4CH:NC_6H_4COOH$	*p*-(*p*-Methylbenzalamino)-benzoic acid	220	243	(26)
$C_{15}H_{13}NO_3$	$CH_3OC_6H_4CH:NC_6H_4COOH$	*p*-(Anisalamino)-benzoic acid	197	298 d.	(15, 46)
$C_{15}H_{14}N_2O_3$	$O_2NC_6H_4CH:NC_6H_4OC_2H_5$	*p*-Nitrobenzalphenetidine	124		(26)
$C_{15}H_{16}N_2O_5$	$CH_3OC_6H_4NONC_6H_4OC_2H_5$	*p*-Anisylazoxyphenetol	94 ± 1	149 ± 1	(4, 7, 32)
$C_{15}H_{17}N_3$	$C_2H_5NHC_6H_4CH:NNHC_6H_5$	*p*-Ethylaminobenzalphenylhydrazone	160	182	(34)
$C_{16}H_{12}O_6$	$CH_3COOC_6H_4COOC_6H_4COOH$	*p*-Hydroxybenzoic acid *p*-acetoxybenzoate	228 d.	>250	(45)
$C_{16}H_{12}O_7$	$CH_3OCOOC_6H_4COOC_6H_4COOH$	*p*-Hydroxybenzoic acid *p*-carbomethoxyoxybenzoate	218 d.	d.	(45)
$C_{16}H_{14}N_2O$	$CNC_6H_4CH:NC_6H_4OC_2H_5$	*p*-Cyanobenzalphenetidine	115	132	(17)
$C_{16}H_{14}N_2O$	$C_2H_5OC_6H_4CH:NC_6H_4CN$	*p*-Ethoxybenzal-*p*-cyanoaniline	105	124	(12)
$C_{16}H_{14}N_2O_2$	$O_2NC_6H_4CH:CHCH:NC_6H_4CH_3$	*p*-Nitrocinnamal-*p*-toluidine	130	141	(26)
$C_{16}H_{14}N_2O_3$	$O_2NC_6H_4CH:CHCH:NC_6H_4OCH_3$	*p*-Nitrocinnamalanisidine	155	160	(26)
$C_{16}H_{15}NO_2$	$CH_3OC_6H_4CH:NC_6H_4COCH_3$	Anisal-*p*-aminoacetophenone	121.5	135	(15)
$C_{16}H_{15}NO_3$	$CH_3COOC_6H_4CH:NC_6H_4OCH_3$	*p*-Acetoxybenzalanisidine	112	128	(15)
$C_{16}H_{15}NO_3$	$CH_3OC_6H_4CH:NC_6H_4OCOCH_3$	*p*-(Anisalamino)-phenol acetate	81.5	108	(15)
$C_{16}H_{16}N_2O_2$	$CH_3COC_6H_4N:NC_6H_4OC_2H_5$	*p*-Acetophenoneazophenetol	130		(47)
$C_{16}H_{16}N_2O_2$	$CH_3OC_6H_4CH:NN:CHC_6H_4OCH_3$	Anisaldazine	165 ± 3	180 ± 1	(5, 6, 7, 19)
$C_{16}H_{16}N_2O_3$	$C_2H_5OC_6H_4N:NC_6H_4OCOCH_3$	*p*-Phenetolazophenol acetate	121	138	(46, 47)
$C_{16}H_{16}N_2O_4$	$CH_3OC_6H_4N:NC_6H_4OCOOC_2H_5$	*p*-Anisylazocarbethoxyphenol	90	114	(46, 47)
$C_{16}H_{18}N_2O_3$	$C_2H_5OC_6H_4NONC_6H_4OC_2H_5$	*p*-Azoxyphenetol	137 ± 1	167 ± 1	(3, 14, 19, 23, 30, 32, 35, 42, 45)
$C_{16}H_{20}N_2$	$C_2H_5NHC_6H_4C_6H_4NHC_2H_5$	Diethylbenzidine	115.5	120.5	(34)
$C_{17}H_{15}NO_3$	$CH_3OC_6H_4CH:NC_6H_4CH:CHCOOH$	*p*-(Anisalamino)-cinnamic acid	208	d.	(15)
$C_{17}H_{16}N_2O_3$	$O_2NC_6H_4CH:CHCH:NC_6H_4OC_2H_5$	*p*-Nitrocinnamalphenetidine	134	137	(26)
$C_{17}H_{16}N_2O_4$	$CH_3COC_6H_4N:NC_6H_4OCOOC_2H_5$	*p*-Acetophenoneazocarbethoxyphenol	120	126	(47)
$C_{17}H_{16}N_2O_4$	$CH_3COOC_6H_4N:NC_6H_4COOC_2H_5$	Ethyl *p*-acetoxyazobenzoate	99	102	(31)
$C_{17}H_{17}NO_3$	$CH_3OC_6H_4CH:NC_6H_4CH_2CH_2COOH$	*p*-(Anisalamino)-hydrocinnamic acid	136	162	(45)
$C_{17}H_{18}N_2O_4$	$C_2H_5OC_6H_4N:NC_6H_4OCOOC_2H_5$	*p*-Phenetolazocarbethoxyphenol	96	137	(47)
$C_{18}H_{15}ClO_4$	$CH_3COOC_6H_4CH:CClC_6H_4OCOCH_3$	*p*-Dihydroxychlorostilbene diacetate	125	138	(11, 29)
$C_{18}H_{16}N_2O_4$	$CH_3COOC_6H_4CH:NN:CHC_6H_4OCOCH_3$	Di-(*p*-acetoxybenzalazine)	185	192	(16, 40)
$C_{18}H_{17}NO_3$	$CH_3OC_6H_4CH:NC_6H_4CH:CHCOOCH_3$	Methyl anisal-*p*-aminocinnamate	156	176	(43, 47)
$C_{17}H_{17}N_2O_3$	$CH_3OC_6H_4N:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-anisylazocinnamate	116, 123*	143	(46, 47)
$C_{18}H_{18}N_2O_5$	$C_2H_5OCOC_6H_4NONC_6H_4COOC_2H_5$	*p*-Azoxyethyl benzoate	114 ± 0.6	121 ± 0.5	(7, 11, 19, 27, 40, 42, 45)
$C_{18}H_{18}N_2O_6$	$C_2H_5OCOOC_6H_4N:NC_6H_4OCOOC_2H_5$	*p*-Azocarbethoxyphenol	97	118	(15)

Index formula	Formula	Name	Trans. temp.	M. P.	Lit.
$C_{18}H_{18}N_2O_7$	$C_2H_5OCOOC_6H_4NONC_6H_4OCOOC_2H_5$	*p*-Azoxycarbethoxyphenol	95	130	(15)
$C_{18}H_{18}O_2$	$CH_3OC_6H_4CH:CHCH:CHC_6H_4OCH_3$	Di-(*p*-anisylbutadiene)	225	238	(34)
$C_{18}H_{20}N_2O_2$	$C_2H_5OC_6H_4CH:NN:CHC_6H_4OC_2H_5$	Di-(*p*-ethoxybenzalazine)	172	195	(13, 24, 45)
$C_{18}H_{20}N_2O_2$	$CH_3OC_6H_4C(CH_3):NN:C(CH_3)C_6H_4OCH_3$	Di-(*p*-methoxyacetophenoneazine)	195	202	(16)
$C_{18}H_{20}N_2O_4$	$HOC_2H_4OC_6H_4CH:NN:CHC_6H_4OC_2H_4OH$	Di-(hydroxyethoxybenzalazine)	184	207	(13)
$C_{18}H_{22}N_2O_3$	$C_3H_7OC_6H_4NONC_6H_4OC_3H_7$	Di-(*p*-*n*-propoxyazoxybenzene)	116	122	(4, 40)
$C_{19}H_{16}N_2O_2$	$CNC_6H_4CH:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-cyanobenzal-*p*-aminocinnamate	131	179	(17)
$C_{19}H_{18}N_2O_4$	$CH_3COOC_6H_4N:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-acetoxyphenylazocinnamate	132	152	(47)
$C_{19}H_{19}NO_2$	$CH_3C_6H_4CH:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-(*p*-methylbenzalamino)-cinnamate	96, 107*	118	(46, 47)
$C_{19}H_{19}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CCH_3COOH$	*p*-(*p*-Ethoxybenzalamino)-α-methylcinnamic acid	180	265	(20)
$C_{19}H_{19}NO_3$	$CH_3OC_6H_4CH:NC_6H_4CH:CHCOOC_2H_5$	Ethyl (*p*-anisalamino)-cinnamate	100, 108*, 117*	138	(9, 43, 46, 47)
$C_{19}H_{19}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CHCOOCH_3$	Methyl *p*-(*p*-ethoxybenzalamino)-cinnamate	132	187	(43, 47)
$C_{19}H_{22}N_2O_3$	$C_2H_5OC_6H_4N:NC_6H_4OCOC_4H_9$	*p*-Phenetolazophenol *n*-valerate	78–83	125	(47)
$C_{20}H_{13}N_3O_2$	$CNC_6H_4N:NC_6H_4OCOC_6H_5$	*p*-Cyanobenzeneazophenol benzoate	181	226	(12)
$C_{20}H_{14}Br_2N_2$	$BrC_6H_4N:CHC_6H_4CH:NC_6H_4Br$	*p*-Phthalal-di-(*p*-bromoaniline)	208	288	(17)
$C_{20}H_{14}Cl_2N_2$	$ClC_6H_4N:CHC_6H_4CH:NC_6H_4Cl$	*p*-Phthalal-di-(*p*-chloroaniline)	176	282	(17)
$C_{20}H_{14}I_2N_2$	$IC_6H_4N:CHC_6H_4CH:NC_6H_4I$	*p*-Phthalal-di-(*p*-iodoaniline)	262	268	(12)
$C_{20}H_{14}N_4O_4$	$O_2NC_6H_4CH:NC_6H_4N:CHC_6H_4NO_2$	(Di-*p*-nitrobenzal)-*p*-phenylenediamine	242	315	(46)
$C_{20}H_{16}N_2O_3$	$CH_3OC_6H_4N:NC_6H_4OCOC_6H_5$	*p*-Anisylazophenol benzoate	159–163	178	(47)
$C_{20}H_{17}NO$	$CH_3OC_6H_4CH:NC_6H_4C_6H_5$	Anisal-*p*-aminodiphenyl	161	177	(12, 46)
$C_{20}H_{17}N_3O$	$CH_3OC_6H_4CH:NC_6H_4N:NC_6H_5$	Anisal-*p*-aminoazobenzene	151	182	(15, 39, 46)
$C_{20}H_{18}N_2O_5$	$CH_3OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOCH_3$	Methyl azoxycinnamate	221	257	(40)
$C_{20}H_{20}N_2O_2$	$CH_3OC_6H_4CH:CHCH:NN:CHCH:CHC_6H_4OCH_3$	Di-*p*-methoxycinnamicaldazine	210	218	(34)
$C_{20}H_{20}N_2O_4$	$C_2H_5COOC_6H_4CH:NN:CHC_6H_4OCOC_2H_5$	Di-*p*-propionylhydroxybenzalazine	160	187	(16)
$C_{20}H_{20}N_2O_5$	$C_2H_5OCOOC_6H_4N:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-carbethoxyphenolazocinnamate	114	152	(47)
$C_{20}H_{21}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-(*p*-ethoxybenzalamino)-cinnamate	69, 113,* 152*	159	(43, 45, 46, 47)
$C_{20}H_{21}NO_3$	$CH_3OC_6H_4CH:H_4CH:NC_6CCH_3COOC_2H_5$	Ethyl *p*-(anisalamino)-α-methylcinnamate	90	93	(20, 43)
$C_{20}H_{21}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CCH_3COOCH_3$	Methyl *p*-(*p*-ethoxybenzalamino)-α-methylcinnamate	105	147	(20, 43)
$C_{20}H_{24}N_2O_2$	$C_2H_5OC_6H_4CCH_3:NN:CCH_3C_6H_4OC_2H_5$	Di-*p*-ethoxyacetophenoneazine	142	163	(16)
$C_{21}H_{14}O_7$	$HOC_6H_4COOC_6H_4COOC_6H_4COOH$	*p*-Hydroxybenzoic acid *p*-(*p*-hydroxybenzoxy) benzoate	283	d.	(45)
$C_{21}H_{16}N_2O_3$	$CH_3COC_6H_4N:NC_6H_4OCOC_6H_5$	*p*-Acetophenoneazophenol benzoate	211 d.		(47)
$C_{21}H_{17}NO$	$C_6H_5C_6H_4CH:NC_6H_4COCH_3$	*p*-(*p*-Phenylbenzalamino)-acetophenone	187.5		(2)
$C_{21}H_{18}N_2O_3$	$C_2H_5OC_6H_4N:NC_6H_4H_4OCOC_6H_5$	*p*-Phenetolazophenol benzoate	173	193	(46, 47)
$C_{21}H_{19}NO$	$C_2H_5OC_6H_4CH:NC_6H_4C_6H_5$	*p*-(*p*-Ethoxybenzalamino) diphenyl	145	184	(12)
$C_{21}H_{19}NO$	$C_6H_5C_6H_4CH:NC_6H_4OC_2H_5$	*p*-Phenylbenzal-*p*-phenetidine	164	189.5	(2)
$C_{21}H_{19}N_3O$	$C_2H_5OC_6H_4CH:NC_6H_4N:NC_6H_5$	*p*-(*p*-Ethoxybenzalamino)-azobenzene	131.5	199	(2)
$C_{21}H_{21}NO_5$	$C_2H_5OCOOC_6H_4CH:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-[(*p*-carbethoxyoxybenzal)-amino] cinnamate	80	151	(47)
$C_{21}H_{23}NO_3$	$CH_3OC_6H_4CH:NC_6H_4CH:CHCOOC_4H_9$	*n*-Butyl anisal-*p*-aminocinnamate	58	76	(43)
$C_{21}H_{23}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CCH_3COOC_2H_5$	Ethyl *p*-(*p*-ethoxybenzalamino)-α-methylcinnamate.	95	122 ± 2	(9, 19, 20, 39, 43, 46)

Index formula	Formula	Name	Trans. temp.	M. P.	Lit.
$C_{21}H_{23}NO_3$	$CH_3OC_6H_4CH:NC_6H_4CH:CCH_3COOC_3H_7$	*n*-Propyl *p*-(anisalamino)-*α*-methylcinnamate	50	85	(20, 43)
$C_{22}H_{14}H_4$	$CNC_6H_4N:CHC_6H_4CH:NC_6H_4CN$	*p*-Phthalal-di-(*p*-cyanoaniline)	164	209	(12)
$C_{22}H_{17}NO_4$	$C_6H_5CH:NC_6H_4COOC_6H_4COOCH_3$	Methyl benzal-*p*-aminobenzoyl-*p*-hydroxybenzoate	174	177	(45)
$C_{22}H_{19}NO_2$	$C_6H_5C_6H_4CH:NC_6H_4COOC_2H_5$	Ethyl *p*-(*p*-phenylbenzalamino)-benzoate	121.5	128.5	(2)
$C_{22}H_{20}N_2$	$CH_3C_6H_4CH:NC_6H_4N:CHC_6H_4CH_3$	Di-(*p*-tolual)-*p*-phenylenediamine	194	266	(46)
$C_{22}H_{20}N_2$	$CH_3C_6H_4N:CHC_6H_4CH:NC_6H_4CH_3$	*p*-Phthalal-di-(*p*-toluidine)	186	238	(17)
$C_{22}H_{20}N_{22}$	$CH_3OC_6H_4CH:NC_6H_4N:CHC_6H_4OCH_3$	Dianisal-*p*-phenylenediamine	210	338	(46)
$C_{22}H_{22}N_2O_2$	$CNC_6H_4C:HNC_6H_4CH:CHCOOC_5H_{11}$	*act*-Amyl *p*-(*p*-cyanobenzalamino)-cinnamate	95	107	(17, 38, 46)
$C_{22}H_{22}N_2O_4$	$C_2H_5OCOCH:CHC_6H_4N:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-azocinnamate	155	230	(15, 43)
$C_{22}H_{22}N_2O_5$	$C_2H_5OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-azoxycinnamate	140 ± 1	249 ± 1	(7, 15, 25, 40, 43, 45)
$C_{22}H_{22}O_3$	$CH_3OC_6H_4CH:C_6H_6O:CHC_6H_4OCH_3$	Dianisalcyclohexanone	159	170	(2, 28, 44)
$C_{22}H_{24}N_2O_4$	$C_3H_7COOC_6H_4CH:NN:CHC_6H_4OCOC_3H_7$	Di-*p*-butyryloxybenzalazine	146	181	(16)
$C_{22}H_{25}NO_3$	$CH_3OC_6H_4CH:NC_6H_4CH:CHCOOC_5H_{11}$	*act*-Amyl anisal-*p*-aminocinnamate	49	90	(43)
$C_{22}H_{25}NO_3$	$CH_3OC_6H_4CH:NC_6H_4CH:CHCOOC_5H_{11}$	*iso*-Amyl anisal-*p*-aminocinnamate	52	90	(43)
$C_{22}H_{25}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CHCOOC_4H_9$	*n*-Butyl *p*-(*p*-ethoxybenzalamino)-cinnamate	68, 88*	125	(43)
$C_{22}H_{25}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CHCOH_3COOC_3H_7$	*n*-Propyl *p*-(*p*-ethoxybenzalamino)-*α*-methylcinnamate	88	121	(20, 43)
$C_{23}H_{16}O_8$	$CH_3COOC_6H_4COOC_6H_4COOC_6H_4COOH$	*p*-Hydroxybenzoic acid *p*-(*p*-acetoxybenzoxy)-benzoate	248	d.	(45)
$C_{23}H_{19}NO_2$	$C_6H_5C_6H_4CH:NC_6H_4CH:CHCOOCH_3$	Methyl *p*-(*p*-phenylbenzalamino)-cinnamate	208, 216*	247	(2)
$C_{23}H_{19}NO_5$	$CH_3OC_6H_4CH:NC_6H_4COOC_6H_4COOCH_3$	Methyl *p*-(anisalamino)-benzoyl-*p*-hydroxybenzoate	217	300	(45)
$C_{23}H_{21}NO_4$	$CH_3OC_6H_4CH:NC_6H_4CH_2OC_6H_4COOCH_3$	Methyl *p*-(anisalamino)benzyl-*p*-hydroxybenzoate	157	165	(45)
$C_{23}H_{24}O_3$	$C_2H_5OC_6H_4CH:C_5H_4O:CHC_6H_4OC_2H_5$	Di-(*p*-ethoxybenzal)-cyclopentanone.	189, 194*	200	(44)
$C_{23}H_{27}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CHCOOC_5H_{11}$	*act*-Amyl *p*-(*p*-ethoxybenzalamino)-cinnamate	68, 114*	121	(43)
$C_{23}H_{27}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CHCOOC_5H_{11}$	*iso*-Amyl *p*-(*p*-ethoxybenzalamino)-cinnamate	81	137	(43)
$C_{23}H_{27}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CCH_3COOC_4H_9$	*n*-Butyl *p*-(*p*-ethoxybenzalamino)-*α*-methylcinnamate	55, 65*	82	(20, 43)
$C_{23}H_{27}NO_3$	$CH_3OC_6H_4CH:NC_6H_6CH:CCH_3COO\ C_5H_{11}$	*act*-Amyl *p*-(anisalamino)-*α*-methylcinnamate	62	69	(46)
$C_{24}H_{18}O_6$	$C_2H_5OCOOC_6H_4COOC_6H_4COOC_6H_4COOH$	*p*-Hydroxybenzoic acid *p*-(*p*-carbethoxyoxybenzoxy) benzoate	215	d.	(45)
$C_{24}H_{20}N_2O_4$	$C_6H_5COOC_6H_4N:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-benzoyloxyphenylazocinnamate	135	212	(47)
$C_{24}H_{21}NO_2$	$C_6H_5C_6H_4CH:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-(*p*-phenylbenzalamino)-cinnamate.	145, 180,* 205,* 210*	219	(2, 39, 43, 46)
$C_{24}H_{22}N_2O_4$	$CH_3OC_6H_4CH:NC_6H_4CONHC_6H_4COOC_2H_5$	Ethyl *p*-(anisalamino)-benzoyl-*p*-aminobenzoate	212, 220*	247	(45, 46)
$C_{24}H_{24}Br_2N_2O_5$	$C_2H_5OCOCCH_3:CBrC_6H_4NONC_6H_4CBr:CCH_3COOC_2H_5$	Ethyl *p*-azoxy-*α*-methyl-*β*-bromcinnamate	110, 132*	138	(20)
$C_{24}H_{24}N_2O_2$	$C_2H_5OC_6H_4CH:NC_6H_4N:CHC_6H_4OC_2H_5$	Di-(*p*-ethoxybenzal)-*p*-phenylenediamine	200		(2)
$C_{24}H_{24}N_2O_2$	$C_2H_5OC_6H_4N:CHC_6H_4CH:NC_6H_4OC_2H_5$	*p*-Phthalal-di-(*p*-phenetidine)	197	324	(17)
$C_{24}H_{24}N_2O_5$	$C_3H_6OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOC_3H_6$	Allyl *p*-azoxycinnamate	124	235	(40)
$C_{24}H_{26}N_2O_5$	$C_2H_5OCOCCH_3:CHC_6H_4NONC_6H_4CH:CCH_3COOC_2H_5$	Ethyl *p*-azoxy-*α*-methylcinnamate	109, 134*	140	(20, 21)

Index formula	Formula	Name	Trans. temp.	M. P.	Lit.
$C_{24}H_{26}N_2O_5$	$C_3H_7OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOC_3H_7$	*iso*-Propyl *p*-azoxycinnamate	150	184	(40)
$C_{24}H_{26}N_2O_5$	$C_3H_7OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOC_3H_7$	*n*-Propyl *p*-azoxycinnamate	123	243	(40)
$C_{24}H_{26}O_3$	$C_2H_5OC_6H_4CH:C_6H_6O:CHC_6H_4OC_2H_5$	Di-(*p*-ethoxybenzal)-cyclohexanone	146	176	(44)
$C_{24}H_{28}N_2O_4$	$C_4H_9COOC_6H_4CH:NN:CHC_6H_4OCOC_4H_9$	Di-(*p*-valerylhydroxy)-benzalazine	145	160	(16)
$C_{24}H_{28}N_2O_4$	$C_4H_9COOC_6H_4CH:NN:CHC_6H_4OCOC_4H_9$	Di-(*p*-isovalerylhydroxy)-benzalazine	131	156	(16)
$C_{24}H_{29}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CCH_3COOC_5H_{11}$	*act*-Amyl *p*-(*p*-ethoxybenzalamino)-α-methylcinnamate	86	100	(20, 43)
$C_{24}H_{29}NO_3$	$C_2H_5OC_6H_4CH:NC_6H_4CH:CCH_3COOC_5H_{11}$	*iso*-Amyl *p*-(*p*-ethoxybenzalamino)-α-methylcinnamate	83	90	(20, 43)
$C_{25}H_{18}N_2O_2$	$C_6H_5C_6H_4N:NC_6H_4OCOC_6H_5$	*p*-Diphenylazophenol benzoate	194	240	(12)
$C_{25}H_{19}N_3$	$C_6H_5C_6H_4CH:NC_6H_4N:NC_6H_5$	*p*-(*p*-Phenylbenzalamino)-azobenzene	207	252	(2)
$C_{25}H_{20}O_8$	$CH_3COOC_6H_4COOC_6H_4COOC_6H_4COOC_2H_5$	Ethyl *p*-hydroxybenzoate *p*-(*p*-acetoxybenzoxy) benzoate	142	282	(45)
$C_{25}H_{21}NO_4$	$C_6H_5COOC_6H_4CH:NC_6H_4CH:CHCOOC_2H_5$	Ethyl *p*-(*p*-benzoxybenzalamino)-cinnamate	125	217	(47)
$C_{25}H_{23}NO_2$	$C_6H_5C_6H_4CH:NC_6H_4CH:CCH_3COOC_2H_5$	Ethyl *p*-(*p*-phenylbenzalamino)-α-methylcinnamate	120, 148*	175	(20, 43)
$C_{25}H_{28}N_2O_5$	$C_3H_7OCOCCH_3:CHC_6H_4NONC_6H_4CH:CHCOOC_3H_7$	*n*-Propyl *p*-azoxy-α-methylcinnamate	70, 125*?	128	(20)
$C_{26}H_{18}Br_2N_2$	$BrC_6H_4CH:NC_6H_4C_6H_4N:CHC_6H_4Br$	Di-(*p*-bromobenzal)-benzidine	285	312	(12)
$C_{26}H_{18}Cl_2N_2$	$ClC_6H_4CH:NC_6H_4C_6H_4N:CHC_6H_4Cl$	Di-(*p*-chlorobenzal)-benzidine	265	318	(12)
$C_{26}H_{18}Cl_2N_4O$	$ClC_6H_4N:CHC_6H_4NONC_6H_4CH:NC_6H_4Cl$	*p*-Azoxybenzaldi-*m*-chloraniline	174, 181,* 198*	213	(46)
$C_{26}H_{18}I_2N_2$	$IC_6H_4CH:NC_6H_4C_6H_4N:CHC_6H_4I$	Di-(*p*-iodobenzal)-benzidine	>300		(12)
$C_{26}H_{18}N_2O_4$	$C_6H_5COOC_6H_4N:NC_6H_4OCOC_6H_5$	*p*-Dibenzoylazophenol	208	250	(15, 39)
$C_{26}H_{18}N_2O_5$	$C_6H_5COOC_6H_4NONC_6H_4OCOC_6H_5$	*p*-Dibenzoylazoxyphenol	192	280	(15)
$C_{26}H_{18}N_4O_6$	$O_2NC_6H_4CONHC_6H_4C_6H_4NHCOC_6H_4NO_2$	Di-(*p*-nitrobenzoyl)-benzidine	365	d.	(45)
$C_{26}H_{18}O_4$	$C_6H_5OCOC_6H_4C_6H_4COOC_6H_5$	Diphenyl *p, p'*-diphenylcarboxylate	213	245	(45)
$C_{26}H_{20}N_2$	$C_6H_5CH:NC_6H_4C_6H_4N:CHC_6H_5$	Dibenzalbenzidene	234	260	(6, 24)
$C_{26}H_{20}N_2$	$C_6H_5C_6H_4CH:NN:CHC_6H_4C_6H_5$	Di-*p*-phenylbenzalazine	245	271	(2)
$C_{26}H_{22}N_2$	$CH_3C_6H_4CH:NC_{10}H_6N:CHC_6H_4CH_3$	Di-*p*-tolual-1, 5-naphthylenediamine	210	230	(46)
$C_{26}H_{22}N_2O_2$	$CH_3OC_6H_4CH:NC_{10}H_6N:CHC_6H_4OCH_3$	Dianisal-1, 5-naphthylenediamine	206	313	(46)
$C_{26}H_{22}N_4O_2$	$H_2NC_6H_4CONHC_6H_4C_6H_4NHCOC_6H_4NH_2$	Di-(*p*-aminobenzoyl)-benzidine	312	d.	(45)
$C_{26}H_{24}N_2O_4$	$C_6H_4(CH:NC_6H_4COOC_2H_5)_2$	Ethyl *p*-phthalal-di-(*p*-aminobenzoate)	189	230	(17)
$C_{26}H_{25}NO_2$	$C_6H_5C_6H_4CH:NC_6H_4CH:CHCOOC_4H_9$	*n*-Butyl *p*-phenylbenzal-*p*-aminocinnamate	167	203	(43)
$C_{26}H_{26}N_2O_5$	$C_3H_5OCOCCH_3:CHC_6H_4NONC_6H_4CH:CCH_3COOC_3H_5$	Allyl *p*-azoxy-α-methylcinnamate	75	115	(20)
$C_{26}H_{26}N_2O_9$	$C_2H_5OCOCH_2OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOCH_2COOC_2H_5$	*p*-Azoxycinnamic acid ethyl glycolate ester	148	235	(40)
$C_{26}H_{30}N_2O_5$	$C_4H_9OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOC_4H_9$	*n*-Butyl *p*-azoxycinnamate	111	214	(40)
$C_{27}H_{27}NO_2$	$C_6H_5C_6H_4CH:NC_6H_4CH:CHCOOC_5H_{11}$	*act*-Amyl *p*-(*p*-phenylbenzalamino)-cinnamate	115, 153*	180	(43)
$C_{27}H_{27}NO_2$	$C_6H_5C_6H_4CH:NC_6H_4CH:CHCOOC_5H_{11}$	*iso*-Amyl *p*-(*p*-phenylbenzalamino)-cinnamate	164, 188*	197	(43)
$C_{27}H_{27}NO_2$	$C_6H_5C_6H_4CH:NC_6H_4CH:CCH_3COC_4H_9$	*n*-Butyl *p*-(*p*-phenylbenzalamino)-α-methylcinnamate	99, 137*	149	(20, 43, 46)
$C_{27}H_{27}NO_2$	$C_6H_5C_6O_4CH:NC_6H_4CH:CC_2H_5COOC_3H_7$	*n*-Propyl *p*-(*p*-phenylbenzalamino)-α-ethylcinnamate	119	135	(20, 21, 43)
$C_{28}H_{18}O_4$	$C_6H_5COOC_6H_4C:CC_6H_4OCOC_6H_5$	Di-*p*-oxytolanedibenzoate	214	254	(41)
$C_{28}H_{20}N_2O_4$	$C_6H_5COOC_6H_4CH:NN:CHC_6H_4OCOC_6H_5$	Di-*p*-benzoxybenzalazine	227	290	(16, 40)

Index formula	Formula	Name	Trans. temp.	M. P.	Lit.
$C_{28}H_{20}O_4$	$C_6H_5COOC_6H_4CH:CHC_6H_4OCOC_6H_5$	Di-*p*-hydroxystilbene dibenzoate	224	285 d.	(41)
$C_{28}H_{24}N_2$	$(C_6H_4N:CHC_6H_4CH_3)_2$	Di-(*p*-tolual)-benzidene	231	>300	(6, 24)
$C_{28}H_{24}N_2O_2$	$(C_6H_4N:CHC_6H_4OCH_3)_2$	Dianisalbenzidene	258		(46)
$C_{28}H_{28}N_2O_4$	$C_6H_5COOC_6H_4N:NC_6H_4CH:CCH_3COOC_5H_{11}$	*act*-Amyl *p*-benzoylazophenol-α-methylcinnamate	88	120	(20)
$C_{28}H_{34}N_2O_5$	$C_5H_{11}OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOC_5H_{11}$	*iso*-Amyl *p*-azoxycinnamate	144	186	(40)
$C_{28}H_{34}N_2O_5$	$C_4H_9OCOCCH_3:CHC_6H_4NONC_6H_4CH:CCH_3COOC_4H_9$	*iso*-Butyl *p*-azoxy-α-methylcinnamate	86, 110*	125.5	(20)
$C_{28}H_{34}N_2O_5$	$C_4H_9OCOCCH_3:CHC_6H_4NONC_6H_4CH:CCH_3COOC_4H_9$	*n*-Butyl *p*-azoxy-α-methylcinnamate	60	100	(20)
$C_{30}H_{22}N_2O_3$	$C_6H_5COCH:CHC_6H_4NONC_6H_4CH:CHCOC_6H_5$	*p*-Azoxybenzalacetophenone	213		(47)
$C_{30}H_{28}N_2O_2$	$(C_6H_4N:CHC_6H_4OC_2H_5)_2$	Di-(*p*-ethoxybenzal)-benzidine	248	>300	(13)
$C_{30}H_{28}N_2O_2$	$(C_6H_4N:CHC_6H_3CH_3OCH_3)_2$	Di-(*p*-methoxy-*o*-methylbenzal)-benzidine	171	>300	(13)
$C_{30}H_{28}N_2O_4$	$C_6H_4(CH:NC_6H_4CH:CHCOOC_2H_5)_2$	Ethyl *p*-phthalal-di-(*p*-aminocinnamate)	174, 270*	310	(17)
$C_{30}H_{50}O_2$	$C_2H_5COOC_{27}H_{45}$	Cholesterol propionate	97 ± 2	112 ± 2	(6, 10, 18, 30)
$C_{30}H_{50}O_3$	$C_2H_5OCOOC_{27}H_{45}$	Cholesterol ethyl carbonate	83	103.5	(8)
$C_{31}H_{52}O_2$	$C_3H_7COOC_{27}H_{45}$	Cholesterol *n*-butyrate	96.4	107.3	(18)
$C_{31}H_{52}O_3$	$C_3H_7OCOOC_{27}H_{45}$	Cholesterol *n*-propyl carbonate	99	101	(8)
$C_{32}H_{24}N_2$	$C_6H_4(N:CHC_6H_4C_6H_5)_2$	Di-(*p*-phenylbenzal)-*p*-phenylenediamine	284	>300	(2)
$C_{32}H_{24}N_2O_4$	$C_6H_5CH:CHCOOC_6H_4CH:NN:CHC_6H_4OCOCH:CHC_6H_5$	Di-(*p*-cinnamylhydroxy)-benzalazine	206	245	(16)
$C_{32}H_{24}O_{10}$	$CH_3COOC_6H_4COOC_6H_4COOC_6H_4COOC_6H_4COOC_2H_5$	Ethyl *p*-hydroxybenzoate *p*-[*p*-(*p*-acetoxybenzoxy)benzoxy]benzoate	187 d.	d.	(45)
$C_{32}H_{26}O$	$C_6H_5C_6H_4CH:C_6H_6O:CHC_6H_4C_6H_5$	Di-(*p*-phenylbenzal)-cyclohexanone	236.5	237.5	(2)
$C_{32}H_{32}N_2O_2$	$C_2H_5OCH_3C_6H_3CH:NC_6H_4C_6H_4N:CHC_6H_3CH_3OC_2H_5$	Di(-*p*-ethoxy-*o*-methylbenzal)-benzidine	167	>300	(13)
$C_{32}H_{54}O_2$	$C_4H_9COOC_{27}H_{45}$	Cholesterol valerate	91.8	99.2	(18)
$C_{32}H_{54}O_3$	$C_4H_9OCOOC_{27}H_{45}$	Cholesterol *n*-butyl carbonate	78	90	(8)
$C_{33}H_{24}O_5$	$C_6H_5COOC_6H_4CH:C_5H_4O:CHC_6H_4OCOC_6H_5$	Di-(*p*-benzoxybenzal)-cyclopentanone	234	236	(44)
$C_{33}H_{56}O_2$	$C_5H_{11}COOC_{27}H_{45}$	Cholesterol capronate	91.2	100	(18)
$C_{34}H_{26}N_2O_7$	$C_6H_5COCH_2OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOCH_2COC_6H_5$	Phenacyl *p*-azoxycinnamate	231	238	(40)
$C_{34}H_{46}N_2O_5$	$C_8H_{17}OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOC_8H_{17}$	*n*-Octyl *p*-azoxycinnamate	94	175	(40)
$C_{34}H_{50}O_2$	$C_6H_5COOC_{27}H_{45}$	Cholesterol benzoate	146 ± 1	178.5 ± 0.3	(18, 22, 30, 35, 42, 45)
$C_{36}H_{40}N_2O_4$	$C_6H_4(CH:NC_6H_4CH:CHCOOC_5H_{11})_2$	*act*-Amyl *p*-phthalal-di-(*p*-aminocinnamate)	133, 195*	268	(17)
$C_{36}H_{50}N_2O_5$	$C_8H_{17}OCOCCH_3:CHC_6H_4NONC_6H_4CH:CCH_3COOC_8H_{17}$	*n*-Octyl *p*-azoxy-α-methylcinnamate	41, 62*	85	(20)
$C_{37}H_{64}O_2$	$C_9H_{19}COOC_{27}H_{45}$	Cholesterol caprinate	82.2	90.6	(18)
$C_{38}H_{44}N_2O_4$	$C_6H_4(CH:NC_6H_4CH:CCH_3COOC_5H_{11})_2$	*act*-Amyl *p*-phthalal-di-(*p*-amino-α-methylcinnamate)	144, 211*	248	(17)
$C_{40}H_{28}N_6O_6$	$(C_6H_4NHCOC_6H_4N:CHC_6H_4NO_2)_2$	Di-(*m*-nitrobenzal-*p*-aminobenzoyl)-benzidine	>370	d.	(45)
$C_{40}H_{34}N_4$	$C_6H_5CH:NC_6H_4CH_2NHC_6H_4C_6H_4NHCH_2C_6H_4N:CHC_6H_5$	Di-*p*-(benzalaminobenzyl)-benzidine	217	246 d.	(46)
$C_{42}H_{38}N_4O_2$	$(C_6H_4NHCH_2C_4H_4N:CHC_6H_4OCH_3)_2$	Di-*p*-(anisalaminobenzyl)-benzidine	202 d.	d.	(45)
$C_{50}H_{78}N_2O_5$	$C_{16}H_{33}OCOCH:CHC_6H_4NONC_6H_4CH:CHCOOC_{16}H_{33}$	*n*-Cetyl *p*-azoxycinnamate	105	141	(40)
$C_{52}H_{82}N_2O_5$	$C_{16}H_{33}OCOCCH_3:CHC_6H_4NONC_6H_4CH:CCH_3COOC_{16}H_{33}$	*n*-Cetyl *p*-azoxy-α-methylcinnamate	77	84	(20)
$C_{55}H_{90}O_3$	$C_{27}H_{45}OCOOC_{27}H_{45}$	Cholesterol carbonate	177	235	(8)
$C_{14}H_{12}ClHgNO$	$CH_3OC_6H_4CH:NC_6H_4HgCl$	*p*-Anisalaminophenylmercury chloride	274	d.	(46)

Index formula	Formula	Name	Trans. temp.	M. P.	Lit.
$C_{15}H_{12}ClHgN$	$C_6H_5CH{:}CHCH{:}NC_6H_4HgCl$	*p*-Cinnamalaminophenylmercury chloride	255	265	(46)
$C_{16}H_{15}HgNO_3$	$CH_3OC_6H_4CH{:}NC_6H_4HgOCOCH_3$	*p*-Anisalaminophenylmercury acetate	177	180	(46)
$C_{26}H_{18}HgN_4O_4$	$O_2NC_6H_4CH{:}NC_6H_4HgC_6H_4N{:}CHC_6H_4NO_2$	Mercury di-(*p*-nitrobenzalaminophenyl)	236	241	(46)
$C_{26}H_{20}HgN_2$	$C_6H_5CH{:}NC_6H_4HgC_6H_4N{:}CHC_6H_5$	Mercury di-(benzalaminophenyl)	180	184	(46)
$C_{28}H_{24}HgN_2$	$Hg(C_6H_4N{:}CHC_6H_4CH_3)_2$	Mercury di-(*p*-tolualaminophenyl)	217	229	(46)
$C_{28}H_{24}HgN_2O_2$	$Hg(C_6H_4N{:}CHC_6H_4OCH_3)_2$	Mercury di-(anisalaminophenyl)	209	285	(46)
$C_{30}H_{24}HgN_2$	$Hg(C_6H_4N{:}CHCH{:}CHC_6H_5)_2$	Mercury di-(cinnamalaminophenyl)	208	269	(46)
$C_{30}H_{28}HgN_2O_2$	$Hg(C_6H_4N{:}CHC_6H_4OC_2H_5)_2$	Mercury di-(*p*-ethoxybenzalaminophenyl)	204	272	(46)

LITERATURE

(For a key to the periodicals see end of volume)

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CRYSTALLOGRAPHY OF COMPOUNDS OF CARBON

George L. Keenan and Raymond M. Hann

Standard arrangement. For abbreviations, *see* p. 100. Literature, p. 338

𝕭-TABLE

Formula	Name	System	Class	Sign	2V	2E	Orientation	Lit.
16 *See* 𝕮-Table								
18 $SiC_{24}H_{24}N_4$	Silico tetraphenylamide	M.	Bi.	−	17° 40′		Ax. pl. b (010); $X \wedge c = 27\frac{1}{2}°$ in obtuse $\angle\beta$	(G)
$SiC_{28}H_{28}$	Tetra-*p*-tolylsilicane	M.	Bi.	−		83° 30′	Ax. pl. ⊥b(010)	(G)
$SnC_{14}H_{20}N_2Cl_6$	*p*-Toluidine tin chloride	M.	Bi.	+	77°		Ax. pl. ⊥b(010); $Z \wedge c = 19°$ in obtuse $\angle\beta$	(G)
23 $PbC_2H_2O_4$	Lead formate	R.	Bi.	−	70° 34′		Ax. pl. b(010); X‖c	(G)
$PbC_4H_6O_4.3H_2O$	Lead acetate	M.	Bi.	+	83° 55′		Ax. pl. b(010); $Z \wedge c = 55° 18'$ in obtuse $\angle\beta$	(G)
$PbC_{18}H_{26}O_{10}S_2.6H_2O$	Lead sulfocamphylate	R.	Bi.	−		78° 17′	Ax. pl. b(010); X‖c	(G)
27 TlC_2HO_4	Thallium acid oxalate	M.	Bi.	+		74° 5′ (red)	Ax. pl. ⊥b(010)	(G)
$TlC_2HO_4.\frac{1}{2}H_2O$	Thallium acid oxalate	M.	Bi.	+		106° 5′ (red)	Ax. pl. b(010); $Z \wedge c = 79° 36'$ (red) in obtuse $\angle\beta$	(G)
$Tl_2C_4H_4O_6$	Thallium mesotartrate	Tri.	Bi.	+	73° 54′			(G)
$Tl_2C_4H_4O_6.\frac{1}{2}H_2O$	Thallium tartrate	R. (?)	Bi.	−		69°	Ax. pl. b(010); X‖c	(G)
$TlC_6H_2O_7N_3$	Thallium picrate	M.	Bi.				Ax. pl. b(010)	(G)
$Tl_2C_4H_4O_6$	Thallium *dl*-tartrate	M.	Bi.	+	88° 22′		Ax. pl. b(010); $Z \wedge c = 84° 44'$ in obtuse $\angle\beta$	(G)
$Tl_2C_4H_4O_6$	Thallium tartrate	Trig.	Un.	+				(G)
$TlC_4H_4O_7Sb.H_2O$	Thallium antimonyl tartrate	R.	Bi.	−		20°–25°		(G)
28 $ZnC_4H_6O_4.3H_2O$	Zinc acetate	M.	Bi.	+	84° 30′		Ax. pl. b(010); $Z \wedge c = 54.75°$ in acute $\angle\beta$	(G)
$ZnC_8H_{14}O_4$	Zinc butyrate	M.	Bi.	+		Large		(37)
$ZnC_{20}H_{36}O_8$	Zinc methylethylvalerate	?	Bi.					(37)
$ZnC_5H_3O_4Br.8H_2O$	Zinc bromomesaconate	M.	Bi.	−	71° 21′	118° 15′	Ax. pl. ⊥b(010); $X \wedge c = 14°$ in obtuse $\angle\beta$	(G)
$ZnC_{10}H_6O_6S_2.6H_2O$	Zinc naphthalene-1, 5-disulfonate	M.	Bi.		58° 16′		Ax. pl.‖(010); $\eta_\alpha \wedge c = 74°$	(41)
$ZnC_{20}H_{32}N_2I_4$	Phenyldimethylethylammonium zinc iodide.	M.	Bi.	+	86° 52′		Ax. pl. ⊥b(010); $Z \wedge c = 43°$ in acute $\angle\beta$	(G)
$ZnC_9H_{22}ON_2Cl_4.3H_2O$	Triacetonediamine hydrochloride zinc chloride	M.	Bi.	+	36° 14′	58° 20′	Ax. pl. ⊥b(001); $Z \wedge c = 49°$ in obtuse $\angle\beta$	(G)
30 $HgC_2H_8NI_3$	1, 1-Dimethylammonium mercuric iodide	M.	Bi.	−	Large			(16)
$HgC_3H_9NI_2$	1, 1-Trimethylammonium mercuric iodide	R.	Bi.	−	Large			(16)
$HgC_4H_{12}NI_3$	1, 1-Diethylammonium mercuric chloride	R.	Bi.	+	Very large			(16)
$CuC_2H_2O_4.4H_2O$	Cupric formate	M.	Bi.	−	34° 54′	55° 6′	Ax. pl. b(010); $X \wedge c = 23° 35'$ in obtuse $\angle\beta$	(G)
$CuC_{10}H_6O_6S_2.6H_2O$	Copper naphthalene-1, 5-disulfonate	M.	Bi.				Ax. pl.‖(010); $\eta_\alpha \wedge c = 75°$	(14)

VALUE OF AN OLFACTY EXPRESSED AS DEGREE OF SATURATION OF AIR WITH THE ODORIVECTOR

Substance	% Saturation	Substance	% Saturation
Eucalyptol	0.058	Methyl alcohol	1.388
Eugenol	0.144	Toluidine	1.515
Toluene	0.158	Ethyl alcohol	2.5
Benzene	0.169		

VALUE OF AN OLFACTY IN CM OF THE ZWAARDEMAKER OLFACTOMETER

The constants of Zwaardemaker olfactometer are: width of cylinder, 0.8 cm; length, 10 cm; contents, 50 cc; air contact per cc of cylinder, 2.5 cm^2; velocity of air in the air tube, 100 cc per sec (exposure, 0.33 sec).

MINIMUM PERCEPTIBLE IN CM OF OLFACTOMETER SCALE

Saturated solutions (9)

Substance	cm	Substance	cm
Terpineol—H_2O	0.01	Caproic acid—H_2O	0.10
Ethyl propionate—H_2O	0.02	Trinitroisobutyltoluene—H_2O	0.10
Ionone—H_2O	0.02	Guaiacol—H_2O	0.20
Camphor—H_2O	0.07	Trimethylamine—Paraffin	0.20

Aqueous solutions (10)

Substance	Concentration Wt. %	cm
Pyridine	0.05	0.1
Ethyl disulfide	0.02	0.5
Citral	0.01	0.2
Scatole	0.01	0.4
Valeric acid	0.01	0.5
Isoamyl acetate	0.01	0.7
Guaiacol	0.0007	1.0

Aqueous solutions (10).—(*Continued*)

Paraffin solutions (11)

Substance	Concentration Wt. %	cm	Substance	Concentration Wt. %	cm
Borneol	1.0	0.001	Citral	1.0	0.09
Cadaverine	0.1	0.001	Isoamyl acetate	0.5	0.29
Scatole	0.1	0.002	Guaiacol	0.1	0.62
Ethyl sulfide	0.01	0.01	Ionone	0.0004	0.62
Pyridine	1.0	0.03	Safrol	3.0	1.12
Valeric acid	0.01	0.04	Terpineol	2.5	1.60
Nitrobenzene	5.0	0.06			

LITERATURE

(For a key to the periodicals see end of volume)

(1) Allison and Katz, *45*, **11**: 336; 19. (2) Backman, *278*, **168**: 351; 17. (3) Henning, *Der Geruch*, 1924. (4) Hermanides, *Thesis*, *Utrecht*, 1907. (5) Heyninx, *Thesis*, *Brussels*, 1919. (6) Huyer, *Thesis*, *Utrecht*, 1917. (7) Tempelaar, *Thesis*, *Utrecht*, 1913. (8) Zwaardemaker, *Physiol. des Geruchs*, **1895**: 247. (9) Zwaardemaker, *Arch. Anat. Physiol.*, *Physiol. Abt.*, **1903**: 48.

(10) Zwaardemaker, *In* Abderhalden, *Handb. biol. Arbeitsm.* **5**, pt. 7: 455; 23. (11) Zwaardemaker, *In* Tigerstedt, *Handb. Physiol.* **3**, pt. **1**: 49; 14. (12) Zwaardemaker, *Arch. Neerl. Physiol.*, **1** : 347; 17.

RADIOACTIVITY

S. C. LIND, SPECIAL EDITOR

1923 INTERNATIONAL TABLE
RADIOACTIVE ELEMENTS AND THEIR CONSTANTS

λ (*sec*)$^{-1}$ is the *radioactive constant of transformation.*

$$dQ = -\lambda Q dt, \qquad Q = Q_0 e^{-\lambda t}, \qquad \log_{10}\frac{Q_0}{Q} = 0.4343\lambda t,$$

in which Q_0 is the initial quantity and Q the quantity remaining after a time t (seconds).

$\lambda = -\frac{dQ}{Q}\frac{1}{dt}$ represents the fraction of the element transformed, reduced to the unit of time.

In the case of a double transformation, the values between brackets [ ] refer to the constants corresponding with the separate branches; the constant for both branches not being put between brackets.

The sign (?) indicates that the value has been indirectly deduced from the range of the α-rays expelled.

$\theta = \frac{1}{\lambda}$ is the *average life* of the radioactive atoms.

T is *the half period, i.e.,* the time in which the quantity of radioelement is diminished to one half:

$$\lambda T = -\log_e 0.5 = 0.69315 \text{ and } \theta = 1.443T$$

Radiation.—The brackets ( ) indicate that the radiation is relatively feeble.

REMARKS CONCERNING THE NOMENCLATURE

It is desirable that the nomenclature adopted by the international commission should be accepted universally but that now put forward for the present year is provisional, to serve as a basis of discussion with the view to the adoption ultimately of a standard nomenclature.

The most important points are:

1. The three radioactive emanations have been given the names radon, actinon, and thoron, with the symbols Rn, An, Tn, to suggest both their origin and their chemical character as members of the family of the rare gases of which the valency is zero;
2. In the branches which occur at the C members the sign (′) has been used to indicate the products resulting from the emission of β-rays (isotopes of polonium) and the sign (″) to indicate the products resulting from the emission of α-rays (isotopes of thallium);
3. The ultimate products have been indicated by the letter Ω.

EXPLANATION OF THE NOTES

NOTE 1.—*Uranium I.*—The value given for θ is that obtained from the equation:

$$\theta = \frac{1}{\lambda} = 2440 \times 0.97 \times 3 \times 10^6 \times \frac{226}{238} = 6.75 \times 10^9$$

in which the number 2440 represents the average life of radium in years, the number 0.97 the branching coefficient and $3 \times 10^6 \times \frac{226}{238}$ is the ratio between the numbers of atoms of uranium and radium in equilibrium in minerals.

If the actinium series is independent from that of uranium I, λ cannot be calculated by this method.

The value of λ obtained by the direct counting of the α-particles from a compound of uranium is 4.57×10^{-18} from which $\theta = 7 \times 10^9$ years and $T = 4.8 \times 10^9$ years.

NOTE 2.—*Uranium X_2* is also called brevium.

NOTE 3.—Radon replaces the names *radium emanation* and *niton* (the latter of which was proposed by Sir William Ramsay).

NOTE 4.—*Radium C* undergoes a double disintegration: 99.97% of the atoms emit β-rays and produce the substance Ra-C′ which gives α-rays, and 0.03% of the atoms emit α-rays and produce the substance Ra-C″ which gives β-rays.

a_0 is the *range* in cm of the α-rays in air at 0°C and a pressure of 760 mm of mercury.

The range at τ° C. and under p mm of mercury is

$$a = \frac{a_0(273 + \tau)760}{273p}$$

V is the velocity of α or β-rays relatively to that of light.

To convert to cm per sec multiply by 3×10^{10}.

For the α-rays:

$$V = 0.0342\, a^{1/3}$$

$\mu_{\beta Al}$ is the absorption coefficient of the β-rays in aluminium, the thickness being measured in cm.

$\mu_{\gamma Al}$ and $\mu_{\gamma Pb}$ are the absorption coefficients of the γ-rays in aluminium and lead respectively, the thickness being measured in cm; the latter is only given for the most penetrating type of γ-rays.

If I_0 is the initial intensity and I the intensity after the rays have traversed x cm of the absorbent:

$$I = I_0\, e^{-\mu x} \qquad \log_{10}\frac{I_0}{I} = 0.4343\mu x$$

If D is the thickness corresponding with the absorption of one-half of the rays:

$$\mu D = 0.693$$

NOTE 5.—*Radium D* is also called radiolead.

NOTE 6.—*Radium C″* is also called radium C_2.

NOTE 7.—*Uranium Y* is the first known member of the actinium series. It may be derived from Uranium I or Uranium II. In this case, 3% of the atoms of Uranium produce the actinium family, and 97% the radium family.

The hypothesis has also been put forward that the actinium series may be produced independently from a third (hypothetical) isotope of Uranium for which the name actinouranium has been proposed.

NOTE 8.—*Protoactinium* is also called eka-tantalum.

NOTE 9.—A new radioactive substance named uranium Z, and isotopic with protoactinium, accompanies uranium in minute quantity. (*25*, **54B**: 1131; 21). Its period is from 6 to 7 hours. It emits a β-radiation for which D_{AI} varies from: 0.0014 to 0.012. Its parent is an isotope of thorium, but it cannot yet be placed in the series.

NOTE 10.—*Actinon* is also called actinium emanation.

NOTE 11.—*Actinium C.* 0.2% of the α-rays emitted by this substance have a range $a_0 = 6.10$, instead of 5.12. From this it has been concluded that 0.2% of the atoms undergo a transformation by the emission of β-rays as is the case in the radium C and thorium C branches (*3*, **27**: 690; 14. **28**: 818; 14). Confirmatory evidence appears to be desirable.

NOTE 12.—*Actinium C″* is also called actinium D.

NOTE 13.—*Thorium.* The value given for λ is that obtained from the direct counting of the α-particles emitted by a compound of thorium. All the other values are less; the smallest being 0.55 of that given in the table and giving $\theta = 3.45 \times 10^{10}$ years and $T = 2.37 \times 10^{10}$ years (*63*, **19**: 259; 18).

NOTE 14.—*Thoron* is also called thorium emanation.

NOTE 15.—*Thorium C* undergoes a double disintegration: 65% of the atoms emit β-rays and produce the substance Th-C′ which gives α-rays, and 35% emit α-rays and produce the substance Th-C″ which gives β-rays.

NOTE 16.—*Thorium C.* The value $a_0 = 4.69$ is that corresponding with $V = 0.0572$ which has been directly measured.

NOTE 17.—*Thorium C″* is also called thorium D.

NOTE 18.—*Potassium* and *rubidium* emit β-rays but show no other evidence of radioactivity.

T	$\theta = \frac{1}{\lambda}$	λ (sec)$^{-1}$	Name	Symbol	Atomic		Isotope	Radiation	a_0	V	μ_β Al	μ_γ Al	μ_γPb	Notes
					Wt.	No.								
SERIES OF URANIUM AND RADIUM														
4.67×10^9 yrs	6.75×10^9 yrs	4.7×10^{-18}	Uranium I	U$_{\text{I}}$	238	92	U	α	2.37	0.0456				1
24.6 days	35.5 days	3.26×10^{-7}	Uranium X$_1$	U-X$_1$	234	90	Th	β			463			
1.15 min	1.65 min	0.010	Uranium X$_2$	U-X$_2$	234	91	Pa	β (γ)			14.4	24; 0.7; 0.14	0.72	2
2×10^6 yrs	3×10^6 yrs	10^{-14} (?)	Uranium II	U$_{\text{II}}$	234	92	U	α	2.75	0.0479				
6.9×10^4 yrs	10^5 yrs	3.2×10^{-13}	Ionium	Io	230	90	Th	α	2.85	0.0485				
1690 yrs	2440 yrs	1.30×10^{-11}	Radium	Ra	226	88	Ra	α (β + γ)	3.13	α 0.0500; β 0.52; 0.65	312	354; 16; 0.27		
3.85 days	5.55 days	2.085×10^{-6}	Radon	Rn	222	86	Rn	α	3.94	0.0540				3
3.0 min	4.32 min	3.85×10^{-3}	Radium A	Ra-A	218	84	Po	α	4.50	0.0565				
26.8 min	38.7 min	4.30×10^{-4}	Radium B	Ra-B	214	82	Pb	β (γ)		0.36; 0.41; 0.63; 0.70; 0.74	13.1; 80	230; 40; 0.51		
19.5 min	28.1 min	5.92×10^{-4}	Radium C	Ra-C	214	83	Bi	99.97% β and γ		0.786; 0.862; 0.949; 0.957	13.2; 53	0.115	0.50	4
10^{-6} sec	10^{-6} sec	10^6 (?)	Radium C′	Ra-C′	214	84	Po	α	6.57	0.0641				
16.5 yrs	23.8 yrs	1.33×10^{-9}	Radium D	Ra-D	210	82	Pb	(β and γ)		0.33; 0.39	5500	45; 0.99		5
5.0 days	7.2 days	1.61×10^{-6}	Radium E	Ra-E	210	83	Bi	β			43.3			
136 days	196 days	5.90×10^{-8}	Radium F (Polonium)	Ra-F (Po)	210	84	Po	α (γ)	3.58	0.0523		585		
			Radium Ω (Lead)	Ra Ω′ Pb^{206}	206	82	Pb							
		[1.8×10^{-7}]	Radium C	Ra-C	214	83	Bi	0.03% α	?					
1.4 min	2.0 min	8.3×10^{-3}	Radium C″	Ra-C″	210	81	Tl	β						6
			Radium Ω″ (hypothetical)	Ra Ω″	210	82	Pb							
SERIES OF ACTINIUM														
			Uranium ?		?	92	U	α						7
1.04 days	1.5 days	7.8×10^{-6}	Uranium Y	U-Y	?	90	Th	β			About 300			
1.2×10^4 yrs	1.7×10^4 yrs	1.9×10^{-12}	Protoactinium	Pa	?	91	Pa	α	3.314	0.0510				8, 9
20 yrs	28.8 yrs	1.1×10^{-9}	Actinium	Ac	?	89	Ac							
19.5 days	28.1 days	4.11×10^{-7}	Radioactinium	Rd-Ac	?	90	Th	α (β)	4.36	α 0.0559; β 0.38; 0.43; 0.49; 0.53; 0.60; 0.67; 0.73	About 170	25; 0.19		
11.4 days	16.4 days	7.06×10^{-7}	Actinium X	Ac-X	?	88	Ra	α	4.17	0.0550				
3.9 sec	5.6 sec	0.178	Actinon	An	?	86	Rn	α	5.40	0.0600				10
2.0×10^{-3} sec	2.9×10^{-3} sec	345	Actinium A	Ac-A	?	84	Po	α	6.16	0.0627				
36.1 min	52.1 min	3.2×10^{-4}	Actinium B	Ac-B	?	82	Pb	(β and γ)			Very large	120; 31; 0.45		11
2.15 min	3.10 min	5.37×10^{-3}	Actinium C	Ac-C	?	83	Bi	α	5.12	0.0589				
4.71 min	6.83 min	2.44×10^{-3}	Actinium C″	Ac-C″	?	81	Tl	β and γ			28.5	0.198	1.2 to 1.8	12
			Actinium Ω″ (hypothetical)	Ac Ω″	?	82	Pb							
SERIES OF THORIUM														
1.31×10^{10} yrs	1.89×10^{10} yrs	1.68×10^{-18}	Thorium	Th	232	90	Th	α	2.58	0.0469				13
6.7 yrs	9.67 yrs	3.28×10^{-9}	Mesothorium 1	Ms-Th1	228	88	Ra							
6.2 hrs	8.9 hrs	3.12×10^{-5}	Mesothorium 2	Ms-Th2	228	89	Ac	β and γ		0.37; 0.39; 0.43; 0.50; 0.57; 0.60; 0.66 and >0.70	20.2 to 38.5	26; 0.116	0.62	
2.02 yrs	2.91 yrs	1.09×10^{-8}	Radiothorium	Rd-Th	228	90	Th	α (β)	3.67	α 0.0527; β 0.47; 0.51				
3.64 days	5.25 days	2.20×10^{-6}	Thorium X	Th-X	224	88	Ra	α	4.08	0.0546				
54 sec	78 sec	0.0128	Thoron	Tn	220	86	Rn	α	4.74	0.574				14
0.14 sec	0.20 sec	5.0	Thorium A	Th-A	216	84	Po	α	5.40	0.0600				
10.6 hrs	15.3 hrs	1.82×10^{-5}	Thorium B	Th-B	212	82	Pb	β and γ		0.63; 0.72	110	160; 32; 0.36		
60 min	87 min	1.92×10^{-4}	Thorium C	Th-C	212	83	Bi	65% β		(C + C″) 0.29; 0.36; 0.93 to 0.95	14.4			15
10^{-11} sec	10^{-11} sec	1.25×10^{-4}	Thorium C′	Th-C′	212	84	Po	α	8.16	0.0688				
		10^{11} (?)	Thorium Ω′ (Lead)	Th Ω′ Pb^{208}	208	82	Pb							
		[6.7×10^{-5}]	Thorium C	Th-C	212	83	Bi	35% α	4.55 ?4.69	0.0572				16
3.1 min	4.5 min	3.70×10^{-3}	Thorium C″	Th-C″	208	81	Tl	β and γ		(See Th-C)	21.6	0.096	0.46	17
			Thorium Ω″ (Lead)	Th Ω″ Pb^{208}	208	82	Pb							
			Potassium	K	39.1	19	K	β			22 to 38			18
			Rubidium	Rb	85.5	37	Rb	β			308 to 347			

PHYSICAL PROPERTIES OF THE RADIOELEMENTS AND THEIR COMPOUNDS

(Except Ra, Th, U and Rn)

GEORG HEVESY

1. Atomic Weights.—Io (mixture of Io + Th), 231.51 (2). RaΩ (=U-Pb), 206.04 (2). ThΩ (=Th-Pb), 207.97.

2. Molecular Weights.—An (=Ac-Em), 220–232 (4). Tn (=Th-Em), 201–210 (4). Rate of effusion method.

3. Density (5).—RaΩ, 11.273 g cm^{-3} at 19.94°C.

4. Melting Point (26).—RaΩ′, differs from Pb $<0.05°$.

5. Boiling Point (32).—Ra-FH_2, 37°C.

6. Solubility.—S = solubility mol l^{-1}. $\alpha' = \frac{C_{Air}}{C_{H_2O}}$. An (14), $\alpha' = 2$ at 18°. Tn (15), $\alpha' = 1$ at 18°. Rn (16). $S = 1.7989$ (15b) in H_2O at 25°. $S\,[RaΩ'(NO_3)_2] - S[Pb(NO_3)_2] < 10^{-4}$.

RELATIVE SOLUBILITY OF AN IN DIFFERENT SOLVENTS AT 18°

H_2O	Sat. KCl soln.	Conc. H_2SO_4	C_2H_5OH	$C_5H_{11}OH$	C_6H_5CHO	C_6H_6	$C_6H_5CH_3$	Kerosene	CS_2
1	0.9	0.95	1.11	1.6	1.7	1.7	1.8	1.9	2.1

7. Rate of Solution.

PERCENT DISSOLVED FROM SURFACE AT 18°

By H_2SO_4 in 15 sec (17)

H_2SO_4, equiv. per liter =	10^{-3}	10^{-2}	10^{-1}	1
Ra-B from glass	80	80	97	88
Ra-C from glass	28	60	88	99

By HNO_3 in 60 sec (18)

HNO_3, equiv. per liter =	0	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1
Th-B from quartz	60	61	60	80	81	83	84
Th-C from quartz	37	38	35	61	72	77	87

PERCENT RA-B AND RA-C DISSOLVED FROM GLASS SURFACE (17)

By H_2O in 5 min

t	Ra-B	Ra-C	t	Ra-B	Ra-C
0°	0.29	0.19	42°	0.78	0.67
17°	0.47	0.35	70°	0.97	0.91

By H_2SO_4 in 15 sec

t	Ra-B	Ra-C	t	Ra-B	Ra-C
0°	0.74	0.52	42°	0.895	0.71
17°	0.80	0.60	70°	0.96	0.81

8. Adsorption.—Ratio of molal conc. in gas at equilibrium to moles adsorbed per liter of charcoal at 18°, An (19) 0.05, Tn (20) 0.02. Percent of initial amount present (per 50 cc of solution) adsorbed by 1 g of adsorbent (21). (*a*) By $BaSO_4$, from 0.1 *N* HCl, Th-B 81, Th-C 32; from 0.1 *N* KOH, Th-B 20, Th-C 64; from 0.1 *N* NH_3, Th-B 100, Th-C 86. (*b*) By Cr_2O_3, from 0.1 *N* HCl, Th-B 2.5, Th-C 69. (*c*) By AgBr, from 0.1 *N* HBr, Th-B 81, Th-C 34. (*d*) By $BaSO_4$, from 1 *N* HCl, Ra 80. (*e*) By Cr_2O_3, from 1 *N* HCl, Ra 0. (*f*) By AgCl, from 1 *N* HCl, Ra 0.

9. Vapor Pressure.—$p_{700°}$ for RaΩ′ is 2% greater than for Pb (22).

10. Temperature of Volatilization.—Depends on nature of surface and chemical state of the radioactive element. *v.* (23, 24, 25).

11. Coefficient of Diffusion.

(*a*) IN GASES AT 76 CM AND 15°

An, in	Air	H_2		CO_2	SO_2	A
Δ, $cm^2\ sec^{-1}$	0.098–0.123 (6, 7, 8, 9)	0.330 (7)	0.412 (8)	0.075 (7, 8)	0.062 (7)	0.107 (7)

Tn, in	Air	A
Δ, $cm^2\ sec^{-1}$	0.085–0.103 (6, 7, 9)	0.084 (7)

(*b*) THE CATIONS IN WATER (10) AT 18°

Ion	UX_1^{++++}	Io^{++++}	$Ra\text{-}D^{++}$	$Ra\text{-}E^{+++}$	$Ra\text{-}F^{++}$	Ac^{+++}
Δ, $cm^{-2}\ day^{-1}$	0.4	0.33	0.65	0.45	0.76	0.46

Ion	AcX^{++}	$Rd\text{-}Th^{++++}$	ThX^{++}	$Th\text{-}B^{++}$	$Th\text{-}C^{+++}$
Δ, $cm^{-2}\ day^{-1}$	0.69	0.33	0.66	0.67	0.5

Th-CCl_3 in $\frac{1}{12}$ *N* NH_3, Δ = 0.37. Ra-FCl_2 in $\frac{1}{2}$ *N* NH_3, Δ = 0.19.

(*c*) IN METALS. Δ IN CM^{-2} DAY^{-1}

	t	Δ
Th-B in Pb	343°	2.2 (11)
Ra-D in Pb	280°	$<10^{-4}$ (12)
Ra-F in Pb	280°	$<10^{-4}$ (12)
Ra-F in Au	470°	*ca.* 10^{-9} (13)
Ra-B + Ra-C in Ag	470°	3.8×10^{-7} (13)
Ra-B in Au	470°	8.2×10^{-7}
Ra-B in Pt	470°	3.4×10^{-7}

In re diffusion of Th-B in single crystals, in lead foils and in thallium foils *v.* (35).

12. Refractive Index (27).—$n_D^{25°}$ for cryst. RaΩ′$(NO_3)_2$ = 1.7814.

13. X-ray Spectra.—All lines of the L series and the M_α and M_β lines of RaΩ′ differ by less than 5×10^{-12} cm from the same lines for Pb (28).

14. Relative Ionic Mobilities (10).—In capillary tubes by comparison against Ra (Λ = 57.3 mhos).

Cation	Ra	Ra-C	Ra-D	Ra-E	Ra-F	AcX	ThX	Th-B	Th-C
Λ	57.3	54.5	61.9	61.9	68.8	56.1	58.0	55.4	54.0

15. Emf.—RaΩ′ / *N* RaΩ′$(NO_3)_2$ // *N* $Pb(NO_3)_2$ / Pb. <0.1 millivolt (31).

16. Deposition Voltage.—From $\frac{1}{10}$ *N* HNO_3 containing 10^{-8} mole Ra-F, cathodic deposition occurs on Au electrodes at E_{Hg} = 0.35 volt, anodic at E_{Hg} = 1.05 volt (30).

LITERATURE AND REMARKS

(For the key to periodicals see end of volume)

(1) Hönigschmid, *9*, **22**: 21; 16. This mixture contained about 30% Io and 70% Th and was probably contaminated with some Th not present in the pure pitchblende (*cf.* Soddy and Hitchins, *3*, **47**: 1148; 24. Meyer and Ulrich, *75*, **132**: 279; 23). (2) Lowest value found. Higher values probably due to presence of lead. Richards and Lembert, *1*, **36**: 1329; 14. *93*, **88**: 429; 14. Hönigschmid and Horowitz, *75*, **123**: 2407; 14. *9*, **20**: 319; 14. Curie, *34*, **148**: 1676; 14. *198*, **34**: 586; 23. Richards, *Ann. Rep. Smithsonian Inst.* **1918**: 205. Richards and Putzeys, *1*, **45**: 2954; 23. (3) Highest value found. Lower values probably due to presence of lead and RaΩ. Hönigschmid, *9*, **25**: 91; 19. Soddy, *4*, **105**: 1402; 14. *58*, **94**: 615; 15. **98**: 469; 17. **99**: 244; 17. (4) Leslie, *4*, **24**: 637; 12. *34*,

153: 328; 11. Marsden and Wood, *4*, **26**: 948; 13. (5) Richards and Wadsworth, *1*, **38**: 221, 1658; 16. *Cf.* Soddy, *58*, **107**: 41; 21. Egerton and Lee, *5*, **103**: 487; 23. (6) Rutherford, "*Radioactivity*," Cambridge, 1913, p. 387. (7) Russ, *4*, **17**: 540; 09. (8) B. Bruhat, *199*, **6**: 67; 09. *Cf.* Debierne, *199*, **4**: 213; 07. McLennan, *2*, **30**: 660; 10. Eckmann, *200*, **9**: 177; 12. Thomsen, *201*, **15**: 377; 09. Hevesy, *200*, **10**: 198; 13. (9) Leslie, *34*, **153**: 328; 11. Rutherford, *l.c.*

(10) Hevesy, *63*, **14**: 49, 1202; 13. *4*, **26**: 586; 14. Paneth, *75*, **122**: 1636; 13. The radioelements probably present in colloidal state. (11) Gróh and Hevesy, *8*, **63**: 85; 20. Diffusion rate of a mixture of Th-B and Pb in lead. Th-B used as indicator. (12) Gróh and Hevesy, *8*, **65**: 216; 21. Diffusion rate of a mixture of Ra-D and Pb in lead. (13) Wertenstein and Dobrowolska, *51*, **4**: 324; 23. Diffusion rate of active deposit (probably of oxides). (14) Hevesy, *63*, **12**: 1214; 11. *50*, **16**: 429; 12. (15) Klaus, *63*, **6**: 820; 05. Boyle, *Macdonald Phys. Build. Bull.*, No. **1**: 52; 10. α of short-lived An and Tn determined by making assumptions only partly justified. α of An and Tn probably practically identical with that of Rn. (16) Richards and Schumb, *1*, **40**: 1403; 18. The RaΩ′ used contained some common lead, its atomic weight being 206.34. The solubility of common lead (at. wt. 207.19) was found by the same authors to be 1.7993. *Cf.* Fajans and Lembert, *93*, **95**: 297; 16. (17) Ramstedt, *147*, II: No. **31**; 13. *Cf.* Arrhenius, *199*, **7**: 228; 10. Godlewski, *199*, **10**: 250; 13. Schräder, *4*, **24**: 131; 12. Hevesy, *9*, **19**: 291; 13. (18) Hevesy and Rona, *7*, **89**: 294; 15. *In re* Ra-F, *cf.* Paneth and Hevesy, *75*, **123**: 1050; 13. (19) Hevesy, *63*, **12**: 9; 12. *50*, **18**: 429; 12.

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ARTIFICIAL DISINTEGRATION OF THE ELEMENTS

G. Rudorf

Disintegration by the splitting off of positively charged hydrogen nuclei by the action of rapidly moving α-particles.

(*a*) Disintegration obtained with B, N, F, Ne, Na, Mg, Al, Si, P, S, Cl, A, K (1, 2, 3, 5).

(*b*) No disintegration obtained with H, He, Li, C, O, Ni, Cu, Zn, Sc, Kr, Mo, Pd, Ag, Sn, X, Au, U (2, 3, 5).

(*c*) Doubtful, Be (4, 5).

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Range of Emitted Hydrogen Nuclei (2, 3, 5)

Element	Forward range in cms	Backward range in cms
B	58	38
N	40	18
F	65	48
Na	58	36
Al	90	67
P	65	49
Mg, Si, S, Cl, A, K	18–30	
Ne	16	

The values for B, F, Na, P are possibly somewhat in error (3) but are certainly greater than 40 (2).

ELECTRON EMISSION PRODUCED BY RADIATION FROM RADIOACTIVE SUBSTANCES

Pierre Auger

Relative Ionization of Gases by Po α-Rays Having a 3.8 cm Range (1)

Gas	Air	O_2	N_2	CO_2	Illuminating gas
I	1	1.12	0.97	1.23	0.38

Relative Molecular Ionization of Gases by β and γ Rays (2)

Gas	Air	H_2	O_2	NH_3	N_2O	CO_2	C_2N_2	SO_2	CS_2	C_5H_{12}
$I\beta$	1	0.16	1.17	0.89	1.55	1.60	1.86	2.25	3.62	4.55
$I\gamma$	1	.16	1.16	.90	1.55	1.58	1.71	2.27	3.66	4.53

Gas	C_6H_6	CH_3OH	CH_3Br	$CHCl_3$	CH_3I	CCl_4	C_2H_4O
$I\beta$	3.95	1.69	3.73	4.94	5.11	6.28	2.12
$I\gamma$	3.94	1.75	3.81	4.93	5.37	6.33	2.17

Gas	C_2H_5Cl	C_2H_5Br	C_2H_5I	$(C_2H_5)_2O$	$Ni(CO)_4$
$I\beta$	3.24	4.41	4.39	5.90	
$I\gamma$	3.19	4.63	4.29	6.47	5.98

Residual Ionization as Dependent on the Pressure

Ionization from the walls (a secondary radiation) in air confined for 10 days. N_I = number of ions per cm^3 per sec (3).

P. atm.	0	10	20	27	40	46	50	60
N_I	0	17	30	38	46	50	50	50

Number of Electrons (δ-rays) Liberated by α-rays

l = thickness of metal traversed. N_E = electrons emitted per incident particle (4).

$10^5\,l$ (g cm^{-2})	In Al							In Ag		In Au	
	81	162	243	324	410	492	570	28.5	591	12.3	1223
N_E	11.9	14.2	15.0	17.2	17.8	18.9	19.4	8.12	13.76	9.82	18.16

Pairs of Ions Produced by α-rays

If R_0 cms is the range of the α-particle in air, it will produce n pairs of ions. $n = n_0 R_0^{2/3}$, where $n_0 = 6.233 \times 10^4$. Direct measurement for Ra-C′ gives $n = 2.20 \times 10^5$ (5).

Energy

Energy of electrons (Sec. β-rays) emitted by metals subjected to the action of γ-rays from Ra(C + E). Three groups of rays (6).

Metal	Pb	Pt	W	U	Ba
Atomic number	82	78	74	92	56
Energy of the secondary rays. Volts × 10^{-5}.	1.49 2.03 2.60	1.58 2.12 2.69	1.66 2.20 2.76	1.22 1.74 2.31	2.53

SECONDARY β-RAY VELOCITIES

Pb subjected to the action of γ-rays from Ra-B has been found to emit the following secondary β-rays:

$RH = \frac{mu^2}{e(1-\beta^2)}$ = 3610, 3250, 2990, 2735, 2225, 2130, 2000, 1935, 1825, 1750, 1620, 1560, 1400, 1240, 1150, 1010, 950, 820, 800 (8).

ABSORPTION

Absorption of the secondary β-rays emitted by metals when subjected to the radiation from Ra(B + C). μ_h for the hard rays, μ_s for the soft rays. Absorbing screen, Al (7).

Metal	Ag	Al	Au	Cu	Fe	Ni	Pb
μ_h, cm^{-1}	69	14	118	35	41	52	118
μ_s, cm^{-1}	207	52.5	345	105	165	165	345

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ENERGY OF RADIOACTIVE PROCESSES

STEFAN MEYER

HEAT PRODUCTION OF RADIOACTIVE SUBSTANCES

Joules per hour per gram of the radioactive element and the decay products in equilibrium therewith. (1 Joule = 0.2390 g-cal.)

Substance	Rays	Meyer & Hess (4)	Hess (2)	Rutherford & Robinson (7)
Ra	α and recoil	573	105.5	
Rn	α and recoil		467.7	105.0
Ra-A	α and recoil			119.7
Ra-B + Ra-C	α and recoil			127.6
	and β, γ			211.3
Total		573	573	565

Substance	Heat	Lit.
Th	10.0 × 10^{-5}	(5)
U	4.2 × 10^{-4}	(6)
Pitchblende (*ca.* 64% U)	27.2 × 10^{-5}	(6)

Ellis and Wooster (1) have determined the γ-heat effect of Ra-B to be 3.6; Ra-C, 32.2; total, 36 joules/h. Calculations of the heat effect of β-α and γ-rays have been made by Meitner (3) and Thibaud (8).

LITERATURE

(For a key to the periodicals see end of volume)

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CHEMICAL EFFECTS OF α-PARTICLES

S. C. LIND AND D. C. BARDWELL

M is the total number of molecules reacting (on the left hand of the equation, first column); N is the total number of ion pairs produced in the reactants by α-particles.

$$\frac{M}{N} = \frac{\left(\frac{k_\mu}{\lambda}\right)'\cdot V}{D\cdot F\cdot G\cdot H} \times 1.66 \times 10^3$$

V = volume in cm³ of, and D = diameter in cm of, the reaction sphere.

F = average intensity of ionization (1). G = specific molecular ionization (air = 1).

$H = (\alpha + R)/\alpha$ where α and R are α-ray and recoil atom effects resp. (2).

$$\left(\frac{k\mu}{\lambda}\right)' = \left(ln\frac{P_1}{P_2}\right) \div [E_o(e^{-\lambda_{t_1}} - e^{-\lambda_{t_2}})] \quad (3)$$

where E_o = initial radon (in curies), P = pressure (mm Hg), λ = decay constant of radon (in reciprocal days) and t = time (in days).

Where the quantity of gas in the reaction vessel at atmospheric pressure exceeds the air equivalent of a bulb 2.5 cm in diameter, the ionization is calculated by equations developed by W. Mund (17), slightly modified:[1]

$$I = N_0\,(1-e^{-\lambda t})k\Big[r^{2/3} + \frac{1}{2}r'^{2/3} + \frac{1}{2}r''^{2/3} - \frac{3}{20R}\Big\{3r^{5/3} + r'^{5/3} + r''^{5/3} - 3\,(r-2R)^{5/3} - (r'-2R)^{5/3} - (r''-2R)^{5/3}\Big\} + \frac{81r^{1\,1/3}}{3520R^3} - \frac{27}{160}(r-2R)^{2/3}\Big\{\left(\frac{r-2R}{R}\right)^2 + \frac{3}{22}\left(\frac{r-2R}{R}\right)^3\Big\}\Big]$$

I = Number of ions produced by the three sets of α-particles in the time t.

N_2 = Number of atoms of radon present initially (t = 0) (1 curie = 1.772 × 10¹⁶ atoms Rn)

R = Radius of reaction bulb in cms.

λ = Decay constant of radon (as above)

$k = 6.67 \times 10^4 \frac{\text{ions}}{\text{cm}^{2/3}}$ = ionization constant per α-particle as a function of the range (5); $i = kr^{2/3}$ or $kr'^{2/3}$ or $kr''^{2/3}$ for Rn, Ra-A, and Ra-C, resp. (air at 760 mm and 0°C)

r, r', r'' = ranges of α-particles from Rn, Ra-A, and Ra-C, resp. Wourtzel's (13) M/N values are recalculated by the Mund equation

The values adopted for the number of α-particles per sec per g of radium, and the total ions from one α-particle of Ra-C in its completed path in air are respectively, for column (*a*) 3.72 × 10¹⁰ (4) and 2.37 × 10⁵ (5), and for (*b*) 3.40 × 10¹⁰ (6, 7) and 2.20 × 10⁵ (8). Other combinations of these numbers give intermediate values of M/N.

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[1] The modified equation is derived by correcting the integration of Mund's function $\varphi(r) = \int_0^{2R}(r-x)^{2/3}x^2dx$ (equation 5, p. 340). In the large bulbs used by Mund no error was introduced by employing his equation since $2R > r$.

Reaction l = liquid, g = gas, s = solid	$\frac{M}{N}$ (a)	$\frac{M}{N}$ (b)	Lit.
$2H_2g + O_2g \rightarrow 2H_2Ol$	5.13	6.05	(9, 10)
Dry or moist; at 25°C to −75°C			
$2H_2Ol \rightarrow 2H_2g + O_2g$	0.86	1.01	(11)
	1.05	1.24	(11)
$2H_2Og \rightarrow 2H_2g + O_2g$	<0.01	<0.01	(11)
$2H_2Os \rightarrow 2H_2g + O_2g$	0.05	0.06	(11)
$CO_2g \rightarrow$ 1% disappearance of gas, no decomposition products	5×10^{-3}	6×10^{-3}	(18)
$COg \rightarrow CO_2g + C_nO_ms + Cs$	1.85	2.18	(18)
$2COg + O_2g \rightarrow 2CO_2g$ at room temperature	5.7	6.7	(18)
$2COg + O_2g \rightarrow 2CO_2s$ at liquid air temp.	>3.1	>3.7	(18)
$COg + H_2g \rightarrow$ carbohydrate s	3.13	3.7	(18)
$CO_2g + H_2g \rightarrow$ carbohydrate $s + H_2Ol$	1.44	1.70	(18)
$CO_2g + CH_4g \rightarrow$ carbohydrate $s + H_2Ol$	0.76	0.90	(10)
$CH_4g \rightarrow H_2g$ + hydrocarbons g,l and s	2.0	2.4	(10)
$C_2H_6g \rightarrow H_2g$ + hydrocarbons g,l and s	1.7	2.0	(10)
$C_3H_8g \rightarrow H_2g$ + hydrocarbons g,l and s	1.5	1.8	(10)
$C_4H_{10}g + H_2g$ + hydrocarbons g,l and s	1.4	1.6	(10)
$CH_4g + 2O_2g \rightarrow CO_2g + H_2Ol$	4.4	5.2	(10)
$CH_4g + 2O_2g + [1\ \mathrm{mol}\ \%\ (C_2H_5)_2Se] \rightarrow CO_2g + H_2Ol$	5.7	6.7	(10)
$2C_2H_6g + 7O_2g \rightarrow CO_2g + H_2Ol$	6.8	8.0	(10)
$(CN)_2g \rightarrow \begin{cases} 5\%\ \text{to}\ N_2g\ \text{and}\ Cs \\ 95\%\ \text{to paracyanogen}\ s \end{cases}$	7.8	9.2	(12)
$2NH_3g \rightarrow N_2g$ and $3H_2g$ 18°	1.01	1.19	(13)
25°	1.0	1.2	(10)
108°	2.0	2.35	(13)
220°	2.92	3.44	(13)
315°	3.15	3.80	(13)
$H_2Sg \rightarrow H_2g + Ss$ 18°	3.40	4.00	(13)
95°	2.80	3.30	(13)
220°	2.38	2.80	(13)
$H_2Ss \rightarrow H_2g + Ss$ −190°	3.?	4.?	(13)
$N_2Og \rightarrow \begin{cases} N_2g + O_2g \\ N_2g + NOg \end{cases}$ −78°	2.74	3.23	(13)
18°	2.21	2.61	(13)
220°	2.95	3.48	(13)
$H_2g + Cl_2g \rightarrow 2HClg$	4000	4700	(14)
$2HClg \rightarrow H_2g + Cl_2g$	0.76	0.90	(15)
	1.24	1.46	(10)
$H_2g + Br_2g \rightarrow 2HBrg$	0.54	0.64	(16)
$2HBrl \rightarrow H_2g + Br_2g$	2.6	3.1	(16)
KI in acid soln.→free I	0.76	0.90	(16)
$xHCN \rightarrow (HCN)_xs + 5\%\ N_2g$	10.5	12.4	(12)
$C_2N_2g + O_2g \rightarrow \begin{cases} 63\% \rightarrow (CNO)_xs \\ 37\% \rightarrow CO_2g + N_2g \end{cases}$	7.2	8.5	(10)
$C_2N_2g + H_2g \rightarrow \begin{cases} 67\%\ C_2N_2 \rightarrow (HCN)_xs \\ 33\%\ C_2N_2 \rightarrow (C_2N_2)_xs \end{cases}$	6.8	8.0	(10)
$C_2H_4g \rightarrow H_2g$ + hydrocarbons g, l, and s	5.0	5.9	(10)
$C_2H_2g \rightarrow (C_2H_2)_xs + 2\%\ H_2g$	19.5	23.0	(10)
$C_2H_2g \rightarrow (C_2H_2)_xs + 1{+}\%\ H_2g$	20.5	24.2	(19)
$C_2H_2g + H_2g \rightarrow (C_2H_2)_xs$ (11% H_2 reacted)	19.6	23.1	(10)

Catalytic Effect of Inert Gases (10, 20, 21)

The $-M/N$ values in the table below give the total number of molecules of reactants disappearing for each ion pair of both catalyst and reactants. Example: $\frac{M_{C_2H_2}}{N_{(C_2H_2 + N_2)}} = 18.7$, means that 18.7 molecules of C_2H_2 polymerize to $(C_2H_2)_xs$ for each ion pair whether formed in the reactant or in the catalyst. With the increasing ratio of catalyst to reactant, a decrease in the $-M/N$ is indicated—probably attributable to exhaustion effects. Values by the (a) method only are given.

Reactants	Catalysts: Pure gas	N_2	H	Ne	A	Xe	CO_2	H_2
C_2H_2	19.5	18.7 to 17.8	20.1 to 17.0	19.6 to 16.3	18.2 to 15 0	18.5	17.4	19.6
C_2N_2	7.2	7.2				7.2		reacts
HCN	10.8	10.0				10.0		
$2H_2 + O_2$	5.13	5.0					reacts	
$2CO + O_2$	5.7				3.9		none	

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SATURATION CURRENT. ABSORPTION IN LIQUIDS AND SOLIDS

Stefan Meyer

SATURATION CURRENT AND NUMBER OF IONS FOR α-RADIATORS

The saturation current is $I_s = Zke$ where Z = number of α-particles per sec per unit mass, k = number of ion-pairs per α-particle and $e = 4.774 \times 10^{-10}$ es.

Number of Ions, k

Based on the values of Ra-C′ and the following alternative Z values for 1 g of Ra: (a) $Z_{\mathrm{Ra}} = 3.72 \times 10^{10}$ (19, 25); (b) $Z_{\mathrm{Ra}} = 3.45 \times 10^{10}$ (12).

$k = \mathrm{A} \times 10^5$ (9, 11, 13, 18, 45, 47)

Element	A (a)	A (b)	Element	A (a)	A (b)
UI	1.16	1.25	An	1.95	2.10
UII	1.27	1.37	Ac-A	2.12	2.28
Io	1.31	1.41	Ac-C	1.88	2.03
Ra	1.36	1.47	Ac-C′	(2.09?)	(2.25?)
Rn	1.55	1.67	Th	1.23	1.32
Ra-A	1.77	1.83	Rd-Th	1.53	1.64
Ra-C	(1.47?)	(1.58?)	Th-X	1.61	1.73
Ra-C′	2.20*	2.37*	Tn	1.78	1.92
Po	1.50	1.62	Th-A	1.92	2.07
Pa	1.44	1.55	Th-C	1.71	1.85
Rd-Ac	1.69	1.82	Th-C′	2.54	2.73
AcX	1.61	1.74			

* Basic values.

The value of $Z_U = Z_{U_I} + U_{II}$ may be obtained from Z_{Ra} and the basic equilibrium ratio $Z_{Ra}/Z_U = 3.4 \times 10^{-7}$.

The value of Z_{Th} may be calculated from the decay constant of Th. For the following assumed values of the half-life, $T_{½}$, of Th we find for Z_{Th}: 1.25×10^{10} yrs, 4.5×10^3 α sec^{-1}; 1.65×10^{10}, 3.4 α sec^{-1}; and 2.2×10^{10}, 2.6 α sec^{-1}.

Saturation Current

1. (In Electrostatic Units) (**2,3, 4, 5, 6, 7, 8, 20, 26, 31, 32, 34, 43**)

Element		U_I U_{II}	Io	Ra	Rn	Ra-A	99.96 % Ra-C′	Po
In equilibrium with 1 g U	I_s =	1.47	0.79	0.82	0.94	1.08	1.38	0.91
In equilibrium with 1 g Ra	$I_s \times 10^{-6}$ =	4.32	2.38	2.42	2.75	3.02	3.91	2.66

2. On the basis of a branching ratio of 3% for the Ac family in equilibrium with 1 g Ra (**1, 2, 10, 15, 16, 17, 23, 30, 33, 38, 41**).

Element =	Pa	Rd-Ac	Ac-X	An	Ac-A	99.7% Ac-C
$I_s \times 10^{-4}$ =	7.93	9.00	8.86	10.7	11.7	10.4

3. 1 g U in ores [*i.e.* U + 97% (Io→Ra-G) + 3% (Pa→Ac-D)] is equivalent to $I_s = 7.30$; 1 g (U_3O_8→Ra-G) to $I_s = 6.2$; and 1 g average ore with 50% U_3O_8 to $I_s = 3.1$.

4. 1 curie Rn is equivalent to $I_s = 2.75 \times 10^6$ and 1 curie Rn + ½(Ra-A + Ra-C′) to $I_s = 6.22 \times 10^6$.

5. In equilibrium with 1 g Th and based on the following alternative Z values for 1 g Th: (*a*), $Z_{Th} = 4.5 \times 10^3$ α sec^{-1} and (*b*), $Z_{Th} = 3.4 \times 10^3$ α sec^{-1}.

Element		Th	Rd-Th	Th-X	Tn	Th-A	35% Th-C	65% Th-C′
I_s =	(*a*)	0.264	0.329	0.346	0.382	0.413	0.129	0.355
	(*b*)	0.200	0.248	0.261	0.289	0.312	0.097	0.268

RANGE OF α-PARTICLES IN LIQUIDS AND SOLIDS

All values in microns, $\mu = 10^{-4}$ cm

A. In Liquids

	From Po (35)								From Ra-C′ (37, 48)				
Liquid.....	$C_2H_5OC_2H_5$	C_2H_5OH	CS_2	C_6H_6	$CHCl_3$	$C_6H_5NH_2$	H_2O	$C_3H_5(OH)_3$	C_2H_5OH	C_6H_6	C_5H_5N	H_2O	
$R_{15°}$.......	43.0	37.1	36.7	36.3	34.3	33.0	32.0	27.9	7.05	$70.^{-}$	63.9	60.0	59.5

B. In Solids

From Ra-C′ (**49, 50, 51**)

Solid............	Li	Mg	Al	Ca	Fe	Ni	Cu	Zn
$R_{15°}$............	129.1	57.8	40.6	78.8	18.7	18.4	18.3	22.8
Solid....................		Ag	Cd	Sn	Pt	Au	Tl	Pb
$R_{15°}$....................		19.2	24.2	29.4	12.8	14.0	23.3	24.1

C. In Photographic Plates

Source	Ra-A	Ra-C′			Th-C	Po	
Type of plate	Ilford	Sigurd (Jahr)	Ilford			Sigurd	
$R_{15°}$........	34.8	50.0	50.7	54	48.2	27.7	23
Lit..........	(21)	(36)	(21)	(21)	(22)	(36)	(35)

D. Pleochroitic Haloes *v.* (53)

STOPPING POWER EQUIVALENTS OF AIR AND METALS AT DIFFERENT PARTS OF THE PATH OF AN α-RAY

Milligrams per cm² of foil equivalent to 1 cm air lying between the distances given, measured from end of range. 15°C and 1 atm. (**29**).

Distances cms	0–1	1–2	2–3	3–4	4–5	5–6	6–7
Al..........	1.90	1.71	1.65	1.64	1.63	1.62	1.62
Ag..........	3.805	3.28	3.10	3.01	2.93	2.86	2.81
Au..........	6.10	4.84	4.44	4.25	4.06	3.96	3.91

INITIAL VELOCITIES OF RECOIL ATOMS

$u = A \times 10^7$ cm sec^{-1}

From	To	A =	From	To	A =
U_I	UX_I	2.39	An	Ac-A	3.36
U_{II}	Io	2.54	Ac-A	Ac-B	3.58
Io	Ra	2.62	Ac-C	Ac-C″	3.44
Ra	Rn	2.72	Ac-C′	Ac-D	3.61
Rn	Ra-A	2.96	Th	$Ms-Th_1$	2.40
Ra-A	Ra-B	3.16	Rd-Th	Th-X	2.86
Ra-C	Ra-C″	2.99	Th-X	Tn	2.99
Ra-C′	Ra-D	3.66	Tn	Th-A	3.20
Po	Ra-G	3.08	Th-A	Th-B	3.39
Pa	Ac	2.74	Th-C	Th-C″	3.26
Rd-Ac	Ac-X	3.02	Th-C′	Th-D	3.97
Ac-X	An	3.01			

RANGES (PENETRATION) OF RECOIL ATOMS

Ra-A to Ra-B, 0.14 mm in air; 0.83 mm in H_2; *ca.* 20$\mu\mu$ in Ag (**52**).

Rn to Ra-A—Ra-C, *ca.* 10$\mu\mu$ in Cu and Ni (**14, 40**).

Th-C to Th-C″, at 15° and 1 atm., 0.553 mm in H_2; 0.129 mm in air (**24**).

Th-C to Th-D, 15° 1 atm., 0.963 mm in H_2; 0.224 mm in air (**24**).

THE McCOY NUMBER

The McCoy number is the ratio of the total α radiation to the uni-directional radiation per cm² from a U_3O_8 surface of α-saturated thickness. McCoy (**27, 28**) found 793 with $I_s = 1.74 \times 10^{-3}$ es per cm² U_3O_8 and St. Meyer and Paneth (**34**) found 790 with $I_s = 1.73 \times 10^{-3}$. These numbers are smaller than the theoretical.

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RADIOACTIVE RADIATIONS IN GASES

R. D. Kleeman

I. RANGE AND VELOCITY OF α-RAYS IN GASES AT 1 ATMOSPHERE

At $t°$ and 1 atm., $R_t = R_0 \dfrac{T}{273.1}$

Range in Air at 0° and 1 Atm. (13)

From	U_I	U_{II}	Io	Ra	Rn	Ra-A
R_0, cms	2.531	2.910	3.028	3.212	3.907	4.476

From	Ra-C′	Ra-C′$_1$*	Ra-C′$_2$*	Ra-F, Po	Pa	Rd-Ac
R_0, cms	6.608	8.8	10.6	3.721	3.482	4.432

* Two new α-rays from Ra-C′ by the scintillation method (24).

From	Ac-X	An	Ac-A	Ac-C	Th	Rd-Th
R_0, cms	4.141	5.487	6.241	5.224	2.749	3.810

From	Th-X	Tn	Th-A	Th-C	Th-C′
R_0, cms	4.127	4.799	5.387	4.538	8.168

Measured Ranges in Other Gases

	From Ra-C′				From Po		
Gas	Air	O_2	H_2	He	Air	O_2	H_2
$R_{15°}$	6.93 to 6.97	6.26	30.93	32.54	3.76 to 3.95	3.43	16.8
Lit	(12, 15, 17, 27)	(27)	(27)	(27)	(9, 12, 14, 16, 18, 19, 20, 21, 22, 23, 27)	(21, 27)	(21, 27)

	From Po							
Gas	He	N_2	CH_4	CO	CO_2	NO	SO_2	CH_3Br
$R_{15°}$	17.62	3.82	4.18	3.70	2.49	3.41	2.08	1.86
Lit	(27)	(21)	(21)	(21)	(21)	(21)	(21)	(21)

For range of recoil atoms, *see* p. 368.

Distribution of Ranges.—This follows a probability law. Thus the most probable range for a Ra-F (=Po) α-ray is 3.85 cm at 15° and 1 atm.; 90% lie between 3.75 and 3.95, and 60% between 3.8 and 3.9 (8). For long range particles from Th-C, Ac-C, and Ra-F, *v.* (2). I. Curie (8.5) found for a very narrow beam for Po, the range $R_{15}^{760} = 3.87$ cm, as against the much greater value of H. Geiger, $R_{15}^{760} = 3.925$ cm.

Velocity of α-particles.—The velocity, u, of any α-ray may be computed from the relation $u^3 = aR$ where a is a constant and R the length of the remaining path (11). Taking $u = 1.922 \times 10^9$ cm sec^{-1} (25) as the *initial* velocity of the α-particles from Ra-C′, at 0° and 1 atmosphere in air, this becomes $u = 1.024_6 \times 10^9 R^{1/3}$ where R is the range.

Example: R_0 for Th-C′ in air is 8.168 cm (Table 1, *supra*). Hence $u = 1.024_6 \times 10^9 \times \sqrt[3]{8.168} = 2.064$ cm sec^{-1}, the initial velocity.

The following values of $u \times 10^{-9}$ at 0° and 1 atm. have been directly measured: Ra-A, 1.690 (28); Ra-C′, 1.922 (25); Po, 1.593 (7); Th-C, 1.714 (30); Th-C′, 2.060 (30). S. Rosenblum (22.5) determined directly the ratio of the initial velocities of the α-particles from Th-C—Th-C′ = 1.209.

For velocity of recoil atoms see p. 368.

II. NATURE OF PATH

The path of an α-particle may undergo sudden bends (4, 26, 29). The table gives the number of bends (whose angles lie between the limits $\theta_1 - \theta_2$) for path-lengths (between bends) within the limits $l_1 - l_2$, for 281 Ra-F α-rays in air containing 75% A. The unit of l is $1/126$ cm. 0° and 1 atm. (3).

	$\theta_1-\theta_2 =$	20°–30°	30°–40°	40°–50°	50°–60°	60°–70°	70°–80°	80°–90°	90°–180°
$l_1 - l_2$	3–7	11	20	22	8	13	7	6	8
	7–15	21	17	16	5	7			5
	15–30	12	8	7	2	5			
	$\theta_1 - \theta_2 =$	10°–20°	20°–30°	30°–180°					
	30–100	20	3	3					

The ionization along the path of a β particle varies inversely as the square of the velocity of the particle (28.5). The table gives the number, N_I, of ions produced by a ray per first cm of path (13.5). $e = 4.774 \times 10^{-10}$ es.

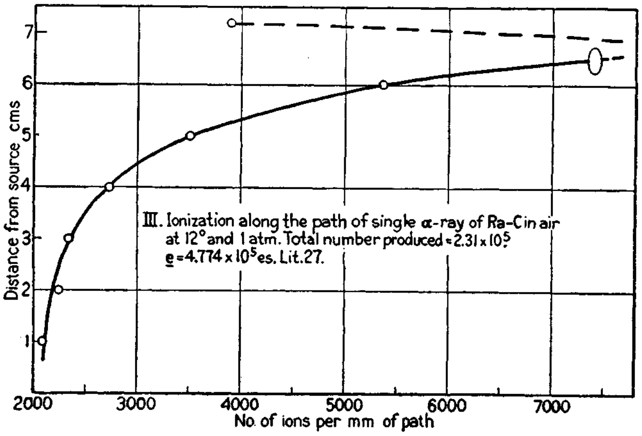
Source	Ac-C″	Th-C″	Ra-B	Ra-C	Ra-E	U
N_I	132	132	130	105	67	76

Coefficients of absorption, λ, of β rays in air and CO_2 at 1 atm. and 22° (18.5).

Substance	Ra-E	Ac-C″	Th-C″	U-X$_2$
Air, λ in cm^{-1}	0.0152	0.0091	0.0068	0.0065
Air, λ in (g/cm^2)$^{-1}$	12.70	7.60	5.68	5.43
CO_2, λ in cm^{-1}	0.0297	0.0175	0.0129	0.0114
CO_2, λ in (g/cm^2)$^{-1}$	16.31	9.62	7.08	6.26

Substance	U-X$_1$	Ra-D	Ra-D very soft	Th-B	Ac-B
Air, λ in cm^{-1}	0.12	0.097	0.64	0.090	0.31
Air, λ in (g/cm^2)$^{-1}$	100	81	535	75	260
CO_2, λ in cm^{-1}	0.23	0.183	1.69	0.142	
CO_2, λ in (g/cm^2)$^{-1}$	126	101	930	78	

Coefficient of absorption λ in cm^{-1} of γ rays from Ra-C′ in air at 1 atm. and 22° is 0.447×10^{-4} (17.5).



III. Ionization along the path of single α-ray of Ra-C in air at 12° and 1 atm. Total number produced = 2.31×10^5. $e = 4.774 \times 10^5$ es. Lit. 27.

IV. STOPPING POWER OF GASES

$S = \frac{R_{Gas}}{R_{Air}}$ for the same temperature and pressure (6).

1. Ionization method (5). 2. Track-condensation method using Ra-F (21). 3. Scintillation method. α-rays of $R_{15°}$ 6.15 cm (1).

Gas	S	Method	Gas	S	Method
A	0.951 Ra-C′	1	CO	.985 Ra-C′	1
	.934 Ra-A			.976 Ra-A	
A	.930	3	CO	1.02 Ra-F	2
H_2	.24	1	CO_2	1.505 Ra-C′	1
H_2	.22 Ra-F	2		1.488 Ra-A	
He	.201	1	CO_2	1.52 Ra-F	2
He	.1757	3	CH_4	0.860 Ra-C′	1
Kr	1.330	3		.880 Ra-A	
N_2	.989 Ra-C′	1	CH_4	.91 Ra-F	2
	.982 Ra-A		CCl_4	4.00	1
N_2	.99 Ra-F	2	CS_2	2.18	1
Ne	.586	3	$CHCl_3$	3.16	1
O_2	1.064 Ra-C′	1	CH_3Br	2.03	1
	1.057 Ra-A		CH_3Br	2.04 Ra-F	2
O_2	1.08 Ra-F	2	CH_3I	2.58	1
Xe	1.804	3	C_2H_2	1.118 Ra-C′	1
Air	1.00	1		1.121 Ra-A	
H_2O	.77 Ra-F	2		1.122 Rn + Ra	
SO_2	1.82 Ra-F	2	C_2H_4	1.349 Ra-C′	1
N_2O	1.46	1		1.369 Ra-A	
N_2O	1.11 Ra-F	2		1.379 Rn	

Gas	S	Method	Gas	S	Method
	1.405 Ra		C_2H_6O	2.00	1
C_2H_5Cl	2.371 Ra-C′	1	$C_4H_{10}O$	3.437 Ra-C′	1
	2.385 Ra-A			3.471 Ra-A	
C_2H_5I	3.12	1	C_5H_{12}	3.544 Ra-C′	1
C_2H_6	1.514 Ra-C′	1		3.595 Ra-A	
	1.526 Ra-A		C_6H_6	3.33	1

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ABSORPTION AND DIFFUSION OF β-RAYS IN LIQUIDS AND SOLIDS

Pierre Auger

Absorption Coefficients.—If I_0 be the initial intensity, and I_x the intensity after screen thickness x is traversed, $I_x = I_0 e^{-x\mu}$ where μ, the absorption coefficient, varies slightly with the thickness traversed. d = density.

Absorption by Al

Source	Ra-D	Th-A	Ra-E	Ac-C	Th-D	Ra-C
μ, cm^{-1}	130	111.0	43.3	28.5	16.3	13.5
Lit.	(12)					

Source	Ra-D very soft	Ra-B		Rb	Ra	U-X_1	U-X_2
		Soft	Hard				
μ, cm^{-1}	5500	91	13	347	312	500	15
Lit.	(13)	(6)		(10)	(9)	(5)	(5)

Absorption of β-rays from U-X (11)

Screen material.	Ag	Al	C	Ca	Cd	Fe	Ir	Mg	Ni	Pb
μ/d, cm^2 g^{-1}	7.31	4.1	3.75	6.3	7.4	6.61	9.5	4.0	6.35	9.75

Screen material	Rh	S	Sb	Sn	Ta	Zn	NH_4Cl	$CaSO_2$	$SrSO_4$
μ/d, cm^2 g^{-1}	7.0	4.52	7.74	7.6	8.9	6.4	5.2	4.95	6.50

Screen material	$BaCl_2$	$BaSO_4$	NaCl	KF	KCl	KBr	KI
μ/d, cm^2 g^{-1}	8.07	7.7	4.68	4.8	4.88	6.1	7.8

Absorption of β-rays of Ra-E (7)

Screen	C	Al	Cu	Mo	Ag	Sn
μ/d	15.8	16.9	19.2	21.0	21.7	22.1

If N is the atomic number of the screening element, $\mu/d = 15 + 0.142\ N$.

Range in Aluminum of β-rays of Various Velocities (Linear Extrapolation) (15)

RH	1380	1930	2535	3170	3790	4400
Range in cm	0.018	0.064	0.124	0.189	0.279	0.360

RH	5026	6230	7490	8590	11 370
Range in cm	0.440	0.580	0.785	0.925	1.36

Velocity Decrease.—R = Radius of curvature of the β-ray in a magnetic field of N units and field force H gauss. ΔRH is the change in RH due to a screen of 0.01 g cm^{-2} and is proportional to the velocity. According to Bohr, $\frac{\Delta RH}{c^3} u^3$ = a constant, K. u = the velocity of the particle, and c that of light (14).

Decrease of Velocity for β-rays from Ra-B and Ra-C

RH	ΔRH	K	ΔRH	K	ΔRH	K
No screen	Mica screen		Sn screen		Au screen	
1392	138.1	34.8	89.2	22.8		
1660	101.4	34.7	67.4	23.4		
1925	78	33.1	56.8	24.1		
2235	72.6	36.2				
2960	66.7	43.5				
3260	59.2	41				
4840	47.3	39.9	37.6	31.7	32.2	27.3
5255	49.3	42.2	37.8	32.5		
5880	43.1	38	32.2	28.6	32.6	29
6160	41	36.7				
7060	38.4	35.4	30.2	27.8		

Dispersion of β-rays (2, 3, 8).

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(For a key to the periodicals see end of volume)

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WAVE LENGTHS OF γ-RAYS

E. von Schweidler

GENERAL RELATIONS

A wave length of λ milli-Ångstroms (10^{-3} Å $= 10^{-11}$ cm $= 1$ *X*-unit), corresponds to:

A Frequency (ν) $= 2.9986 \times 10^{21}/\lambda$ sec^{-1}
An Energy ($E = h\nu$) $= 1.9653 \quad 10^{-5}/\lambda$ ergs
A Potential $\left(P = \frac{h\nu}{e}\right) = 1.2344 \quad 10^{7}/\lambda$ volts

The equivalent electron velocity as a fraction of the velocity of light,

$$(\beta) = \sqrt{1 - \frac{1}{\left(1 + \frac{24.288}{\lambda}\right)^2}}$$

$$h\nu = \frac{hc}{\lambda} = E = Pe = c^2 m_0 \left[\frac{1}{\sqrt{1 - \beta^2}} - 1\right].$$

See p. 17 for values of basic constants.

WAVE LENGTHS DETERMINED WITH CRYSTAL GRATINGS

φ = angle of reflexion, d = grating space = 2.814 Å for rock salt = 3.028 Å for calcite. $\lambda = 2d \sin \varphi$. Intensity indicated thus, s = small, m = moderate, g = great, vg = very great.

(*a*) Soft Radiations from Ra-B. Using rock salt (2, 3). Corresponding to L-series of elements of atomic Nos. 82 and 83, according to Swinne (5) and Wagner (6).

λ, in 10^{-3} Å	1365 m	1349 m	1315 s	1286 s	1266 s	1219 s	1196 m
φ, deg. min.	14° 00′	13° 52′	13° 31′	13° 14′	13° 00′	12° 31′	12° 16′
λ, in 10^{-3} Å	1175 g	1141 m	1100 s	1074 s	1055 s	1029 m	1006 m
φ, deg. min.	12° 03′	11° 42′	11° 17′	11° 00′	10° 48′	10° 32′	10° 18′
λ, in 10^{-3} Å	982 g	953 m	917 s	853 m	838 m	809 m	793 m
φ, deg. min.	10° 03′	9° 45′	9° 23′	8° 43′	8° 34′	8° 16′	8° 06′

(*b*) Hard Radiations from Ra-B + Ra-C, Sec. 1. Radiations from Ms-Th and its products, Sec. 2.

λ, in 10^{-3} Å	1. Using rock salt (4)	428	(393)	(324)	296	262	242	229	196
φ, deg. min.		4° 22′	4° 00′	3° 18′	3° 00′	2° 40′	2° 28′	2° 20′	2° 00′
Remarks			Probably 2nd order spectrum to 196 and 159		K-series				

λ, in 10^{-3} Å	169 g	159 g	137	116	99 g	71	72	66
φ, in deg. min.	1° 43′	1° 37′	1° 24′	1° 11′	1° 06′	43′	41′	37.5′
Remarks	K-line						Using calcite (18)	
	Ra-C?	Ra-B?						

λ, in 10^{-3} Å	58	48	37	28	2. Ms-Th (29)	168 g	145 g	62 s	52 m
φ, deg. min.	33′	27.5′	21′	16′					
Remarks	Using calcite (18)						to Rd-Th		to Th-B

WAVE LENGTHS CALCULATED FROM THE ENERGY OF β-RAYS

Primary γ-rays of energy E_γ produce in the disintegrating atom itself, or in other atoms, secondary β-rays of energy $E_\beta = E_\gamma\text{-}A$, where A is the work of removal and depends upon the level from which the β-rays originate. Sometimes it is assumed that the β-rays are primary and produce secondary γ-rays of energy $E_\gamma = E_\beta$. The energy of the β-rays is obtained from their magnetic deflections.

λ, in 10^{-3} Å	Ra	66	Ra-B	230	174	155	51.9	51.3 m
Lit		(14, 28)		(26)	(26)	(26)	(22)	(26, 29)

λ, in 10^{-3} Å	48.0 s	42.6	42.0 m	35.6	35.2 g	Ra-C + Ra-C″	209?	52.1?
Lit	(29)	(22)	(26)	(22)	(26)		(26)	(26)

λ, in 10^{-3} Å	49.8?	44.4?	28.9?	45.4	37.5	32.0	30.2	29.0
Lit	(26)	(26)	(26)	(16)	(16)	(16)	(22)	(29)

λ, in 10^{-3} Å	24.9	24.3	21.2	20.6	20.4	20.3	16.2?	10.93 g
Lit	(16)	(29)	(29)	(22)	(29)	(26)	(29)	(29)

λ, in 10^{-3} Å	10.0 s	9.93 g	7.00 s	6.94 g	5.56? g	Ra-D	269
Lit	(29)	(29)	(29)	(29)	(29)		(13)

λ, in 10^{-3} Å	Ms-Th	171	59.7	53.0	37.1	37.0	29.7	26.9 g
Lit		(22)	(22)	(22)	(29)	(22)	(22)	(29)

λ, in 10^{-3} Å	Rd-Th	147	Th-B	52.9 g	52	41.6	41.3 s	Th-C″	45.2 s
Lit		(13)		(29)	(13)	(16)	(29)		(29)

λ, in 10^{-3} Å	24.5	21.3	13.6 g	13.5 g	12.8 m	Th-B + Th-C	4.84	4.71
Lit	(16)	(29)	(29)	(29)	(29)		(34)	(34)

EFFECTIVE WAVE LENGTHS CALCULATED FROM ABSORPTION AND SCATTERING

The ordinary or "apparent" absorption coefficient, $\mu' = \mu + \sigma$, where μ is the "true" or "fluorescent" absorption coefficient, and σ the coefficient of scattering. For dependence on wave length *v.* Glocker (8); Compton (12); Wingårdh (23); Warburton and Richtmyer (24); Jauncy (28); and Allen (30).

γ-RAYS FROM RA-C

$\lambda_{\text{eff.}}$, in 10^{-3} Å	<63	<60	120–60	80–30
Calc. from	Abs.	Abs.	Scat.	Abs.
Lit	(7)	(9)	(12a)	(10b)

$\lambda_{\text{eff.}}$, in 10^{-3} Å	30–25	21	24	8	19	19.5
Calc. from	Scat.	Abs.	Abs.		Scat.	Scat.
Lit	(12b)	(31)	(33)		(32a, 32b)	

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RADIOACTIVE RADIATIONS FROM ORDINARY METALS

R. B. MOORE

1. POTASSIUM AND RUBIDIUM

β-rays only are emitted spontaneously, the emission being an atomic property independent of the temperature.

ACTIVITY OF K IN ARBITRARY UNITS (4)

Salt	K_2SO_4	KI	KBr	KCl	KF	$KClO_3$	KNO_3
%K	44.91	23.58	32.87	52.48	67.32	28.91	28.69
Activity	37.8	21	27.8	42.2	54.0	25.5	30.6
K/Act	118	112	118	124	123	110	126

ABSORPTION OF THE β-RADIATION (6)

λ = absorption coefficient cm^{-1}, d = density of absorbent

λ/d for β-rays from K		λ/d for β-rays from Rb	
By K_2SO_4	11.32	By Rb_2SO_4	96.7
By Sn (90% of the rays)	14	By paper (90% of the rays)	162
By Sn (10% of the rays)	90	By paper (10% of the rays)	950

ABSORPTION OF β-RAYS FROM Rb BY PAPER (5)

W = wt. paper/cm². I_0, intensity of the initial radiation; I_p, that of the emergent radiation.

W	0	0.00153	0.00305	0.00458	0.00764	0.0107	0.0153	0.0198
I_p/I_0	1	0.725	0.545	0.422	0.260	0.159	0.087	0.034

2. CAESIUM, SODIUM, LEAD, IRON AND ZINC

Cs and Na are not radioactive (8, 9, 10). Ordinary Pb shows a slight, very old Pb only a trace of activity. On account of their exceptionally small activity Fe and Zn are recommended for construction of sensitive instruments for radioactive measurements. Ca, Ba, Sr, C, Cl, Br, Cu, Fe, Pb, Mg, Mn, Ni, Ag, Zn. W, Ta, La, Se, As, Sn, Au, Sb, Al and Hg are inactive (10).

3. NOTES

O. Hahn and M. Rothenbach (3) compared Rb salts of various ages but no difference in activity was detected. The Rb rays were found to be more penetrating than the β-rays of UX_1, but not so penetrating as those of Ra. The ratio of the intensity of the Rb rays to those of UX_1 is 1:15. The half-life of rubidium is calculated to be 10^{11} years and that of potassium 3 to 7 times greater. The absorption coefficient in Al of K is from 39.6 to 55.4 as foil thickness increases from 0.0135 to 0.0405 cm. Rb decreases from 593 to 522 as foil increases from 0.0017 to 0.0051 cm.

According to Bergwitz (1) the velocity of the Rb rays is 1.85×10^{-10} cm–sec^{-1}

Ringer (7) states that pure K and Rb give off homogeneous β-rays, the K rays having 10 times the penetrating power of the Rb rays. Harkins and Guy (10) give this figure as from 10 to 15 and state that the radiation from Rb is slightly heterogeneous.

Geiger (2) found that the saturation current from RbCl is the same at room temperature and at liquid-air temperatures.

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DISTRIBUTION OF RADIOACTIVE MATERIALS IN THE ATMOSPHERE, THE HYDROSPHERE AND THE LITHOSPHERE

HERMAN SCHLUNDT

TABLE OF CONTENTS

RADON IN THE ATMOSPHERE

Method A: Rn absorbed in charcoal.

Method B: Rn condensed with liquid air.

Method C: Rn directly determined in large ionization chamber.

Method D: Rn computed from active deposit on negatively charged wire.

Place	Micro-micro Curies (10^{-12} Curies) Rn per cubic meter	Method	Number of determinations	Lit.
Montreal, Can.	24–127, Mean, 80	A		(21)
Montreal, Can.	Mean, 60	A	50 during 1907–8	(22)
Cambridge, Eng.	35–350, Mean, 105	A	60 during 6 mos	(93)

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SELECTED PHYSICAL PROPERTIES OF STARS AND NEBULAE

ALFRED H. JOY

CONTENTS.—(*A*) Classification of stellar and nebular spectra; (*B*) Stellar temperatures, masses, and densities; (*C*) Stellar diameters. (Data pertaining to the solar spectra will be found with other spectroscopic data; consult index.)

A. CLASSIFICATION OF STELLAR AND NEBULAR SPECTRA

The system[1] is that developed at Harvard College Observatory, as used by Miss Cannon in the Henry Draper Catalogue. Except where the exact nature of the spectral changes is not fully understood, decimal sub-classes, representing progressive steps toward the succeeding class, are used. In denoting objects by their catalogue numbers, the following abbreviations are used: B. D. = Bonn Durchmusterung; C. D. M. = Cordoba Durchmusterung; I. C. = Dreyer's Index Catalogue of nebulae and clusters; N. G. C. = New General Catalogue by Dreyer. The number, or numbers, following the abbreviation is the catalogue designation of the object.

Class P includes practically all the gaseous nebulae. Its unique characteristic is the appearance of lines from an unknown origin (nebulium). In addition there are many lines of H, He, C, He+, C+, and N+. All lines are bright and usually sharp. (The order of the Harvard (2) subdivisions should probably be reversed to indicate decreasing intensity of radiation.)

Class	Typical object	Spectral criteria
Pa	I. C. 418	λ5007 and λ4959 faint, λ3869 not seen
Pb	Orion nebula	λ5007 and λ4959 stronger
Pc	I. C. 4997	λ4363 conspicuous
Pd	N. G. C. 6826	λ5007 and λ4959 strong
Pe	N. G. C. 7662	λ4686 present
Pf	N. G. C. 40	λ4686 strong

Wright (11) has divided these spectra into three classes: Class I, having λ4686 present, Class II, with λ4686 absent but λ3869 present, and Class III with both λ4686 and λ3869 absent.

Class O is distinguished by the presence of the Pickering series of ionized helium, upon a strong continuous spectrum with maximum intensity far in the violet. The elements present are H, He, He+, C+, N+, Mg+, O+, CIII, NIII, SiIII, OIII, SiIV. Broad emission bands occur in the earlier subdivisions. Few absorption lines are found in sub-classes Oa, Ob, Oc, which make up the group known as Wolf-Rayet stars. (The Harvard subclasses Od, Oe, and Oe5 which have absorption lines and in some cases narrow emission lines as well, are included in the subclasses O5 to O9 as suggested by H. H. Plaskett (7), the basis of classification being the absorption lines.)

Class	Typical object	Spectral criteria
Oa	B. D. +35° 4013	Band λ4648 stronger than λ4686
Ob	B. D. +35° 4001	λ4686 stronger than λ4648
Oc	C. D. M. −41° 10972	Bands narrower. λ4686 twice λ4638
O5	B. D. +4° 1302	Pickering series very strong. H lines weak, λ4634 and λ4640 (NIII) present
O6	B. D. +44° 3639	Neutral helium appears
O7	9 Sagittae	λ4471 (He), 1.4 × λ4541. λ4089 (SiIV), 0.8 × λ4097 (NIII)
O8	λOrionis	λ4481 (Mg+) appears
O9	10 Lacertae	H stronger, He weak. λ4471, 2.7 × λ4541. λ4089, 1.4 × λ4097

Class B is characterized by the presence of helium, which has its maximum intensity in B2. The principal elements are those of class O, with the addition, in the later sub-classes, of lines of the ionized atom of several of the metals, such as Sr, Ba, and Fe. The H and K lines of calcium are found in increasing strength in this class. The hydrogen lines increase through the sub-classes, reaching a strong maximum at Ao of the following class.

Class	Typical object	Spectral criteria
B0	ζ Orionis	Pickering series weak, λ4649 (OII), λ4116 (SiIV), and λ4089 (SiIV) maximum intensity
B1	β Canis Majoris	He more prominent than O and Si.
B2	γ Orionis	λ4116 not seen. λ4089 and λ4649 faint
B3	η Aurigae	Strongest lines are helium
B5	*q* Tauri	λ4128 and λ4131 (SiII) stronger than λ4121 (He). λ4481, 0.7 × λ4471
B8	β Orionis	λ4481 equal to λ4471
B9	λ Aquilae	H strong. He weak. Several prominent enhanced metallic lines

Classes A, F, G, K and M, which contain the largest numbers of the stars, show a gradual increase in the number and intensity of the lines of neutral metallic elements of the lower atomic weights, and a decrease in the intensity of lines due to ionized elements. Compounds produce bands in the later classes. The sun's spectrum is Go, and is intermediate between that of the white and the red stars.

Class	Typical object	Spectral criteria
Ao	α Lyrae	H maximum strength. Very few other lines except λ4481 (Mg+)
A5	ρ Sagittarii	K (Ca+) stronger than Hδ. λ4290 well marked. λ4481 weaker
Fo	σ Bootis	K 3.0 × Hδ and equal to H + Hε

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[1] Adopted by International Astronomical Union. It defines a temperature scale which is linear within the present errors of measurement.

Class	Typical object	Spectral criteria
F5	*α* Canis Minoris	Fraunhofer band G first seen. Numerous solar lines
Go	*α* Aurigae	Solar type. H not conspicuous. G band well defined, Hδ = λ4226.
G5	*η* Piscium	Hγ fainter than λ4325
Ko	*α* Bootis	G band conspicuous, λ4226 strong. Hydrogen weaker
K5	*α* Tauri	λ4226 very wide. λ4254 and λ4274 (Cr) strong. Titanium bands very faint
Mo	*β* Andromedae	Titanium bands well marked
M5	*α* Herculis	Titanium bands very stong. Metallic lines fewer

Class R and N stars show the carbon bands in increasing strength. The more advanced stars of class N have very little light in the violet or blue portions of the spectrum. They are the reddest stars known. Typical stars: Class R, B. D. −10° 5057; Class N, 19 Piscium.

Class S spectra resemble those of class K5 except for the presence of bands of zirconium, and other peculiarities in the region near λ4650. The line λ4554 of Ba+ is conspicuous.

Class Q stars are the novae. Near maximum of outburst their spectra are characterized by numerous wide emission bands of hydrogen and helium, and by absorption lines of ionized elements, especially titanium and iron. As the star decreases in light, both absorption and emission lines of N and O become more prominent. In the later stages, bright nebular bands appear; these are ultimately superseded by the bright bands of the Wolf-Rayet spectrum.

B. STELLAR TEMPERATURES, MASSES, AND DENSITIES

Giant stars are characterized by large mass, low density, and great total luminosity. Dwarf stars have smaller mass, higher density, and less total luminosity. Both are found in all classes, but the greatest contrasts between the two are found in the cooler stars of classes K and M. The continuous spectrum of dwarfs has its maximum shifted towards the violet, as compared with that of giants of the same spectral class, indicating that their absolute temperature is about 15% higher than that of the giants. Even with small dispersion, pronounced differences between giants and dwarfs may be noticed in the distribution of intensity in their line spectra. These differences probably arise from differences in the density gradients; they show a correlation with the absolute magnitude and mass of the stars. The low densities of giants favor the enhancement of those lines (absorption) which are produced under conditions of high excitation, such as the spark lines of the metals; the high density of dwarfs favor those produced by low excitation, such as the resonance lines of neutral atoms. The lines λ4077, λ4215 (ionized Sr) are much strengthened in giants, and weakened in dwarfs; the reverse is true of λ4226 (Ca), λ4454 (Ca), λ4607 (Sr).

Stellar Temperatures, Masses and Densities

Units: Temperature, 1000°C abs.; Mass, Mass of Sun; Density, g/cm³.

Class	Effective temperature (giants*)					Mean mass (⁹)		Mean density (⁹)	
	A†	P‡	C§	S‖	F¶	Giants	Dwarfs	Giants	Dwarfs
Oa		23		23					
O5					30	50 (⁶)			
Bo		20	13	18	19	10			
B3					16	9		0.22	
B8	16					7.3		0.24	
Ao	14	11	8	12	10	7.0	6.0	0.16	0.36
A5		9				5.6	4.0	0.071	0.40
Fo		7.5		9	7.5	4.3	2.5	0.025	0.40
F5	6	7.2	6			3.2	1.5	0.0078	0.39
Go	5.8	6.5	6	7	6	2.6	1.0	0.0025	0.68
G5		4.5				2.8	0.76	0.000 87	1.2
Ko		3.7	4		4.5	3.0	0.68	0.000 18	1.3
K5	3	3.5	3.5		3.9	2.6	0.62	0.000 026	1.4
Mo		3	3	5	3	2.0	0.59	0.000 0096	5.4
M5	2.5	2.95		4					
N		2.3							

* Temperatures of dwarfs are 10 % to 20 % higher than giants of same class (indirect methods).

† Abbot (¹). By radiometer.

‡ Potsdam observations. Wilsing *et al.* (¹⁰).

§ Coblentz (³). By thermocouple.

‖ Saha (⁸). Calculated from initial appearance of certain spectral lines under pressure of 0.1 atmosphere. (See note ¶.)

¶ Fowler and Milne (⁴). Calculated from maximum intensity of certain spectral lines under pressure of 1.31 × 10^{-4} atmospheres, assuming 10 000° corresponds to maximum of Balmer lines of H. These temperatures, and those of Saha, are for the reversing layer; true effective temperature is somewhat higher.

Stellar Diameters

Unit: Linear Diameter, 10^6 km.

Star	Class	Parallax	Diameter	
			Angular*	Linear
α Tauri	K5	0.055″	0.022″	60
α Orionis	M2	0.019	0.044	347
α Bootis	Ko	0.088	0.022	37
α Scorpii	M1	0.017	0.040	353

* Measured by means of interferometer (⁵).

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DISTRIBUTION OF STARS

Frederick H. Seares

Restriction.—No account is here taken of globular star clusters nor of stars included in spiral nebulae, many of which contain objects whose essentially stellar character can no longer be doubted.

Apparent Distribution and Number.—Statistically considered, the stars are distributed over the face of the sky with a high degree of regularity, their numbers gradually increasing as the Milky Way is approached from either side. The Milky Way defines what is very nearly a plane of symmetry, and for a first approximation, systematic difference between the two hemispheres, progressive changes in galactic longitude, and all local irregularities can be ignored. The resulting mean distribution, as found by Seares and van Rhijn, is shown in Table 1.

To apparent magnitude (see p. 39) $m = 13.5$ the results depend on data covering a large portion of the sky. From $m = 13.5$ to 18.5 they are derived from counts of stars on photographs of the 139 Selected Areas of Kapteyn between the North Pole and declination −15°. For still higher values of m, the values of $\log N_m$ are extrapolated, but the uncertainty consequent to the extrapolation itself is probably small. Excepting in low galactic latitudes, there is little or no systematic uncertainty arising from the particular choice of fields used for the counts. To $m = 16$ the magnitude scale is the mean of several closely accordant determinations made at different observatories, and is probably accurate within a few hundredths of a magnitude. Below this limit the scale depends wholly upon observations made at the Mount Wilson Observatory. Although this part of the scale has not been confirmed by independent measures made elsewhere, it has been established by methods successfully used for the brighter stars.

The indicated total, to the twenty-first photographic magnitude, of all stars in the sky is 890 000 000, and to the twentieth visual magnitude, 1 000 000 000. Barring losses of light by absorption, scattering etc., the increase in $\log N_m$ for a uniform distribution of stars throughout space would be 0.6 per unit of magnitude. The observed increase nowhere attains this value; the stars thin out with increasing distance from the sun, and at great distances they thin out more rapidly than near the sun; these changes are most pronounced in the direction of the poles of the Milky Way. If the law of decreasing space density indicated by the stars accessible to observation holds for those beyond present telescopic reach, the total number of luminous stars in the galactic system must be of the order of 3×10^{10}.

TABLE 1.—LOGARITHMS OF NUMBERS (N_m) OF STARS, OF MAGNITUDES LESS THAN m, PER SQUARE DEGREE IN DIFFERENT GALACTIC LATITUDES (1)

Units: Last column; m = visual magnitude; average $N_m = 1$, if $m = 8$. Other columns; m = international photographic magnitude (2); $N_m = 1$, if $m = 8$, Lat. = 0. Galactic pole: R. A. $12^h41^m20^s$, Dec. +27° 21′ (1875) (Gould).

m	$\mathrm{Log}_{10} N_m$ at latitude														Log_{10} (average N_m) between latitudes				
	0°	5°	10°	15°	20°	25°	30°	35°	40°	50°	60°	70°	80°	90°	0°–20°	20°–40°	40°–90°	0°–90°	0°–90° (v)
4.0	$\bar{2}.19$	$\bar{2}.17$	$\bar{2}.12$	$\bar{2}.05$	$\bar{3}.99$	$\bar{3}.93$	$\bar{3}.87$	$\bar{3}.82$	$\bar{3}.78$	$\bar{3}.74$	$\bar{3}.71$	$\bar{3}.69$	$\bar{3}.67$	$\bar{3}.66$	$\bar{2}.12$	$\bar{3}.88$	$\bar{3}.73$	$\bar{3}.94$	$\bar{2}.11$
4.5	$\bar{2}.42$	$\bar{2}.40$	$\bar{2}.35$	$\bar{2}.28$	$\bar{2}.22$	$\bar{2}.16$	$\bar{2}.10$	$\bar{2}.05$	$\bar{2}.01$	$\bar{3}.97$	$\bar{3}.94$	$\bar{3}.92$	$\bar{3}.90$	$\bar{3}.88$	$\bar{2}.35$	$\bar{2}.11$	$\bar{3}.96$	$\bar{2}.17$	$\bar{2}.35$
5.0	$\bar{2}.65$	$\bar{2}.63$	$\bar{2}.58$	$\bar{2}.51$	$\bar{2}.45$	$\bar{2}.39$	$\bar{2}.33$	$\bar{2}.28$	$\bar{2}.24$	$\bar{2}.20$	$\bar{2}.17$	$\bar{2}.15$	$\bar{2}.13$	$\bar{2}.12$	$\bar{2}.58$	$\bar{2}.34$	$\bar{2}.19$	$\bar{2}.40$	$\bar{2}.60$
5.5	$\bar{2}.88$	$\bar{2}.86$	$\bar{2}.80$	$\bar{2}.74$	$\bar{2}.68$	$\bar{2}.62$	$\bar{2}.56$	$\bar{2}.51$	$\bar{2}.47$	$\bar{2}.43$	$\bar{2}.40$	$\bar{2}.38$	$\bar{2}.36$	$\bar{2}.34$	$\bar{2}.80$	$\bar{2}.57$	$\bar{2}.41$	$\bar{2}.63$	$\bar{2}.83$
6.0	$\bar{1}.11$	$\bar{1}.08$	$\bar{1}.03$	$\bar{2}.97$	$\bar{2}.90$	$\bar{2}.84$	$\bar{2}.79$	$\bar{2}.74$	$\bar{2}.70$	$\bar{2}.65$	$\bar{2}.62$	$\bar{2}.60$	$\bar{2}.58$	$\bar{2}.57$	$\bar{1}.03$	$\bar{2}.80$	$\bar{2}.64$	$\bar{2}.85$	$\bar{1}.07$
6.5	$\bar{1}.33$	$\bar{1}.31$	$\bar{1}.26$	$\bar{1}.19$	$\bar{1}.13$	$\bar{1}.07$	$\bar{1}.01$	$\bar{2}.97$	$\bar{2}.92$	$\bar{2}.88$	$\bar{2}.85$	$\bar{2}.83$	$\bar{2}.80$	$\bar{2}.79$	$\bar{1}.26$	$\bar{1}.03$	$\bar{2}.86$	$\bar{1}.08$	$\bar{1}.31$
7.0	$\bar{1}.56$	$\bar{1}.53$	$\bar{1}.48$	$\bar{1}.42$	$\bar{1}.35$	$\bar{1}.29$	$\bar{1}.24$	$\bar{1}.19$	$\bar{1}.15$	$\bar{1}.10$	$\bar{1}.07$	$\bar{1}.05$	$\bar{1}.02$	$\bar{1}.01$	$\bar{1}.48$	$\bar{1}.25$	$\bar{1}.09$	$\bar{1}.30$	$\bar{1}.54$
7.5	$\bar{1}.78$	$\bar{1}.76$	$\bar{1}.70$	$\bar{1}.64$	$\bar{1}.57$	$\bar{1}.52$	$\bar{1}.46$	$\bar{1}.41$	$\bar{1}.37$	$\bar{1}.32$	$\bar{1}.29$	$\bar{1}.27$	$\bar{1}.24$	$\bar{1}.23$	$\bar{1}.70$	$\bar{1}.47$	$\bar{1}.31$	$\bar{1}.52$	$\bar{1}.77$
8.0	0.00	$\bar{1}.98$	$\bar{1}.92$	$\bar{1}.86$	$\bar{1}.79$	$\bar{1}.74$	$\bar{1}.68$	$\bar{1}.64$	$\bar{1}.59$	$\bar{1}.54$	$\bar{1}.51$	$\bar{1}.48$	$\bar{1}.46$	$\bar{1}.44$	$\bar{1}.92$	$\bar{1}.69$	$\bar{1}.53$	$\bar{1}.74$	0.00
8.5	0.23	0.20	0.14	0.08	0.01	$\bar{1}.95$	$\bar{1}.90$	$\bar{1}.85$	$\bar{1}.81$	$\bar{1}.76$	$\bar{1}.73$	$\bar{1}.69$	$\bar{1}.67$	$\bar{1}.65$	0.14	$\bar{1}.91$	$\bar{1}.74$	$\bar{1}.96$	0.23
9.0	0.45	0.42	0.36	0.29	0.22	0.17	0.12	0.07	0.03	$\bar{1}.98$	$\bar{1}.94$	$\bar{1}.90$	$\bar{1}.88$	$\bar{1}.86$	0.36	0.13	$\bar{1}.96$	0.18	0.45
9.5	0.67	0.64	0.57	0.50	0.44	0.38	0.33	0.28	0.24	0.19	0.15	0.11	0.08	0.06	0.58	0.34	0.16	0.39	0.68
10.0	0.89	0.85	0.79	0.72	0.65	0.59	0.54	0.50	0.45	0.40	0.35	0.30	0.28	0.26	0.79	0.55	0.37	0.60	0.90
10.5	1.10	1.07	1.00	0.93	0.86	0.80	0.75	0.70	0.66	0.60	0.55	0.50	0.47	0.45	1.00	0.76	0.57	0.81	1.11
11.0	1.32	1.28	1.21	1.14	1.06	1.01	0.96	0.91	0.86	0.80	0.74	0.69	0.65	0.64	1.22	0.96	0.76	1.02	1.32
11.5	1.53	1.49	1.42	1.34	1.27	1.21	1.16	1.11	1.06	0.99	0.92	0.87	0.84	0.82	1.43	1.17	0.95	1.22	1.53
12.0	1.74	1.70	1.63	1.54	1.47	1.41	1.36	1.30	1.25	1.18	1.11	1.05	1.01	1.00	1.63	1.36	1.14	1.42	1.74
12.5	1.96	1.91	1.83	1.75	1.67	1.61	1.55	1.49	1.44	1.36	1.28	1.23	1.18	1.17	1.84	1.56	1.32	1.62	1.94
13.0	2.16	2.12	2.04	1.95	1.87	1.80	1.74	1.68	1.62	1.54	1.46	1.39	1.35	1.33	2.04	1.75	1.50	1.82	2.14
13.5	2.37	2.32	2.24	2.14	2.06	1.99	1.92	1.86	1.80	1.71	1.62	1.56	1.51	1.49	2.24	1.93	1.67	2.01	2.34
14.0	2.57	2.52	2.43	2.34	2.24	2.17	2.10	2.03	1.97	1.88	1.78	1.72	1.67	1.65	2.44	2.11	1.83	2.20	2.52
14.5	2.77	2.72	2.63	2.52	2.43	2.34	2.27	2.20	2.14	2.04	1.94	1.87	1.82	1.80	2.63	2.29	1.99	2.38	2.71
15.0	2.96	2.91	2.82	2.71	2.60	2.51	2.44	2.36	2.30	2.19	2.09	2.01	1.96	1.94	2.82	2.45	2.14	2.56	2.89
15.5	3.15	3.10	3.01	2.89	2.77	2.68	2.60	2.52	2.45	2.34	2.24	2.15	2.10	2.08	3.01	2.62	2.29	2.73	3.07
16.0	3.33	3.28	3.19	3.07	2.94	2.84	2.75	2.67	2.60	2.48	2.37	2.29	2.23	2.21	3.19	2.77	2.43	2.90	3.24
16.5	3.51	3.46	3.37	3.24	3.10	2.99	2.90	2.81	2.74	2.61	2.50	2.42	2.36	2.34	3.37	2.92	2.56	3.07	3.40
17.0	3.68	3.64	3.54	3.41	3.26	3.14	3.04	2.95	2.87	2.74	2.63	2.54	2.48	2.46	3.54	3.07	2.69	3.23	3.56
17.5	3.85	3.81	3.71	3.57	3.41	3.28	3.17	3.08	3.00	2.86	2.75	2.66	2.60	2.57	3.70	3.20	2.81	3.39	3.71
18.0	4.01	3.97	3.87	3.73	3.56	3.42	3.30	3.20	3.12	2.98	2.86	2.77	2.71	2.68	3.86	3.34	2.93	3.54	3.86
18.5	4.16	4.12	4.03	3.88	3.70	3.55	3.42	3.32	3.23	3.08	2.97	2.88	2.82	2.79	4.02	3.46	3.04	3.68	4.00
19.0	4.32	4.28	4.18	4.02	3.84	3.67	3.54	3.43	3.34	3.19	3.08	2.98	2.92	2.89	4.17	3.59	3.14	3.82	4.13
19.5	4.46	4.42	4.32	4.16	3.97	3.79	3.65	3.53	3.44	3.29	3.17	3.07	3.01	2.98	4.31	3.70	3.24	3.96	4.26
20.0	4.60	4.56	4.46	4.29	4.09	3.90	3.75	3.63	3.53	3.38	3.26	3.16	3.10	3.07	4.45	3.81	3.33	4.09	4.38
20.5	4.74	4.69	4.59	4.42	4.21	4.01	3.85	3.72	3.62	3.46	3.34	3.25	3.18	3.15	4.58	3.91	3.42	4.21	
21.0	4.87	4.82	4.72	4.54	4.33	4.11	3.94	3.81	3.70	3.54	3.42	3.33	3.26	3.22	4.71	4.01	3.50	4.33	

Distribution of Intrinsic Brightness.—The range in intrinsic brightness among stars is enormous—at least twenty magnitudes, corresponding to an intensity ratio of 100 000 000 to 1. A knowledge of the frequencies of different luminosities among the stars in a given volume of space is essential (unless questionable assumptions are to be introduced) for the calculation of the space distribution of the stars. It is, however, difficult to obtain, and, at present, the frequencies are but imperfectly known. By assuming that the mean parallaxes of stars of apparent magnitude m and proper motion μ can be represented by a linear function of m and $\log \mu$ supposed to be valid for all magnitudes and proper motions, Kapteyn and van Rhijn derived for the distribution of the absolute magnitudes a Gaussian error curve whose ordinates are given in the second column of Table 2. Seares (4) has shown that their adopted mean parallax formula does not represent the distances of the stars of large motion and faint apparent magnitude, all of which are of low luminosity. A revision of the parallax formula, still only provisionally determined, and a recalculation of the luminosity function from about 500 stars of large proper motion leads to the frequencies in the third column of Table 2.

Table 2.—Approximate Luminosity Function

$\phi(M)$ = number of stars, absolute magnitude M, per cubic parsec in the neighborhood of the sun. Unit of distance for M is 10 parsecs. 1 parsec = 3.26 light years = 30.8×10^{12}km.

M	10 + Log$_{10}$ $\phi(M)$		Diff.
	Kapteyn v. Rhijn (3)	Seares (4)	
−4.64	2.61		
−3.64	3.42		
−2.64	4.17		
−1.64	4.85		
−0.64	5.46	5.58	0.12
+0.36	6.00	6.16	0.16
1.36	6.47	6.66	0.19
2.36	6.88	7.05	0.17
3.36	7.21	7.34	0.13
4.36	7.47	7.58	0.11
5.36	7.67	7.74	0.07
6.36	7.80	7.84	0.04
7.36	7.85	7.87	0.02
8.36	7.84	7.86	0.02
9.36	7.76	7.88	0.12
10.36	7.61	7.92	0.31
11.36	7.39	8.06	0.67
12.36	7.10	8.11	1.01
13.36	6.75	8.11	1.36
14.36	6.3	8.13	1.8

For the stars of low luminosity, the departure of Seares' curve from the error curve, shown by the differences in the fourth column, is important and must be accepted as real, although quantitatively the results are still very uncertain. The possibility of a maximum within the range of absolute magnitude considered is not excluded, but any such maximum must be well below the Kapteyn–van Rhijn limit, $M = 7.7$. Since the frequencies of stars of very low luminosity are still unknown, it is impossible at present to express the luminosity function as a true frequency function.

Space Distribution of Stars.—The space distribution is defined by a density function, preferably in a form expressing the total number of stars per unit volume at different distances from the sun. At present, however, we must be content with so expressing the number of stars which are brighter than some limit of absolute magnitude.

Analytically, the problem is to determine the density function, $\Delta(\rho)$, from the integral equation

$$\frac{dN_m}{dm} = \omega \int_0^\infty \phi(M)\Delta(\rho)\rho^2 d\rho$$

where the left hand member can be found from the data in Table 1; ω is a constant, ρ = distance from sun. Since $\phi(M)$, for $M > 8$, is still very uncertain, the general solution cannot be found at present. Values of the density for the neighborhood of the sun (Table 3) can, however, be calculated incidentally in deriving the data in Table 2. Results in the second column of Table 3 (M = 7.86) are in good agreement with similar results by Kapteyn and van Rhijn; the other tabular values indicate what is to be expected for lower limiting values of M. The uncertainty of the luminosity function for $M > 8$ scarcely justifies the effort required to complete the table.

Table 3.—Average Number of Stars, Brighter than Absolute Magnitude M, per Cubic Parsec at Distance ρ from Sun (4)

Unit of ρ is 1 parsec; of distance for M, 10 parsecs. 1 parsec = 3.26 light years = 30.8×10^{12} km.

M Log$_{10}\rho$	7.86	8.86	9.86	10.86	11.86	12.86	13.86	14.86
0.9	0.028	0.035	0.042	0.050	0.060	0.073	0.087	0.098
1.1	.026	.033	.040	.048	.058	.069	.078	
1.3	.024	.030	.035	.041				
1.5	.023	.028	.033					
1.7	.022							
1.9	.020							
2.1	.017							
2.3	.014							
2.5	.011							
2.7	.008							
2.9	.004							

(Values based upon $\phi(M)$ for stars near the sun, and on the assumption that the relative frequencies of M are the same at all distances.)

Average densities for the whole sky give a very imperfect picture of the real distribution in space, as the latter varies greatly with galactic latitude. Broadly speaking, the surfaces of equal space density are concentric, and approximately similar, ellipsoids of revolution, similarly situated, with axes in the ratio of about 5 to 1. See Table 4.

Table 4.—Radii of Equidensity Ellipsoids(6)

$\Delta(\rho)$ = number of stars per cubic parsec at distance ρ from sun. (Values require revision for recent star counts (Table 1) and for error in luminosity function (*cf.* Table 2)).

Unit of radius = 1 parsec. 1 parsec = 3.26 light years = 30.8×10^{12} km. Latitude is galactic.

$\Delta(\rho)$	Latitude	
	90°	0°
1.00	0	0
0.63	118	602
0.40	198	1010
0.25	296	1510
0.16	413	2106
0.100	553	2820
0.063	717	3656
0.040	902	4600

Size of the Galactic System.—At present we have no certain indication as to the distance of the most remote stars belonging to the galactic system; but if ordinary blue stars of absolute magnitude zero occur among the faintest objects listed in Table 1, the diameter of the system cannot be less than a million light years. Such objects are not to be expected in high galactic latitudes, where the stars of very faint apparent magnitude are almost certainly all dwarfs; but their occurrence in the Milky Way is by no means excluded. We have, indeed, strong, though not conclusive, evidence of the existence in the Milky Way of stars of zero absolute magnitude among those of the sixteenth apparent magnitude. The corresponding diameter of the system is a hundred thousand light years. This value may be accepted with some assurance as a lower limit for the size of the system in the plane of the Milky Way, exclusive of such objects as globular star clusters and spiral nebulae, whose relation to the general stellar system about us is not yet clearly defined.

Position of the Sun.—The symmetrical distribution of stars adopted in Table 1 tacitly assumes the sun to be at the center of the system. This is not actually the case, as is shown by systematic deviations from the adopted mean distribution. Shapley's (5) value for the distance of the sun from the galactic plane is about 60 parsecs, to the north, which is certainly of the right order of magnitude. The sun's distance from the center is much less certain, and different estimates range from a few hundred to many thousand parsecs, according to the underlying assumptions and the method of attack. The question is much complicated by the fact that the sun lies within a local cluster whose members form a considerable fraction of the stars of the brighter apparent magnitudes, and a final answer must await the detailed discussion of the distribution of faint stars in galactic longitude.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Seares and van Rhijn, *197*, **11**: 358; 25; a more detailed account appears in *21*, **62**: 320; 25. (2) *Trans. Internat. Astronomical Union*, **1**: 69; 22. (Standard magnitudes of stars.) (3) Kapteyn and van Rhijn, *21*, **52**: 23; 20. (4) Seares, *21*, **59**: 310; 24. (5) Shapley, *21*, **49**: 333, 19. (6) Kapteyn, *21*, **55**: 302; 22.

DISTRIBUTION OF NEBULAE

FREDERICK H. SEARES

The term nebula is applied to objects of such diversity of form, size, distance, and physical characteristics that any study of their distribution presupposes a consideration of the question of classification. The following general classification by Hubble provides for two mutually exclusive divisions, characterized by position in the sky as well as by physical peculiarities, and five sub-classes representing physical differences.

A GENERAL CLASSIFICATION OF NEBULAE

I. Galactic nebulae, characterized by (1) tendency to concentrate about the Milky Way, (2) conspicuous association with individual stars from which they probably derive their luminosity, (3) early-type spectra, either emission or absorption, depending upon the spectral type of the associated stars, and (4) smooth and cloudy or wispy texture. They include

- (*a*) *Planetaries*, distinguished by symmetrical distribution of nebulosity about central stars, sharply defined edges, and emission spectra.
- (*b*) *Diffuse nebulae*, clouds in low galactic latitudes, usually associated with early-type stars. This type ranges from luminous to dark and from semi-transparent to opaque. Subdivided into predominantly luminous, predominantly obscure, and conspicuously mixed.

II. Non-galactic nebulae, characterized by (1) tendency to avoid the Milky Way, (2) no conspicuous association with stars, (3) late-type absorption spectra, and (4) usually a rotational symmetry about dominating non-stellar nuclei. They include

- (*a*) *Elliptical nebulae*, amorphous objects whose forms can be represented as successive stages of an original globular mass flattening under the influence of increasing rotation.
- (*b*) *Spirals of two kinds, logarithmic and barred*, which, once formed, appear to develop along parallel lines, the arms unwinding and the granulation of the material becoming more and more conspicuous.
- (*c*) *Irregular nebulae*, including a few non-galactic objects having no dominating nuclei and, significantly, showing no rotational symmetry.

Physically, the planetaries and diffuse nebulae, Ia and Ib, are distinct and apparently without genetic relationship, except that the planetaries, which, in some cases at least, seem to be late stages in the development of novae, may represent the catastrophic consequences of the penetration of a star within a nebulous cloud of the diffuse sub-class. The spirals IIb, on the other hand, are apparently an evolutionary development from elliptical nebulae, IIa, although it does not follow that all elliptical nebulae will necessarily become spirals. The few irregular nebulae, IIc, present features that might be expected in the case of spirals in the absence of or through the neutralization of dominating dynamical characteristics.

The distribution of the various classes of nebulae is not in general easily shown in tabular form. The following summary for each of the important sub-classes includes, however, references to diagrams which exhibit the main features of the distribution.

Ia. Planetary Nebulae.—In the whole sky only about 150 of these objects are known, many of which are so small as to be recognizable only from their gaseous emission spectra. The smallest objects are closely associated with the Milky Way, and show a marked concentration in the Aquila-Sagittarius region. With increasing size the mean galactic latitude increases, and the largest known objects, to the extent of a dozen or so, are scattered over the sky with some approach to uniformity (3, 6, 11). This suggests that the linear distances of planetaries from the galactic plane are relatively small and that their angular diameters are correlated with their distances from the sun. Very small nebulae thus appear in low galactic latitudes because their distances from the sun are many times their distances from the galactic plane.

The actual distances of planetary nebulae are still very uncertain. Van Maanen (15) has measured the parallaxes of about 20 of these objects and finds distances ranging from 50 to a few hundred parsecs; but, as he points out, these values are in conflict with the fact that the radial velocities average about 30 km/sec, while the proper motions are apparently small, of the order of the parallaxes themselves.

Ib. Diffuse Nebulae.—The distant star clouds of the Milky Way define the galactic circle. A secondary galaxy, inclined some 12° to the galactic circle proper, is outlined by the bright helium stars of the much-flattened local cluster immediately surrounding the sun, most of whose members are within 500 parsecs (14). The diffuse nebulae outside the Magellanic Clouds, some hundreds in all,[1] are closely associated with the primary and secondary galactic circles (7). Since the mean galactic latitude of those following the primary galaxy is only about 2°, and since the space within the two circles is not well filled, the inference is that these nebulae are directly connected either with the Milky Way star clouds or with the local cluster, and that few are to be found in the intervening regions. We thus have a group of diffuse nebulae whose members are within a few hundred parsecs of the sun; the others, forming a widely scattered group associated with the Milky Way, are at distances probably to be counted in thousands of parsecs (10). Both groups include both luminous and dark nebulae; the luminous members of the two groups present somewhat different physical characteristics, most marked in their spectra, which may be either emission, or predominantly continuous or absorption in type. The continuous and absorption spectra occur mostly among the nearer objects connected with the local cluster. The luminous diffuse nebulae are conspicuously associated with stars of high temperature from which they derive their luminosity, either by excitation or reflection.

II. Non-galactic Nebulae.—The members of this class, consisting chiefly of the related sub-classes, elliptical nebulae (IIa) and spirals (IIb), are far more numerous than the galactic nebulae. On the whole, the elliptical nebulae out number the spirals many times; but if only bright objects are considered, the spirals are the more numerous. The distribution in galactic latitude is shown in

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[1] Less than 200 luminous ones known; no complete list published (*v.* 7, 8). Most complete list of dark nebulae (182 small objects) is given by Barnard (1).

Table 1, which gives to limiting magnitude 18.6 on the international photographic scale the average number per square degree at various latitudes in each hemisphere. The data are compiled from Fath's list (4), based on Mount Wilson photographs (exposure time 1 hour with 60-inch reflector) of the 139 Selected Areas between the North Pole and declination −15°. That part of the northern galactic hemisphere within which nebulae are frequent is wholly covered. About one-half the southern hemisphere is included, but not the south pole itself. Fath's counts have been corrected for losses caused by poor definition in the corners of the negatives (13).

TABLE 1.—NON-GALACTIC NEBULAE: NUMBER PER SQUARE DEGREE(4)

Average number; international photographic magnitude $\leqq 18.6$; *cf.* Table 2 .

Galactic latitude	Hemisphere	
	N	S
5°	0.2	0.0
15	0.8	0.4
25	2.5	5.4
35	13.2	8.2
45	10.3	5.8
55	12.2	7.0
65	22.2	11.9
74	31	
83	(68)	

Fath's list includes all classes of nebulae, but the galactic nebulae are relatively so infrequent that it is practically one of non-galactic nebulae alone. These objects begin to appear at about 20° latitude and increase rapidly in the interval 20° to 35°. From 40° to 70° the numbers increase slowly. The concentration near the north galactic pole is very pronounced. Below latitude 70° the numbers in the southern hemisphere average about three-fourths those of the northern. The assumption of a similar ratio for the regions 70° to 90° leads to integrated totals of 170 000 and 128 000 for the northern and southern hemispheres, a round total of 300 000 for the whole sky (limiting phot. mag. for stars 18.6).

The summary in Table 2 emphasizes the dependence of the distribution on galactic latitude. The uncertainty in the average number per square degree in the region 70°–90° is considerable, and since the number of nebulae in this region is large (29% or 50 000 in the northern hemisphere), the total given for the whole sky is in doubt by many thousand. Curtis (2) has estimated the total (to an undetermined limiting magnitude) to be over 700 000. The difference in the estimates may arise from a difference in magnitude limits or from the fact that the fields counted by Curtis are not certainly representative of the sky as a whole.

TABLE 2.—DISTRIBUTION OF NON-GALACTIC NEBULAE

Lat. = interval in galactic latitude. Sky = % area of sky. Neb. = % number of nebulae. N = northern, S = southern hemisphere.

Lat.	Sky	Neb.	
		N	S
0°–30°	50	7	15
30 –70	44	64	56
70 –90	6	29	29

The distribution of non-galactic nebulae is not, however, simply one of galactic latitude. Data collected by Hardcastle and Hinks (5) and by Reynolds (12) show marked irregularities in longitude, which seem to depend on the angular diameters of the nebulae. Thus objects with diameters >10′ are almost all in the hemisphere including galactic longitudes 50° to 230°. For diameters 5′ to 10′ the northern galactic hemisphere shows high frequencies in longitude 110° and 260°–270°, which become even more marked for diameters 2′ to 5′. For still smaller nebulae, the distribution is again different. Fath's counts, including mostly very small and faint nebulae, show a band of high frequency crossing the northern galactic hemisphere approximately in longitudes 50° and 220°, with other irregularities suggesting a very complicated distribution.

Nothing is known directly of the distances of elliptical nebulae, but their relationship with the spirals is so intimate that the distances of the two sub-classes must be regarded as of the same order. Van Maanen's measures (16) of internal motion in spirals suggest distances of the order of 3000 to 30 000 light years. The application of Shapley's period-luminosity relation by Hubble (9) to numerous typical Cepheid variables discovered by him in the spirals Messier 31 (the Andromeda nebula) and Messier 33 leads to distances of about a million light years for these two objects. The applicability of the period-luminosity relation is assumed, but several lines of corroborative evidence strongly support the larger value of the distance. It is probable, however, that the zero point of the period-luminosity relation requires revision by an amount which would reduce these distances by about 40%.

LITERATURE

(For a key to the periodicals see end of volume)

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MOTIONS OF THE STARS AND NEBULAE

GUSTAF STRÖMBERG

The *proper motion* of a star is defined as the angular motion, per year, referred to a certain fundamental system of apparently bright stars distributed uniformly over the sky. The *radial motion* is determined by the Doppler shift for spectral lines of known wave-length. If the distance to a star is known, the three velocity-components of its *space-velocity* can be determined. Proper motions and radial velocities are in general referred to the sun as origin, by correction for the periodic changes due to the earth's motion. The proper motions are in general very small; for the majority of the stars they are below 0.1″ per year. The largest proper motion is that of Barnard's star R. A. 17^{h} 53.0^{m}, Dec. + 4° 28′, (1900.0), which moves 10.27″ per year. The radial velocities are mostly below 40 km/sec, the largest being that of the variable star V X Herculis, which approaches the sun with a velocity of 390 km/sec. The spiral nebulae have even higher velocities, the highest being 1800 km/sec, recession, (N. G. C. 584).

SOLAR MOTION

The sun's motion relative to the stars can be determined either from proper motions, from radial velocities, or from space-velocities. The point in the sky towards which the sun is moving is called the sun's *apex*.

TABLE 1.—SOLAR APEX AND THE SUN'S VELOCITY
(Referred to apparently bright stars. Unit: velocity, km/sec)

R. A. 1900	Dec. 1900	Velocity	Method	No. of stars	Lit.
18^h 03^m	+34.3°		Proper Motions P. G. C.*	5413	(2)
18 11	+31.6		Proper Motions $m<6.0$†	4041	(5)
17 56	+32.3		Proper Motions P. G. C.	5943	(8)
17 54	+25.3	19.5	Rad. Vel. Lick Obs.	1193	(3)
18 2	+28.6	19.8	Rad. Vel. B to M	1596	(6)
18 4	+29.2	21.5	Rad. Vel. F to M	1405	(9)
18 11	+36.9	18.8	Space Vel. Giants	800	(10)
18 43	+29.5	31.7	Space Vel. Dwarfs	415	(10)
18 40	+32	29	Space Vel. of nearby stars	83	(7)

* Preliminary General Catalogue by L. Boss, Washington, 1910.
† Stars brighter than the 6th magnitude (apparent).

Although the agreement between the different determinations is fairly good, a detailed study shows that the sun's motion can not be regarded as a constant vector. The A stars and giant stars in general give a small velocity for the sun; and dwarf stars, a much higher velocity.

AVERAGE PECULIAR MOTIONS OF THE STARS

After the effect of the sun's motion has been removed, the residual or "peculiar" velocities show certain regularities. The average peculiar velocities are different for stars of different spectral types, and vary also with the intrinsic brightness of the stars.

TABLE 2.—AVERAGE RESIDUAL RADIAL VELOCITIES (θ) OF STARS OF DIFFERENT SPECTRAL CLASSES (Sp) AND ABSOLUTE MAGNITUDES (M)

Unit of θ = 1 km/sec

Sp	M*	θ	Lit.	Sp	M*	θ	Lit.
O5 to O9	−3	20.7	(11)	K	+1	18.4	(1)
B	−1	6.5	(3)	K	+6	27.0	(1)
A	+1	11.0	(11)	M	+1	21.6	(1)
F	+2	15.8	(1)	M	+9	29.6	(11)
G	+1	18.0	(1)	Me†	0	40.1	(11)
G	+5	26.3	(1)	P‡	–	28.6	(11)

* The apparent magnitude as observed from a distance of 10 parsecs.
† Contains M stars with bright hydrogen-lines; all are variable stars of long period.
‡ Bright-line nebulae.

PREFERENTIAL MOTION

The peculiar velocities of the stars are not distributed at random. In general the stars show a tendency to move parallel to the galactic plane. To describe the distribution of the peculiar velocities, a distribution-function is adopted, which gives the relative numbers of stars moving in different directions and with different velocities. The simplest distribution-function is the spherical distribution-law,

$$F(xyz) = \frac{N}{(2\pi)^{\frac{3}{2}}\sigma^3}\,e^{-\frac{z^2+y^2+z^2}{2\sigma^2}}$$

where x, y, and z are the velocity-components referred to the "centroid" of the group. N is the number of stars in the group, and σ is the dispersion or the square-root of the mean of the squares of the velocity-components. The number of stars of velocity-components between $x \pm \frac{1}{2}dx, y \pm \frac{1}{2}dy, z \pm \frac{1}{2}dz$ is then given by $F(xyz)\,dxdydz$. In a spherical distribution, the frequency of a velocity is independent of its direction and only dependent upon its size. Spherical velocity-distributions occur for several classes of stars, but in general the distribution in velocity-space is either flattened (B stars) or elongated (A, F, and dwarf stars). Two functions have been used to describe the elongated distribution. Kapteyn and Eddington have used a sum of two spherical functions and have regarded the stars as belonging to two intermingled systems, "two stream hypothesis." Schwarzschild has introduced the ellipsoidal distribution defined by the distribution-function

$$F(xyz) = \frac{N}{(2\pi)^{\frac{3}{2}}abc}\,e^{-\left(\frac{x^2}{2a^2}+\frac{y^2}{2b^2}+\frac{z^2}{2c^2}\right)}$$

with three principal dispersions a, b, and c, which define the three axes of the "velocity-ellipsoid." The velocity-components x, y, and z are here projected on the principal axes of this ellipsoid. The major axis of the velocity-ellipsoid corresponds to the line joining the two centers in the two stream theory. The direction of this fundamental axis, which is common in the two theories, is about R. A. 6^h 6^m, Dec. + 9°, (true vertex). The dwarf stars give a somewhat higher declination for the true vertex.

In the analysis of proper motions, the two stream theory gives two vertices, which correspond to the directions of motion of the two streams relative to the sun. The coordinates of these vertices are R. A. 6^h 14^m, Dec. −13° (first stream) and R. A. 19^h 16^m, Dec. −60° (second stream).

Analyzing stellar motions on the basis of the two stream theory, we find a number of stars which cannot be regarded as belonging to either of the two streams. The B stars and stars of spectral class M, for instance, have a group-motion intermediate between the two streams. For this reason Halm has introduced a third stream (0 stream). But these streams taken together can be fairly well represented by an ellipsoidal distribution using a smaller number of parameters.

Charlier (4) has introduced a generalization of the ellipsoidal theory which makes it possible to take into account deviations from a strictly ellipsoidal distribution, but it is only when these deviations are small that this generalization is practicable.

MOVING CLUSTERS OR GROUPS

Several stars move nearly parallel to one another, the best known example being 5 of the 7 bright stars in the constellation Ursa Major. Another moving group or cluster is the Hyades in the constellation Taurus (Taurus Group). The proper motions of the stars belonging to such a group converge towards a point in the sky, the "convergent point," whose position in the sky gives the direction of motion of the group relative to the sun. The convergent point for 17 stars belonging to the Ursa Major Group is R. A. 20^h 30^m, Dec. −40°; for the Taurus Group (39 stars) R. A. 6^h 7^m, Dec. + 7°. A number of other moving groups are known.

THE GENERAL DISTRIBUTION OF COSMIC VELOCITIES

When the sun's motion is referred to different clases of objects it has been found that this motion is not a constant vector but varies greatly, from about 12 km/sec for the A stars and the Cepheids of long period up to 300 km/sec for the fast moving objects, the globular clusters and the spiral nebulae. A general relationship between group-motion and dispersion exists, which, according to Strömberg (11), holds for all classes of objects, but with a small deviation for the B star system. This variation in group-motion produces an asymmetry in the velocity distribution, in such a way that all fast moving objects move, relative to the sun, towards the same hemisphere. This asymmetry defines an axis along which the group-motion increases with increasing internal velocity-dispersion. The direction of this axis is R. A. 8^h 39^m, Dec. −57°, and the motion of objects with small velocity-dispersion relative to those of high velocity-dispersion is about 300 km/sec in the opposite direction. The group-motion of objects with high velocity-dispersion is approximately the same as that of the globular clusters and spiral nebulae.

The general distribution of cosmic velocities can be approximately represented by a product of two symmetrical distributions S_1 and S_2. The first of these is a sum of concentric and co-axial ellipsoidal distributions, the velocity of the sun relative to the center of the distribution S_1 being 14.8 km/sec in the direction R. A. $17^h\ 43^m$, Dec. +22°. The sun's motion relative to the second distribution, S_2, is 300 km/sec in the direction R. A. $20^h\ 28^m$, Dec. +56°. The first distribution can be regarded as the velocity-distribution in our local system of stars, the second as a velocity-restriction in a universal world-frame of enormous dimensions. Other interpretations, however, may be possible.

LITERATURE

(For a key to the periodicals see end of volume)

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(10) Strömberg, *21*, **56**: 265; 22. (11) Strömberg, *21*, **61**: 363; 25.

TIME

CHRONOLOGICAL ERAS

Gregorian Calendar

Era	Year	Begins, 1925 A. D.
Byzantine¶	7434	September 14
Diocletian¶	1642	September 11
Grecian*¶	2237	September 14 October 14
Hegira	1344‡	July 21
Japanese	2585†	January 1
Jewish	5686‡	September 18
Julian calendar	1925	January 14
Julian period	6638§	January 14
Mohammedan	1344‡	July 21
Nabonassar¶	2674	May 12
Rome¶	2678‖	January 14
Seleucidae¶	2237	(See Grecian)

* In present-day usage of Syrians, begins in September or October depending upon the sect. In ancient usage of Damascus and Arabia Petraea, began with vernal equinox.

† The 14th year of period Taisho.

‡ Begins at sunset.

§ Julian day number of January 1, 1925 (Gregorian) is 2 424 152.

‖ Since foundation of Rome, according to Varro.

¶ Based upon Julian calendar.

TIME

Interval	Days*
Year:	
Tropical†	365.2422
Sidereal	365.2564
Anomalistic	365.2596
Month:	
Synodical†	29.530 59
Tropical	27.321 58
Sidereal	27.321 66
Day:	
Sidereal	0.997 2696

* Mean solar days. † Ordinary.

EQUATION OF TIME*

(Δ = mean − apparent)

Unit of Δ is minute. Time is Greenwich mean noon

Date	Δ	Date	Δ	Date	Δ
I 1	+ 3.4	V 11	−3.8	IX 18	− 5.6
6	5.8	16	−3.8	23	− 7.3
11	7.8	21	−3.7	28	− 9.0
16	9.7	26	−3.3	X 3	−10.7
21	11.3	31	−2.6	8	−12.2
26	12.6	VI 5	−1.8	13	−13.5
31	13.6	10	−1.0	18	−14.6
II 5	14.1	15	0.0	23	−15.5
10	14.4	20	+1.1	28	−16.1
15	14.3	25	2.2	XI 2	−16.3
20	14.0	30	3.2	7	−16.3
25	13.3	VII 5	4.2	12	−15.9
III 2	12.4	10	5.0	17	−15.1
7	11.4	15	5.6	22	−14.0
12	10.0	20	6.1	27	−12.5
17	8.7	25	6.3	XII 2	−10.7
22	7.2	30	6.3	7	− 8.8
27	5.7	VIII 4	6.0	12	− 6.5
IV 1	4.2	9	5.4	17	− 4.1
6	2.7	14	4.7	22	− 1.6
11	1.2	19	3.7	27	+ 0.9
16	+ 0.0	24	2.5	31	+ 2.8
21	− 1.2	29	+1.1		
26	− 2.2	IX 3	−0.4		
V 1	− 2.9	8	−2.1		
6	− 3.4	13	−3.8		

*Δ is the amount by which mean time exceeds apparent time when it is noon at Greenwich; it is the excess of the right ascension of the actual sun over that of the mean sun at that instant. It varies continuously with the time, and does not exactly repeat its values in successive years; those given are average values for Greenwich mean noon of an ordinary year, and will seldom differ from the actual values for that time by as much as 0.2 min., except in January and December, when the difference may amount to 0.3 min. In leap years, all dates in the table after February must be reduced by one day.

SOLAR SYSTEM

ORBITAL DATA; SOLAR SYSTEM (1925)

Units: Distance, 10^6 km; period, tropical year

Planet	Distance*	Eccentricity	Inclination†	Mean longitude		Sidereal period
				Node‡	Perihelion	
☿ Mercury	57.9	0.2056	7° 0′ 12.0″	47° 26′ 32.1″	76° 17′ 18.9″	0.24085
♀ Venus	108.1	0.0068	3 23 38.0	76 0 16.7	130 30 56.8	0.61521
⊕ Earth	149.5	0.01674			101 39 2.3	1.00004
♂ Mars	227.8	0.0933	1 51 0.6	48 58 45.0	334 40 42.2	1.88089
♃ Jupiter	778	0.0484	1 18 26.4	99 41 26.3	13 6 51.4	11.862
♄ Saturn	1426	0.0558	2 29 28.7	113 0 5.7	91 34 42.0	29.458
♅ Uranus	2869	0.0471	0 46 22.1	73 36 57.7	169 26 56.8	84.015
♆ Neptune	4496	0.00855	1 46 36.7	130 57 13.3	43 58 27.9	164.788

* Mean distance.

† Angle between plane of orbit and plane of ecliptic.

‡ Ascending node.

CHARACTERISTICS OF MEMBERS OF SOLAR SYSTEM

Units: Linear diameter, 1000 km; density, g/cm³; time, mean solar

Name	Diameter		Mass† × 10^6 / Mass sun	Density	Sidereal rotation	Number satellites
	Linear	Angular*				
Mercury	4.84	10.90″	0.1670	5.6		0
Venus	12.19	1′ 0.80	2.451	5.1		0
Earth	12.76§		3.036‡	5.52	23 hr 56.07 min	1
Mars	6.78	17.88	0.3233	3.9	24 37.4	0
Jupiter	142.7§	46.86§	954.8	1.4	9.8 hr	7
Saturn	120.8§	19.52§	285.6	0.7	10.2 hr	9
Uranus	49.7	3.76	43.7	1.3+		4
Neptune	53.0	2.52	50.8	1.3		1
Sun‖	1391	31 59.26	1 001 341	1.4	25.3 da	
Moon	3.48	31 5.16¶	0.037**	3.3	27.32 da	

* At distance = difference mean distance sun to object and mean distance sun to Earth; nearly at distance of nearest approach to Earth.

† Includes satellite (or planetary) system, if any.

‡ Mass of Earth alone = 2.999×10^{-6} mass of sun.

§ Equatorial diameter. Polar diameter: Earth = 12.71; Jupiter = 133.2, 43.74″; Saturn = 108.1, 17.46″. Diameter of sphere of volume = Earth, is 12.74.

‖ At mean distance of Earth, gravitational acceleration due to Sun is $k^2 = 2.9592 \times 10^{-4}$ (mean distance) per day^2 = 0.5926 cm per sec^2. For solar spectrum etc., see index.

¶ At mean distance from Earth. Apparent diameter varies, with distance, from 29.5′ to 33.5′.

** Moon alone. Mass Moon = 0.01227 mass Earth.

SOLAR DATA

Inclination of equator to ecliptic, about	7°
Longitude of ascending node of equator	74.5°
Period of rotation, about	28 da*
Sun spot period, about	11 yr

TERRESTRIAL AND LUNAR DATA†

General precession (retrograde)	50.2564″ + 0.000222″(t − 1900) per yr
Obliquity of the ecliptic	23° 27′ 8.26″ − 0.4684″(t − 1900)

* From observations of sun spots near latitude 45°; spots near equator rotate in about 24 da; those near lat. 80°, in 30 da.

† For geodetic and geophysical data, see p. 393.

Constant of notation	9.21″	Paris conference values
Constant of aberration	20.47″	
Solar parallax	8.80″	

From parallax measurements	8.806″
From velocity of light	8.781
From mass of Earth	8.762
From motion of Moon	8.773
Equatorial horizontal parallax of Moon*	57′ 2.70″ (Brown)
Mean distance Earth to Moon	384 403 km
Inclination of Moon's equator to ecliptic	1° 32.1″
Inclination of Moon's orbit to ecliptic, about	5°
Eccentricity of Moon's orbit (average)	0.055
Revolution of Moon's nodes (retrograde)	18.6 yr

* Mean of greatest and least values; actual values vary from 53′ to 61′ *ca.*

COMPOSITION OF THE ATMOSPHERE

W. J. HUMPHREYS

TABLE 1.—COMPOSITION OF DRY AIR AT SEA-LEVEL (4, 5)

v = volume of the gas in volume V of dry air

Gas........	N_2	O_2	A	CO_2	H_2*	Ne	He	Kr	Xe
$10^4v/V$.....	7803	2099	94	3	1	0.123	0.04	0.005	0.0006

* Values found by analysis vary; the one here given is that accepted by Hann and the Recueil de Constantes Physiques.

TABLE 2.—COMPOSITION OF ATMOSPHERE AT VARIOUS LEVELS

Computed from data of Table 1 on the assumptions: (1) at surface, H_2O vapor supplies 1.2% of the total number of gas molecules, (2) absolute humidity decreases rapidly to a negligible amount at about 10 km, (3) temperature = 11°C at sea-level, decreases normally (6°C per km) to −55°C at 11 km, remains constant above 11 km, (4) relative proportions of the gases, water vapor excepted, remains constant up to 11 km, (5) above 11 km, distribution is in accordance with their molecular weights (3). The amount of H_2 is in doubt (see note Table 1), especially above 11 km; it may become oxidized to H_2O before reaching the upper atmosphere.

v = volume of the gas contained in volume V of atmosphere. Unit of height = 1 km = 0.621 mi.; of pressure = 1 mm of Hg

Height	$100v/V$							Total pressure
	N_2	O_2	H_2O	A	CO_2	H_2	He	
140	0.01					99.15	0.84	0.0040
130	0.04					99.00	0.96	0.0046
120	0.19					98.74	1.07	0.0052
110	0.67	0.02	0.02			98.10	1.19	0.0059
100	2.95	0.11	0.05			95.58	1.31	0.0067
90	9.78	0.49	0.10			88.28	1.35	0.0081
80	32.18	1.85	0.17			64.70	1.10	0.0123
70	61.83	4.72	0.20	0.03		32.61	0.61	0.0274
60	81.22	7.69	0.15	0.03		10.68	0.23	0.0935
50	86.78	10.17	0.10	0.12		2.76	0.07	0.403
40	86.42	12.61	0.06	0.22		0.67	0.02	1.84
30	84.26	15.18	0.03	0.35	0.01	0.16	0.01	8.63
20	81.24	18.10	0.02	0.59	0.01	0.04		40.99
15	79.52	19.66	0.01	0.77	0.02	0.02		89.66
11	78.02	20.99	0.01	0.94	0.03	0.01		168.00
5	77.89	20.95	0.18	0.94	0.03	0.01		405.
0	77.08	20.75	1.20	0.93	0.03	0.01		760.

TABLE 3.—MASSES OF THE ATMOSPHERE AND ITS CONSTITUENTS

Based upon Table 1, the assumptions of Table 2, and the assumption that the average atmospheric pressure at the surface of the earth = 73.7 cm and at base of stratosphere = 14.5 cm (1, 2). Area of earth is taken as 51×10^{17} cm².

Total mass $M = m \times 10^n$ kg; 1000 kg = 1.102 tons (of 2000 lb.)

Gas	All	N_2	O_2	A	H_2O	CO_2	H_2	Ne	Kr	He	Xe
m	511	387	116	624	133	217	129	471	64	63	116
n	16	16	16	14	14	13	12	11	11	11	10

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(For a key to the periodicals see end of volume)

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MISCELLANEOUS GEODETIC DATA

W. D. LAMBERT

With certain exceptions which are especially noted, those of the following data which depend upon the dimensions of the earth have been calculated strictly in accordance with the INTERNATIONAL ELLIPSOID OF REFERENCE, adopted by the Section of Geodesy of the International Geodetic and Geophysical Union, meeting at Madrid, October 6 and 7, 1924. This ellipsoid is based upon the results obtained by J. F. Hayford (Supplementary Investigation in 1909 of the Figure of the Earth and Isostasy, Washington, 1910), but is not absolutely identical with Hayford's ellipsoid. (For some of the other spheroids that are used for geographical purposes, see Special Publication #100, U. S. Coast and Geodetic Survey. Recent attempts have been made to show that the actual figure of the earth can be represented more closely by an ellipsoid of three unequal axes, than by one of revolution, systematic departures from the latter being of the order of 100 to 200 meters in elevation and depression.)

If the positions of the two ends of a line are determined geodetically for any assumed spheroid of reference, the uncertainty in the length of the line as measured along the earth depends almost entirely upon the errors in the survey; for geodetic surveys of the highest class, the uncertainty is a little less than one in 100 000 and for an ordinary fair survey it is about four times as great. The proportional error in the straight-line distance is greater, mainly because the geoid does not coincide with the ellipsoid; these additional errors are not serious for a short line, but for two points almost diametrically opposite may amount to 100 or 200 meters.

If the end points are determined astronomically, the principal error in the computed length is due to the difference in the deflection of the plumb-line at the two points; unless the measured line is short, the *average* uncertainty so introduced is of the order of 200 meters, but may be much more, especially in rugged country.

Latitude.—The latitude of a place is defined as the angle which some line of reference makes with the equatorial plane. Four lines of reference, defining four distinct kinds of latitude, are used. Three of these lines pass through the place considered; *viz.*, (1) The plumb-line, defining the *astronomical* latitude, (2) the normal to the spheroid of reference, defining the *geographical* latitude, and (3) the line to the center of the earth, defining the *geocentric* latitude. The fourth line of reference passes through the center of the earth and that point which is upon the circumscribed sphere (radius = equatorial radius of the spheroid) and at the same distance from the axis of rotation as is the point on the spheroid representing the place considered; this defines the *parametric*, or *reduced*, latitude.

Gravity.[1]—If the earth's sea-level surface were accurately represented by the International Ellipsoid of Reference, and if no attracting matter projected above this surface, then the variation of gravity at sea-level (γ_o) would be represented by the equations

$$\begin{aligned}\gamma_o &= \gamma_e(1 + 0.005\ 288 \sin^2\varphi - 0.000\ 006 \sin^2 2\varphi)\\ &= \gamma_{45}(1 - 0.002\ 637 \cos 2\varphi + 0.000\ 006 \cos^2 2\varphi)\end{aligned}$$

---

[1] The resultant acceleration arising from the gravitational attraction and the rotation of the earth.

where φ is the geographic latitude, and γ_e, γ_{45} are the values of γ_o at the equator and at latitude 45°, respectively. These equations differ slightly from that used in computing the table on p. 396; the latter corresponds to an ellipticity of 1/297.4.

TABLE 1.—FORM AND SIZE OF THE EARTH

Based upon International Ellipsoid of Reference; accepted constants, from which the others are computed, are $a = 6\ 378\ 388$ meters, ellipticity $[=(a - b)/a] = 1/297$. The indicated uncertainties are estimates, by Lambert, based upon a consideration of systematic errors as well as of internal discordances.

a = semi-major axis	= 6 378 388(±60)m
b = semi-minor axis	= 6 356 911.946 m
Radius of sphere of same area	= 6 371 227.7 m
Radius of sphere of same volume	= 6 371 221.3 m
Length of equatorial quadrant	= 10 019 148.4 m
Length of meridonal quadrant	= 10 002 288.3 m
f = ellipticity = $\left(\frac{a-b}{a}\right)$	= 0.003 367 0034
$\frac{1}{f}$ = reciprocal of ellipticity	= 297.0(±0.4)
e^2 = (eccentricity)^2 = $f^2\left(\frac{2}{f} - 1\right) = \frac{a^2 - b^2}{a^2}$	= 0.006 722 6700
Area of the ellipsoid	= 510 100 934 km^2
Land area	= 148 847 000 km^2
Ocean area	= 361 254 000 km^2
Volume of the ellipsoid	= 1 083 319.78 × 10^6 km^3
Mass of the ellipsoid* (d = 5.527 g/cm^3, p. 395)	= 5.988 × 10^{24} kg
Principal moments of inertia ($A = B < C$)†:	
A‡ = B‡	= 0.332 35 Ea^2
C‡	= 0.333 44 Ea^2
$C - A$	= 0.001 0921 Ea^2
$\left(\frac{C - A}{C}\right) = \left(\frac{1}{305.12}\right)$§	= 0.003 2774

* For discussion of variation of density with depth below surface, *see* Adams and Williamson, Smithsonian Annual Report, 1923, p. 241.

† E = mass of earth.

‡ Computed values vary but little with any admissible assumption regarding the constitution of the interior of the earth. Values are based upon computations of De Sitter (*64V*, **27**: 233; 24); ellipticity taken as 1/296.92.

§ Deduced from precession of equinoxes; involves no hypothesis regarding constitution of interior of earth.

TABLE 2.—DISTANCES UPON SURFACE OF THE INTERNATIONAL ELLIPSOID OF REFERENCE

M = length of meridian from equator to geographic latitude φ; S_m = length of meridian from latitude $(\varphi - \frac{1}{2}\Delta\varphi)$ to $(\varphi + \frac{1}{2}\Delta\varphi)$; S_p = length of arc of parallel for 1° of longitude at latitude φ. These may be computed by means of the equations: $M = a\varphi - b \sin 2\varphi + c \sin 4\varphi - d \sin 6\varphi$; $S_m = a\Delta\varphi - b \sin \Delta\varphi \cos 2\varphi + c \sin 2\Delta\varphi \cos 4\varphi - d \sin 3\Delta\varphi \cos 6\varphi$; S_m (for $\Delta\varphi = 1°$) $= a - b \cos 2\varphi + c \cos 4\varphi - d \cos 6\varphi$; $S_p = a \cos \varphi - b \cos 3\varphi + c \cos 5\varphi$; where the coefficients and their logarithms have the following values:

Unit of length = 1 meter; of angle = 1°

	M*		S_m*	
	Value	log$_{10}$	Value	log$_{10}$
a	111 136.537	5.045 856 86	111 136.537	5.045 856 86
b	16 107.035	4.207 015 6	32 214.069	4.508 045 6
c	16.976	1.229 84	33.952	1.530 87
d	0.022	$\bar{2}$.348	0.045	$\bar{2}$.649

	S_m* for $\Delta\varphi = 1°$		S_p*	
	Value	log$_{10}$	Value	log$_{10}$
a	111 136.537	5.045 856 86	111 417.657	5.046 954 02
b	562.213	2.749 901	93.904	1.972 686
c	1.185	0.073 7	0.119	$\bar{1}$.074 6
d	0.002	$\bar{3}$.37		

* Owing to uncertainty regarding the actual size of the earth, actual distances upon the earth at sea-level may differ from these computed distances by about 2 in 100 000 near the equator or the poles, by somewhat less in middle latitudes.

TABLE 3.—EXCESS OF GEOGRAPHIC LATITUDE (φ) OVER GEOCENTRIC (φ') AND PARAMETRIC (θ) LATITUDES

$$\begin{aligned}\varphi - \varphi' &= a \sin 2\varphi - b \sin 4\varphi + c \sin 6\varphi \\ &= a \sin 2\varphi' + b \sin 4\varphi' + c \sin 6\varphi' \\ \varphi - \theta &= a' \sin 2\varphi - b' \sin 4\varphi + c' \sin 6\varphi \\ &= a' \sin 2\theta + b' \sin 4\theta + c' \sin 6\theta\end{aligned}$$

where the coefficients and their logarithms have the following values:

Unit of coefficients = 1″

	Value	log$_{10}$		Value	log$_{10}$
a	695.6635	2.842 3992	a'	347.8327	2.541 3704
b	1.1731	0.069 34	b'	0.2933	$\bar{1}$.467 29
c	0.0026	$\bar{3}$.421	c'	0.0003	$\bar{4}$.52

TABLE 4.—MISCELLANEOUS TERRESTRIAL DATA

Angular velocity of rotation	72.921 × 10^{-6} radians/sec*
Rotational energy	2.160 × 10^{36} ergs
Rotational energy lost by tidal friction	1.1 × 10^{19} ergs/sec†
Work required to dissipate the material of the earth to infinity	2.46 × 10^{39} ergs
Mean elevation of land above sea-level	825 m
Mean depth of the oceans	3681 m
Mean effective viscosity is not known, but perhaps between	10^{20} and 10^{25} poises‡

* Mean solar second.

† Jeffreys, *62*, **221A**: 239; 20; *The Earth, Its Origin, History and Physical Constitution*, 205–237,; 24. Heiskanen, *175*, **18A**: 1; 21.

‡ Schweydar, *Veröffentl. des Preuss. Geodät. Inst.*, No. **79**; 19; Jeffreys, *Monthly Notices, Roy. Ast. Soc.*, **75**: 648; 15. **76**: 84; 16. **77**: 449; 17; also *The Earth, its Origin, History, and Physical Constitution*, 222; 1924.

Rigidity (μ). From the yielding of the solid portions (revealed by observations with horizontal pendulums), and on assumption of incompressibility, Schweydar (Zentralbureau Int. Erdmes., Neue Folge No. 38, 1921) deduces $\mu = 30.8\ (1 - 0.90r^2/a^2) \times 10^{11}$ dynes/cm^2, and mean effective rigidity $= 17.6 \times 10^{11}$ dynes/cm^2 (r = distance from center, a = mean radius). To allow for compressibility, these values must be increased by about 20% (Lambert, preliminary, unpublished computations); even then the value computed for the outer shell of half-radius thickness is much less than that deduced from earthquake data. (*See* Adams and Williamson, Smithsonian Annual Report, 1923.) The discrepancy may arise from Schweydar's assumption of high rigidity in the central portions, which may possibly behave as a fluid. (*See* Knott, *68*, **39**: 157; 19; Sieberg, *Geologische, physikalische und angewandte Erdbebenkunde*, 364; 23.)

D. VARIATION OF GRAVITY WITH ELEVATION AND DEPTH

Elevation; Free Air Method.—If there were no matter projecting above the geoid and the geoid were a smooth ellipsoid of revolution, then the value (g_H) of the acceleration of gravity (cm/sec²) at a height H meters above the surface would be related (15, 16) to that (g_0) at the surface, as indicated by equation (1), in which φ is the latitude.

$$g_H = g_0 - (0.000\,308\,55 + 0.000\,000\,22\cos 2\varphi)H + 0.000\,072\left(\frac{H}{1000}\right)^2 \qquad (1)$$

This is known as the free air correction. For most purposes it is sufficient to use the approximate formula (2).

$$g_H = g_0 - 0.000\,3086\,H \qquad (2)$$

If g_0 is taken from Table 2, the value of g_H obtained for any station by the use of equation (1) will agree fairly well with the true acceleration, if the surrounding topography is not too rugged. In a fairly flat country, the difference will be considerably less than 0.1 cm/sec², except in very rare cases; and even in a mountainous country, the difference will ordinarily be less than 0.2 cm/sec². For stations below sea-level, but not below the surface of the earth, the same formulae apply; but for such stations, H is negative.

More Exact Methods.—In mountainous country, the computed value will be practically as close to the true value as in flat country if an additional term is added to the right hand side of equation (1), to take account of the elevation of the place above or below the general level of the topography within a radius of, say, approximately 160 km. For every 10 m the place in question is above the general level, this term amounts to 0.001 cm/sec², and for every 10 m below the general level, it amounts to −0.001 cm/sec². In computing the height of a coast station above the general level, the water must be considered replaced by an equal mass of rock, of average surface density, resting on the bottom of the ocean.

If it is desired to obtain a somewhat better value for the computed gravity at a place, the correction term just mentioned must be replaced by a correction for topography and isostatic compensation, computed by the method of John F. Hayford (12).

A somewhat larger error should be expected in the computed values of gravity on oceanic islands than on the continents. The rocks forming these islands are evidently somewhat heavier than normal in many cases, or the ocean is over-compensated, and the observed values of gravity are therefore usually larger than the computed values. In such cases, an error of 0.3 cm/sec², or possibly even 0.4 cm/sec² in computed values may be expected.

Depth.—As the density of the crust is less than two-thirds the mean density of the earth, the acceleration of gravity increases as we advance into the crust. The mean rate of increase is 0.000 0851 cm/sec² per meter of depth. The actual rate at any place depends upon the density of the crustal material in that locality, and is approximately given by the formula (13, 17)

$$g_d = g_0 + (0.000\,3086 - 0.000\,0837\rho)d \qquad (3)$$

where g_d = acceleration of gravity (cm/sec²) at the depth of d m, and ρ = density (g/cm³).

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(For a key to the periodicals see end of volume)

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AERODYNAMICS

L. J. BRIGGS AND H. L. DRYDEN

Problems in aerodynamics cannot be idealized with the same readiness as problems in mechanics. The side of a building may not be regarded as a thin, flat plate for the purpose of computing the force of the wind, and data for a cylinder of a particular length cannot be directly applied for computing the wind force on a cylinder of some other length. Nearby objects exert an influence which cannot be neglected.

Results obtained for a particular object can be applied strictly only to geometrically similar (definition 6) objects in similar surroundings. Many of the apparent discrepancies among the results of different experimenters are to be attributed to departures from geometrical similarity of the models, to the effects of the supports or other nearby objects, and to differences in the fine structure (turbulence) of the approximately steady air streams, rather than to errors in measuring the force or wind speed. It is not possible to discuss these matters in detail here, and there is no complete discussion available for reference.

SYMBOLS

A	Some specified area
A_r	Aspect ratio
C	A coefficient
C_{cp}	Coefficient of center of pressure
C_d	Coefficient of drag
C_l	Coefficient of lift
C_M	Moment coefficient (*see* paragraph on air foils)
C_N	Coefficient of force normal to the plane of reference
C_P	Coefficient of power (input)
C_{P0}	Coefficient of power out-put
C_Q	Coefficient of torque
C_{Q0}	Coefficient of torque load (output)
C_T	Coefficient of force parallel to the plane of reference
C_t	Coefficient of thrust
C. P.	Center of pressure
c	Length of chord of air-foil
D	Diameter
F	Resultant wind force
F_d	Drag = Component of F parallel to wind
F_f	Frictional force
F_l	Lift = Component of F normal to wind and to W
F_N	Component of F normal to the plane of reference
F_T	Component of F parallel to the plane of reference
F_t	Thrust of propeller
F_x	Any component of F
L	Some linear dimension
M	Moment of F about forward (leading) edge
N. A. C. A.	National Advisory Committee for Aeronautics, U. S. A.
n	Number of revolutions per second
P_0	Power developed (output)
P_i	Power input to propeller
P. R.	Pitch ratio
p	Pressure at a point on a surface
p_s	Static pressure of the air
Q	Torque
Q_0	Torque load (output)
q	Dynamic pressure, as indicated by Pitot tube (Fig. 1)
q_0	$\rho V^2/2$ ($= q$ if there is no compression of the air)
R	Reynold's number
S	That dimension of the plane of reference which is at right angles to the wind = Span
T	Temperature
t	Thickness
V	Air speed relative to point considered
V_i	Indicated air speed
W	Width = That dimension of plane of ref-

	ence which is normal to S; *i.e.*, makes least angle with wind
x_c	Distance in the plane of reference, from the leading edge, or its projection to *C. P.*
η	Efficiency
θ_A	Angle of attack
μ	Viscosity
ρ	Density of air when undisturbed by bodies movingrelatively to it.
ρ_0	Conventionally chosen "standard" value of ρ
ϕ	A definite but unspecified mathematical function

DEFINITIONS

1. Angle of Attack (θ_A) is the angle which the direction of the wind makes with the plane of reference; it is positive if the wind strikes what is the under side of this plane when the body is in its usual position.

2. Aspect ratio (A_r) = S/W.

3. Center of pressure (*C. P.*) of a body is that point, in the plane of reference, about which the resultant moment of the pressures is zero.

4. Chord (c). See paragraph on airfoils.

5. Coefficient of center of pressure (C_{cp}).

$$C_{cp} = x_c/W; \text{ for airfoil, } C_{cp} = x_c/c.$$

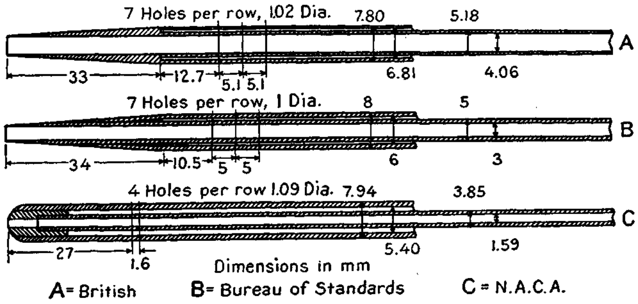


FIG. 1.—Standard Pitot-static tubes.

6. Geometrically similar systems. If two bodies together with their surroundings, are so related geometrically that one system corresponds exactly with a uniformly magnified image of the other, the two systems are said to be geometrically similar.

7. Indicated air speed (V_i) is defined by the relation $q = \rho V^2/2 = \rho_0 V_i^2/2$, where ρ_0 is the "standard" air density.

8. Mean temperature (T_m) of atmospheric air column below Z is that temperature for which the pressure at height Z in an isothermal column of air, pressure at bottom = 760 mm of mercury, would be that actually observed in the atmosphere at Z.

9. Pitch ratio $(P.\ R.)_x$ at any point of the blade of a propeller or of a wind-mill distant x from the axis of revolution is $(P.\ R.)_x = 2\pi x/D \tan \theta_x$, where D is the diameter of propeller or mill wheel, θ_x = angle which face of blade makes with plane of revolution. If $(P.\ R.)_x$ is independent of x, propeller has a constant pitch ratio; if θ_x is independent of x, it has a constant blade angle.

10. Reynold's number (R) = $VL\rho/\mu$, where L is some specified linear dimension. The choice of L depends upon the form of the object, and the problem. R is dimensionless.

CONSTANTS ASSUMED

Standard air density is $\rho_0 = 1.2255$ kg/m³(= 0.002 377 slug/ft.³), which is essentially that of dry air, with normal CO_2 content, at 15°C and one atmosphere.

$$\mu/\rho = 1.427 \times 10^{-5} \text{ m}^2/\text{sec } (= 1.535 \times 10^{-4} \text{ ft.}^2/\text{sec}).$$

For geometrically similar systems $F_x = qL^2\phi(R) = CAq$ (43), where ϕ is independent of the actual size of the system, and q is the value of the dynamic pressure at some specified point. C is a function only of R and of the geometrical form of the system; its value is the same in every self-consistent system of units, and is independent of the actual size of the system. The data in the following tables and graphs apply when all surrounding bodies are so far removed from the one considered that they produce no effect upon F_x.

Reduction of Observations.—To obtain true air speed from speed recorded by cup anemometer, use Table 1. Aerodynamic data are usually reduced to a standard air density (ρ_0). For q, this reduction can be effected by replacing the true air speed (V) by the indicated air speed (V_i) (definition 7), and in most cases the same procedure is amply sufficient for C. *Example:* If V = 100 ft./sec in air at 30°C and 754 mm of mercury, $V/V_i = 1.030$ (Fig. 2); hence V_i = 97.1 ft./sec and q_0 = 11.20 lb./ft.² (Table 2). Owing to isentropic compression of air at this speed, the actual dynamic pressure (q) is 11.20/0.998 (Table 3) = 11.22 lb./ft.² = 54.78 kg/m².

As a basis for the calibration of altimeters, and for use in the comparison of the performances of aircraft, it is assumed that (1) below a certain altitude (Z_i), the rate of decrease (a) of the temperature (T) with the altitude is a constant; (2) above Z_i, $a = 0$; (3) at $Z = 0$, pressure $= p_0$, temperature = T_0. The temperature at $Z_i = T_i$; the mean temperature below Z is T_m. All temperatures are reckoned from absolute zero. Then, if $Z < Z_i$, $T_m = aZ/\log_e(T_0/T)$; if $Z > Z_i$, $T_m = Z/\left(\frac{1}{a}\log_e \frac{T_0}{T_i} + \frac{Z - Z_i}{T_i}\right)$, and for any value of Z, $Z = K \frac{T_m}{T_0} \log_{10}\left(\frac{p_0}{p}\right)$.

The values of these constants define what is called the "standard" atmosphere. There is not entire agreement regarding the values which best represent the average atmospheric condition (28). Those adopted by the governmental aeronautic organizations of the U. S. A. and by many of those of Europe are T_0 = 288°C, T_i = 218°C, p_0 = 760 mm of mercury, a = 6.500 × 10⁻³°C/m (= 1.9812 × 10⁻³°C/ft.), Z_i = 10769 m (= 35332 ft.), K = 19413.3 m (= 63691.8 ft.). These differ slightly from those adopted by the International Commission for Aerial Navigation (see p. 72).

TABLE 1.—ROBINSON CUP ANEMOMETER*

True air speed = V; recorded speed = V_r. If unit is 1 mi./hr, $\log_{10} V = 0.079 + 0.9012 \log_{10} V_r$.

Unit is 1 mi./hr = 1.467 ft./sec = 0.4470 m/sec

V_r	V	V_r	V	V_r	V	V_r	V
1	1.20	26	22.6	51	41.5	76	59.4
2	2.24	27	23.4	52	42.2	77	60.1
3	3.23	28	24.2	53	42.9	78	60.8
4	4.18	29	24.9	54	43.7	79	61.5
5	5.12	30	25.7	55	44.4	80	62.2
6	6.03	31	26.5	56	45.1	81	62.9
7	6.93	32	27.3	57	45.9	82	63.6
8	7.81	33	28.0	58	46.6	83	64.3
9	8.69	34	28.8	59	47.3	84	65.0
10	9.55	35	29.5	60	48.0	85	65.7
11	10.4	36	30.3	61	48.7	86	66.4
12	11.3	37	31.1	62	49.5	87	67.1
13	12.1	38	31.8	63	50.2	88	67.8
14	12.9	39	32.6	64	50.9	89	68.5
15	13.8	40	33.3	65	51.6	90	69.2
16	14.6	41	34.1	66	52.3	91	69.9
17	15.4	42	34.8	67	53.0	92	70.6
18	16.2	43	35.6	68	53.8	93	71.3
19	17.0	44	36.3	69	54.5	94	72.0
20	17.8	45	37.1	70	55.2	95	72.7
21	18.6	46	37.8	71	55.9	96	73.4
22	19.4	47	38.5	72	56.6	97	74.0
23	20.2	48	39.3	73	57.3	98	74.7
24	21.0	49	40.0	74	58.0	99	75.4
25	21.8	50	40.7	75	58.7	100	76.1

* U. S. Weather Bureau type; diameter of cups = 4 in.; centers of cups are 6.72 in. from axis; V_r = 3 times linear speed of centers of cups (3, 82, 83).

TABLE 2.—DYNAMIC PRESSURE ($q = q_0$) FOR INDICATED AIR SPEED V_i

Air compression is negligible, and $q = q_0 = \rho_0 V_i^2/2$ if $V_i < 30$ m/sec (=100 ft./sec); for greater speeds, q exceeds q_0, see Table 3. Metric units are m, kg, sec. English units are ft., lb., sec. 1 lb./ft.² = 4.882 kg/m²; 1 ft./sec = 0.3048 m/sec.

Metric	V_i	English	Metric	V_i	English	English							
q_0		q_0	q_0		q_0	V_i	q_0	V_i	q_0	V_i	q_0	V_i	q_0
0.063	1	0.00119	42.25	26	0.8038	51	3.093	76	6.868	101	12.13	126	18.88
0.250	2	0.00476	45.56	27	0.8668	52	3.215	77	7.050	102	12.37	127	19.18
0.562	3	0.01070	49.00	28	0.9322	53	3.340	78	7.234	103	12.61	128	19.48
1.00	4	0.0190	52.56	29	0.9999	54	3.467	79	7.421	104	12.86	129	19.79
1.56	5	0.0297	56.25	30	1.070	55	3.597	80	7.610	105	13.11	130	20.09
2.25	6	0.0428	60.06	31	1.143	56	3.729	81	7.801	106	13.36	131	20.40
3.06	7	0.0583	64.00	32	1.218	57	3.863	82	7.995	107	13.61	132	20.72
4.00	8	0.0761	68.06	33	1.295	58	4.000	83	8.191	108	13.87	133	21.03
5.06	9	0.0963	72.25	34	1.374	59	4.139	84	8.390	109	14.13	134	21.35
6.25	10	0.1189	76.56	35	1.457	60	4.280	85	8.591	110	14.39	135	21.67
7.56	11	0.1438	81.00	36	1.541	61	4.424	86	8.794	111	14.65	136	21.99
9.00	12	0.1712	85.56	37	1.628	62	4.571	87	9.000	112	14.91	137	22.32
10.56	13	0.2009	90.25	38	1.717	63	4.719	88	9.208	113	15.18	138	22.64
12.25	14	0.2330	95.06	39	1.808	64	4.870	89	9.418	114	15.45	139	22.97
14.06	15	0.2675	100.0	40	1.902	65	5.024	90	9.631	115	15.72	140	23.30
16.00	16	0.3044	105.1	41	1.999	66	5.179	91	9.846	116	16.00	141	23.64
18.06	17	0.3436	110.3	42	2.097	67	5.337	92	10.06	117	16.28	142	23.97
20.25	18	0.3852	115.6	43	2.198	68	5.498	93	10.28	118	16.56	143	24.31
22.56	19	0.4292	121.0	44	2.302	69	5.661	94	10.51	119	16.84	144	24.66
25.00	20	0.4756	126.6	45	2.408	70	5.826	95	10.73	120	17.12	145	25.00
27.56	21	0.5243	132.2	46	2.516	71	5.994	96	10.96	121	17.41	146	25.34
30.25	22	0.5755	138.1	47	2.627	72	6.164	97	11.18	122	17.70	147	25.69
33.06	23	0.6290	144.0	48	2.739	73	6.336	98	11.42	123	17.99	148	26.04
36.00	24	0.6849	150.1	49	2.855	74	6.511	99	11.65	124	18.28	149	26.40
39.06	25	0.7431	156.3	50	2.973	75	6.688	100	11.89	125	18.58	150	26.75

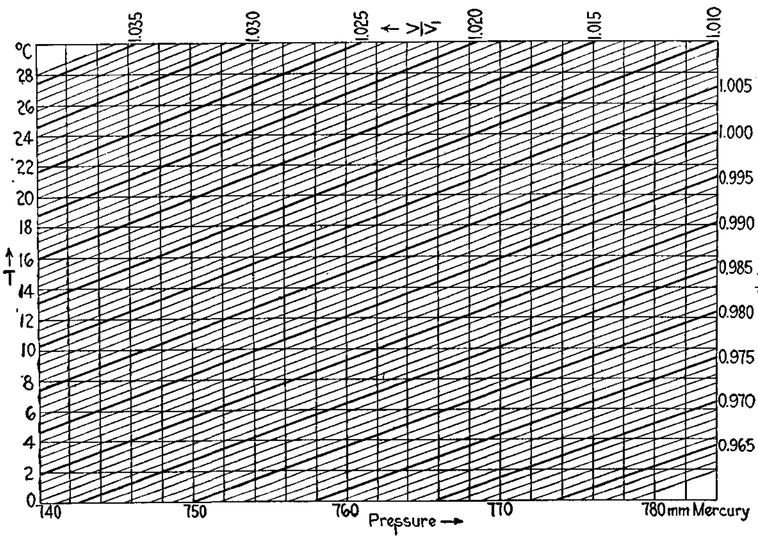


FIG. 2.—Ratio of true air speed (V) to indicated air speed (V_i).

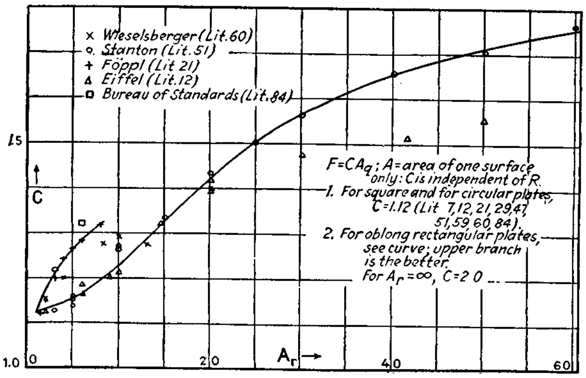


FIG. 3.—Air force: flat plates normal to wind.

TABLE 3.—CORRECTION FOR ISENTROPIC COMPRESSION (63)

Metric (M) unit of V = 1 m/sec; English (E) = 100 ft./sec

V		$\rho v^2/2q$	V		$\rho v^2/2q$
E	M	$= q_0/q$	E	M	$= q_0/q$
1	30	0.998	6	183	0.931
2	61	0.992	7	213	0.907
3	91	0.982	8	244	0.881
4	122	0.969	9	274	0.852
5	152	0.951	10	305	0.822

TABLE 4.—WIND PRESSURE ON STRUCTURES

Reference plane (see below) is normal to wind. $F_N = C_N A q$; A = area of projection of object upon reference plane
Unit of F_N/A = 1 lb./ft.² = 4.88 kg/m²

Object	C_N	F_N/A*
1. Long flat plate	2	30
2. Square flat plate	1.1	16
3. Rectangular prism (1:1:5) (75)	1.6	24
4. Long cylinder	0.8	12
5. Short cylinder	0.7	10

* For V = 76 mi. per hr (=34m /per sec) true speed = 100 mi. per hr recorded by Robinson anemometer.

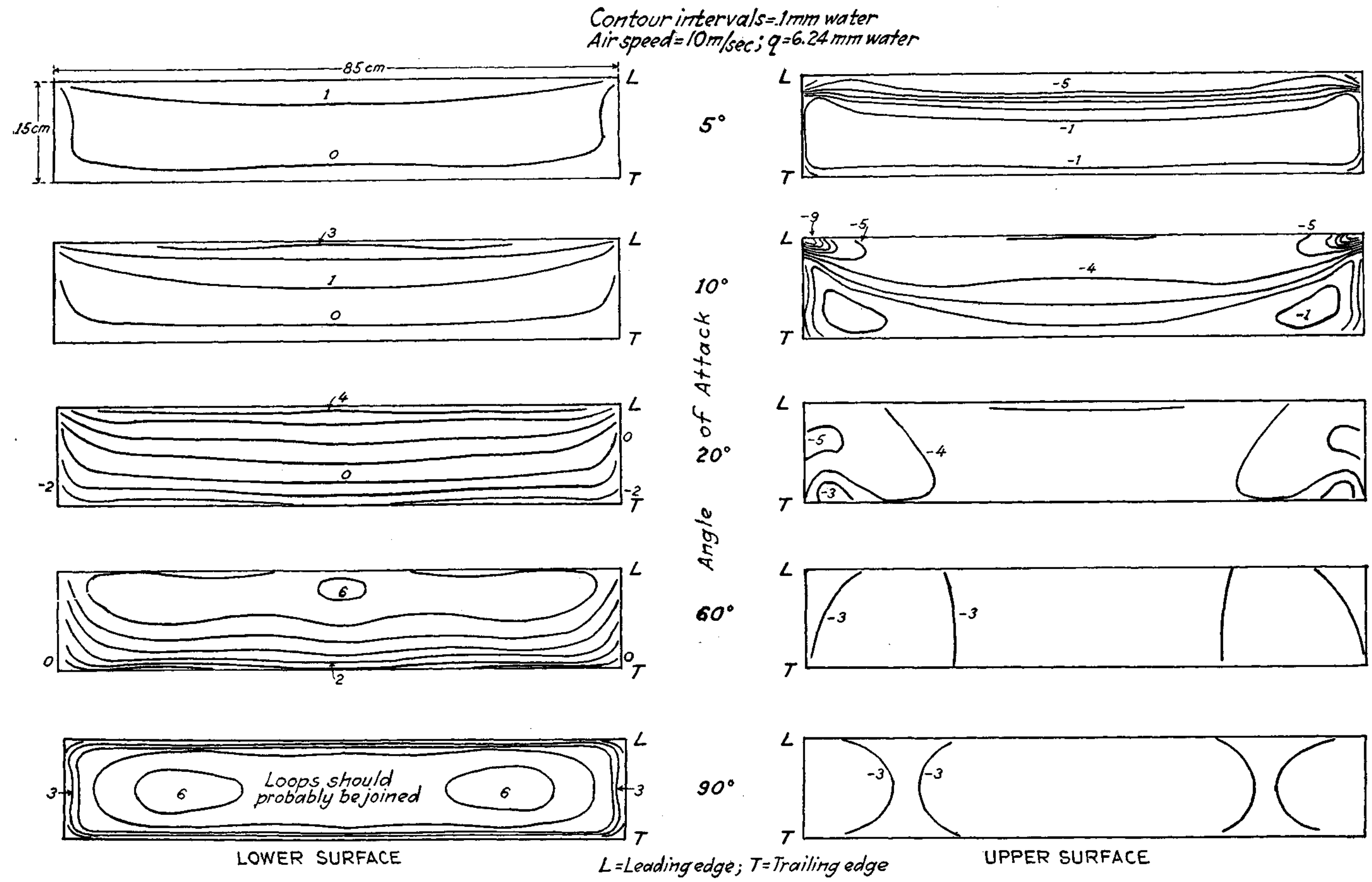


FIG. 4.—Pressure distribution: oblong, rectangular plate, inclined (12, 13).

Wind Pressure on Structures.—One must consider (1) maximum wind speed to which the structure will be subjected, (2) the value of the coefficient C_N, and (3) the effective exposed area. The first and the third depend upon local conditions; in the third, shielding effects are very important. The value of C_N should be determined from observations upon a model of the actual structure, as experiments upon flat plates are of little value for this purpose. Opinions differ regarding whether, in gusty winds, the maximum value of F_N is determined by the average or by the maximum value of V (20, 52). Approximate values of C_N for certain typical cases are given in Table 4, where reference plane for flat plate is surface of plate; for prism, its largest face; for cylinder, the plane through axis and normal to that which contains axis and direction of wind. Object (1) is comparable to such structures as wireless masts and long narrow bridge girders; (2) to thin square signboards; (3) to tall buildings; (4) to chimneys; (5) to cylindrical water tanks.

TABLE 5.—SURFACE FRICTION (F_f) ON THIN FLAT PLATES (Standard density and viscosity)

F_f (= $\int f dA$) = 0.0375 $AqR^{-0.15} = F_0 A K_w K_v$ (5, 61) where A = total area (both sides) exposed to air stream, F_0 is a factor depending upon the density and viscosity of the air and upon the units employed, and K_w and K_v are numerical factors determined, respectively, by the width (W) of the plate in the direction of the stream, and by the speed (V). F_0 is independent of the ratio S/W, provided $0.5 < (S/W) < 2$; if $S/W = 30$, F_0 is 10% less than the value given in the table. For effect of roughness (it is great), and for variation of f from point to point see (22, 24, 32, 53, 54, 55, 62).

English units $F_0 = 0.0420$ lb./ft.^{2} Unit of F_f = 1 lb.; of A = 1 ft.^{2}; of V = 1 ft./sec				Metric units $F_0 = 0.0311$ kg/m^2 Unit of F_f = 1 kg; of A = 1 m^2; of V = 1 m/sec			
W	K_w	V	K_v	W	K_w	V	K_v
1	1.413	10	0.014	1	1.000	10	1.000
2	1.273	20	0.051	2	0.901	20	3.605
3	1.198	30	0.108	3	0.848	30	7.633
4	1.147	40	0.184	4	0.812	40	13.00
5	1.110	50	0.277	5	0.786	50	19.64
6	1.080	60	0.389	6	0.764	60	27.52
7	1.055	70	0.517	7	0.747	70	36.60
8	1.034	80	0.662	8	0.732	80	46.85
9	1.016	90	0.823	9	0.719	90	58.26
10	1.000	100	1.000	10	0.708	100	70.80
11	0.986	110	1.193	11	0.698	110	84.45
12	0.973	120	1.401	12	0.689	120	99.19
13	0.961	130	1.625	13	0.681	130	115.0
14	0.951	140	1.864	14	0.673	140	131.9
15	0.941	150	2.117	15	0.666	150	149.9
20	0.901	160	2.386	20	0.638	160	168.9
30	0.848	170	2.669	30	0.600	170	188.9
40	0.812	180	2.967	40	0.575	180	210.0
50	0.786	190	3.279	50	0.556	190	232.1
100	0.708	200	3.605	100	0.501	200	255.2

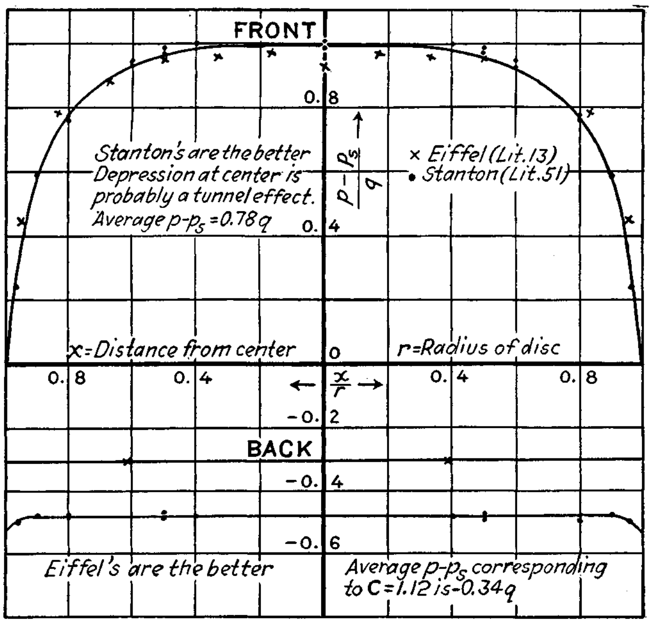


FIG. 5.—Pressure distribution: thin circular disc normal to wind.

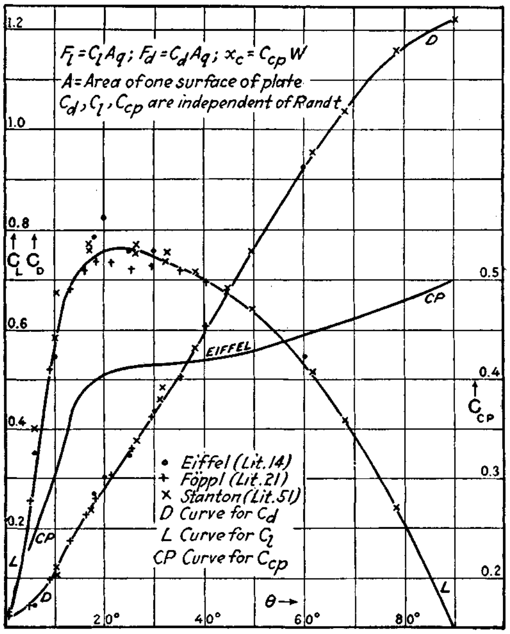


FIG. 7.—Coefficients: inclined, rectangular plates, $A_r = 3$. (See Table 6.)

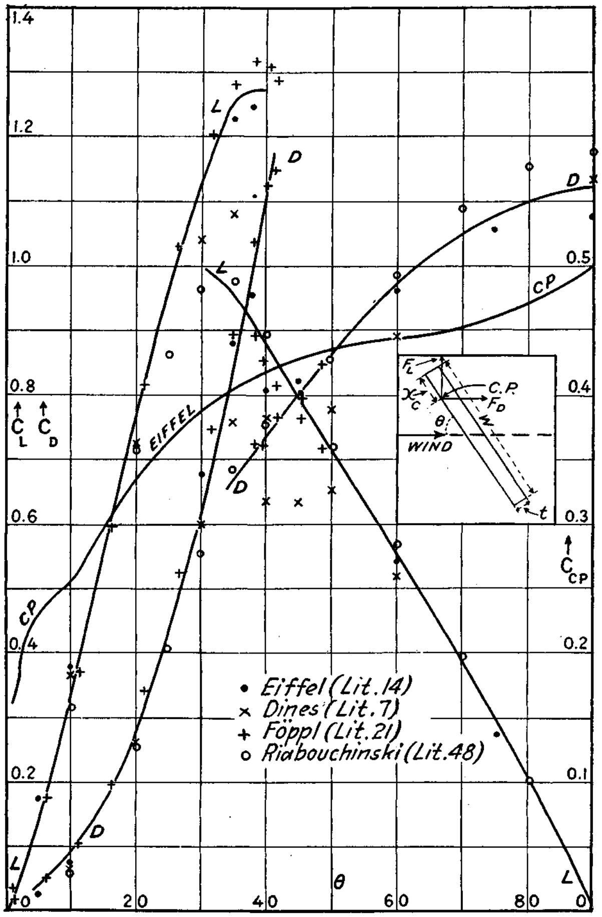


FIG. 6.—Coefficients: square, inclined plates. (See Table 6; for notation, v. Fig. 7.)

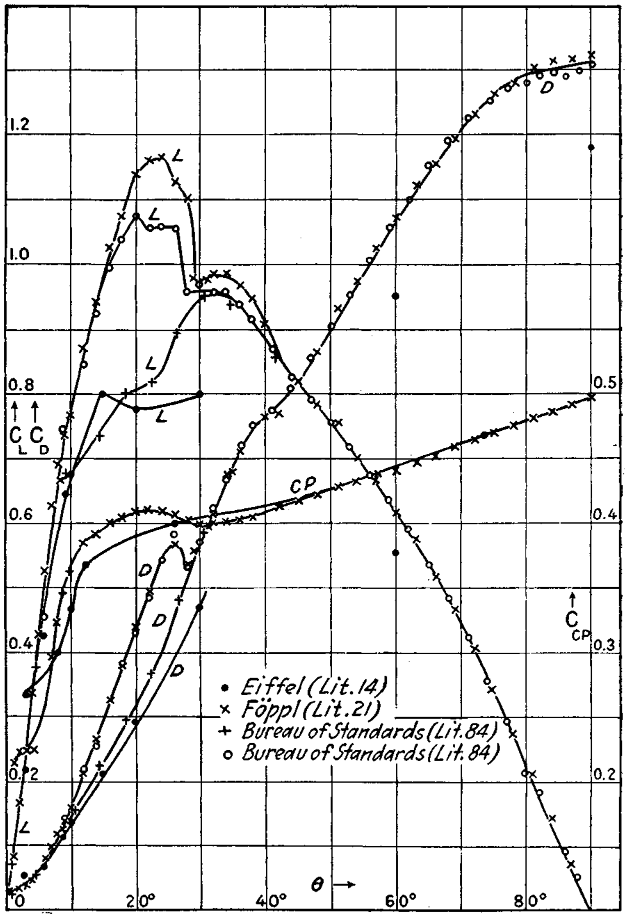


FIG. 8.—Coefficients: inclined rectangular plates, $A_r = 6$. (See Table 6; for notation, v. Fig. 7.)

Fig. 10.—Pressure distribution: spheres.

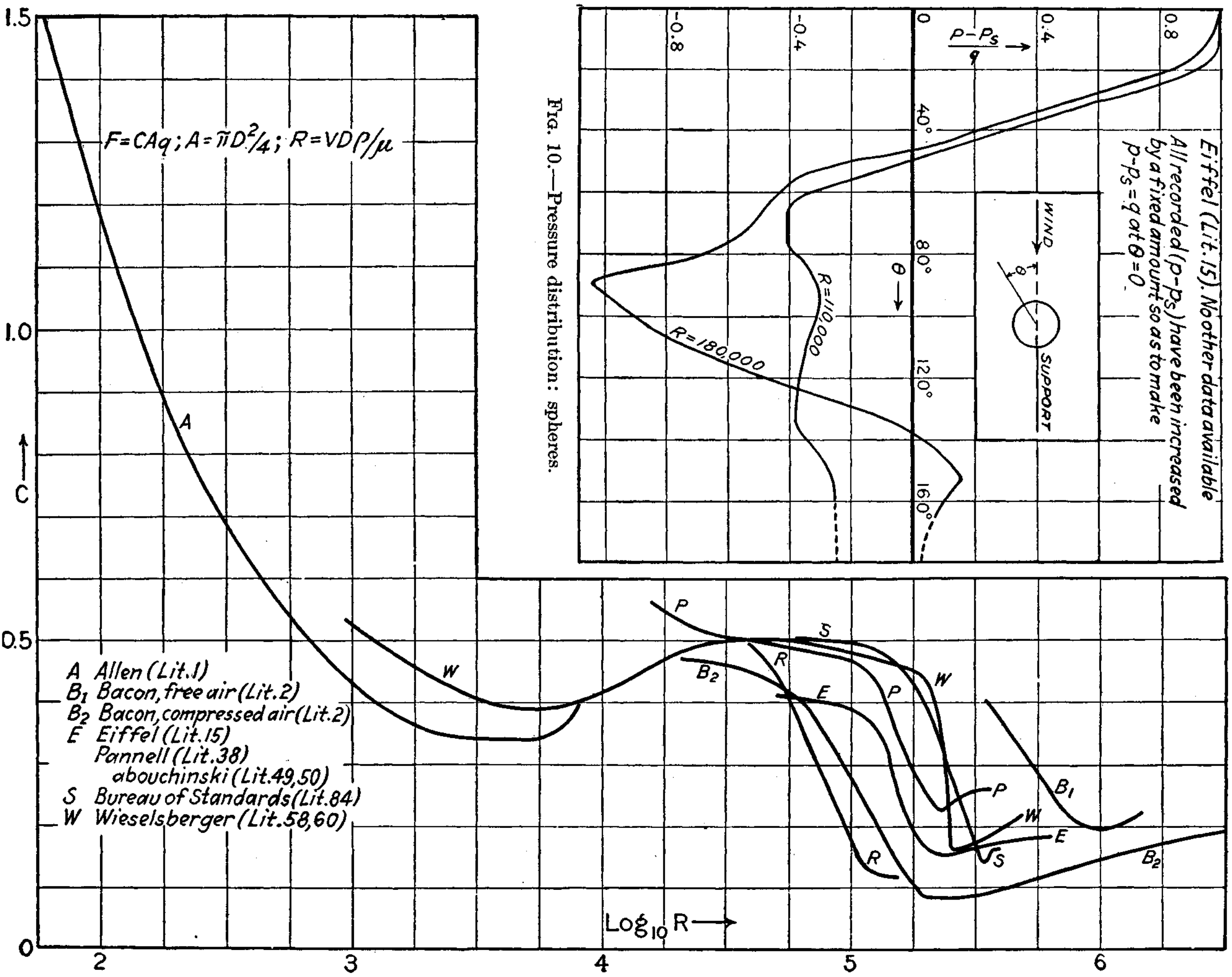


Fig. 9.—Air force: spheres.

Table 6.—Experimental Data; Figures 6, 7, 8

Unit of S and W = 1 cm; of t = 1 mm; of TD = 1 m; of R† = 1000

	Fig. 6				Fig. 7			Fig. 8			
	•	×	+	0	•	×	+	•	×	+	0
S	25	30.5	12	12	45	7.6	36	90	30.5	72	30.5
W	25	30.5	12	12	15	2.5	12	15	5.08	12	5.08
t	3	3.18	1.7		3	0.25	1.7	3	1.17	1.7	1.29
TD*	1.5	∞	2.0	1.2	1.5	0.6	2.0	1.5	1.37	2.0	1.37
R†	210	382	55	42	126	10	55	126	64	55	64

* TD = tunnel diameter.

† R is dimensionless.

The flow about a sphere is extremely sensitive to slight changes in the method of support, and to the condition of turbulence of the air stream. Changes in C are associated with changes in the locus of the points at which the smooth flow leaves the surface, forming a highly turbulent region to the rear. The location of this locus is determined solely by the irregularities in the air stream, as there are no sharp edges or other geometrical feature which might serve to fix it.

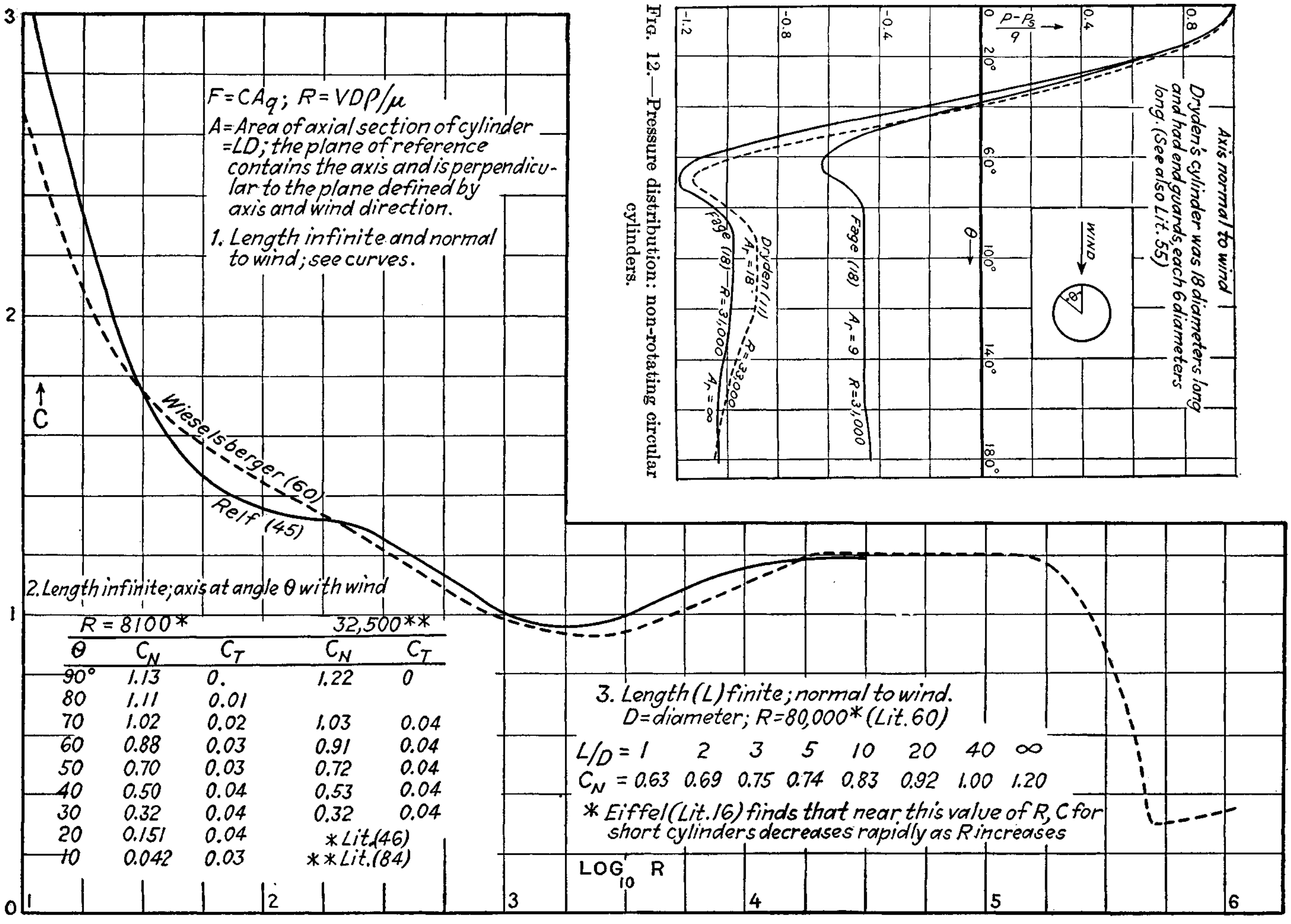
Airfoils.—Aerodynamical characteristics are specified in the same manner as are those of plates. An airfoil's area and angle of attack are conventionally defined with reference to some specified plane. The area of the airfoil is defined as that of its normal projection upon this plane of reference. The length (c) of the projection upon this plane of any fore-and-aft section of the airfoil is called the chord of that section; it is the unit in terms of which all dimensions of that section are expressed. The form of the section is specified by the rectangular coordinates of points upon its boundary; the choice of axes is immaterial, although usually one axis is in the plane of reference. The aspect ratio (A_r) of the airfoil is defined as the ratio of length of span (S) to length of the chord. In addition to the coefficients considered for plates, the moment coefficient $C_M = M/(qAc)$, and the lift-drag ratio (F_l/F_d) are also of importance.

Data are usually given for $A_r = 6$. If $A_r > 3$, then for a given C_l, $\theta_A = \theta'_A + C_l/\pi A_r$ radians, and $C_d = C'_d + C^2_l/\pi A_r$; θ'_A and C'_d are values of θ_A and C_d when $A_r = \infty$; $C_l/\pi A_r$ and $C^2_l/\pi A_r$ are called the induced angle of attack and the induced coefficient of drag, respectively (25, 26, 42, 72).

For airfoils, C_l increases slightly, and C_d decreases very appreciably, as R is increased; C_{cp} remains unchanged. The difference between the values of the coefficients for airfoils of the size used on aircraft and those for models of the size generally employed in laboratory tests, depends upon the form of the airfoil; for a thin, low cambered section (*RAF* 15), it is small; for a highly cambered section, it is large.

For the effects produced by placing one airfoil near another, as in a biplane combination see (26, 27, 36, 42, 74).

For a complete airplane, the drag introduced by the body, and the moment of tail lift, both vary appreciably with the size of the airplane (6, 67, 73).



$F = CAq$; $R = VD\rho/\mu$

A = Area of axial section of cylinder = LD; the plane of reference contains the axis and is perpendicular to the plane defined by axis and wind direction.

1. Length infinite and normal to wind; see curves.

2. Length infinite; axis at angle θ with wind

	R = 8100*		32,500**	
θ	C_N	C_T	C_N	C_T
90°	1.13	0.	1.22	0
80	1.11	0.01		
70	1.02	0.02	1.03	0.04
60	0.88	0.03	0.91	0.04
50	0.70	0.03	0.72	0.04
40	0.50	0.04	0.53	0.04
30	0.32	0.04	0.32	0.04
20	0.151	0.04		
10	0.042	0.03		

* Lit. (46)
** Lit. (84)

3. Length (L) finite; normal to wind.
D = diameter; R = 80,000* (Lit. 60)

L/D =	1	2	3	5	10	20	40	∞
C_N =	0.63	0.69	0.75	0.74	0.83	0.92	1.00	1.20

* Eiffel (Lit. 16) finds that near this value of R, C for short cylinders decreases rapidly as R increases

FIG. 11.—Air force: non-rotating circular cylinders.

FIG. 12.—Pressure distribution: non-rotating circular cylinders.

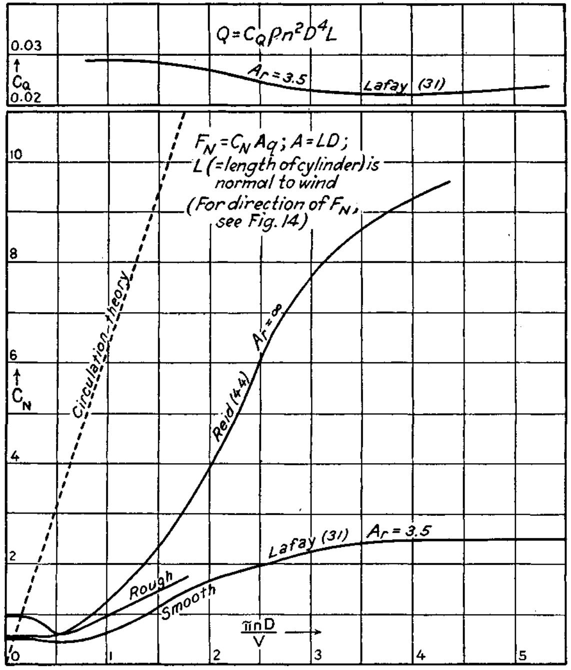


FIG. 13.—Air force: rotating circular cylinders (Magnus effect).

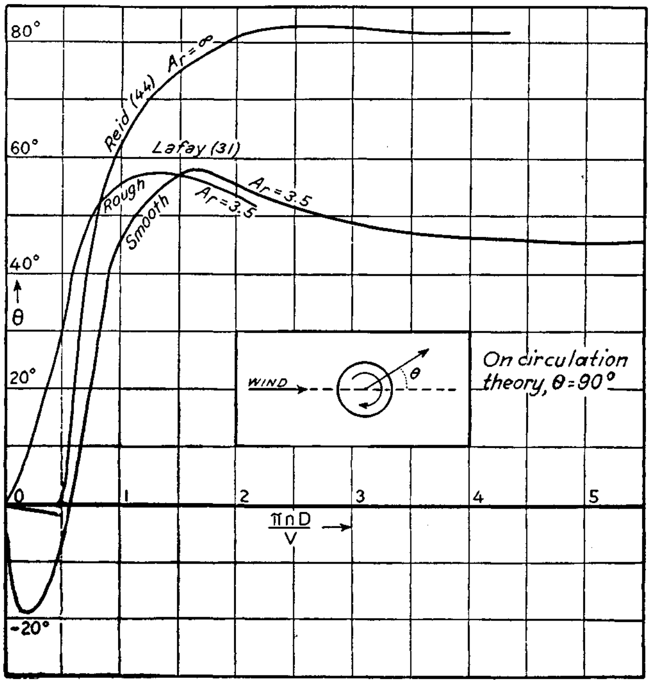


FIG. 14.—Direction of air force: rotating circular cylinders (Magnus effect).

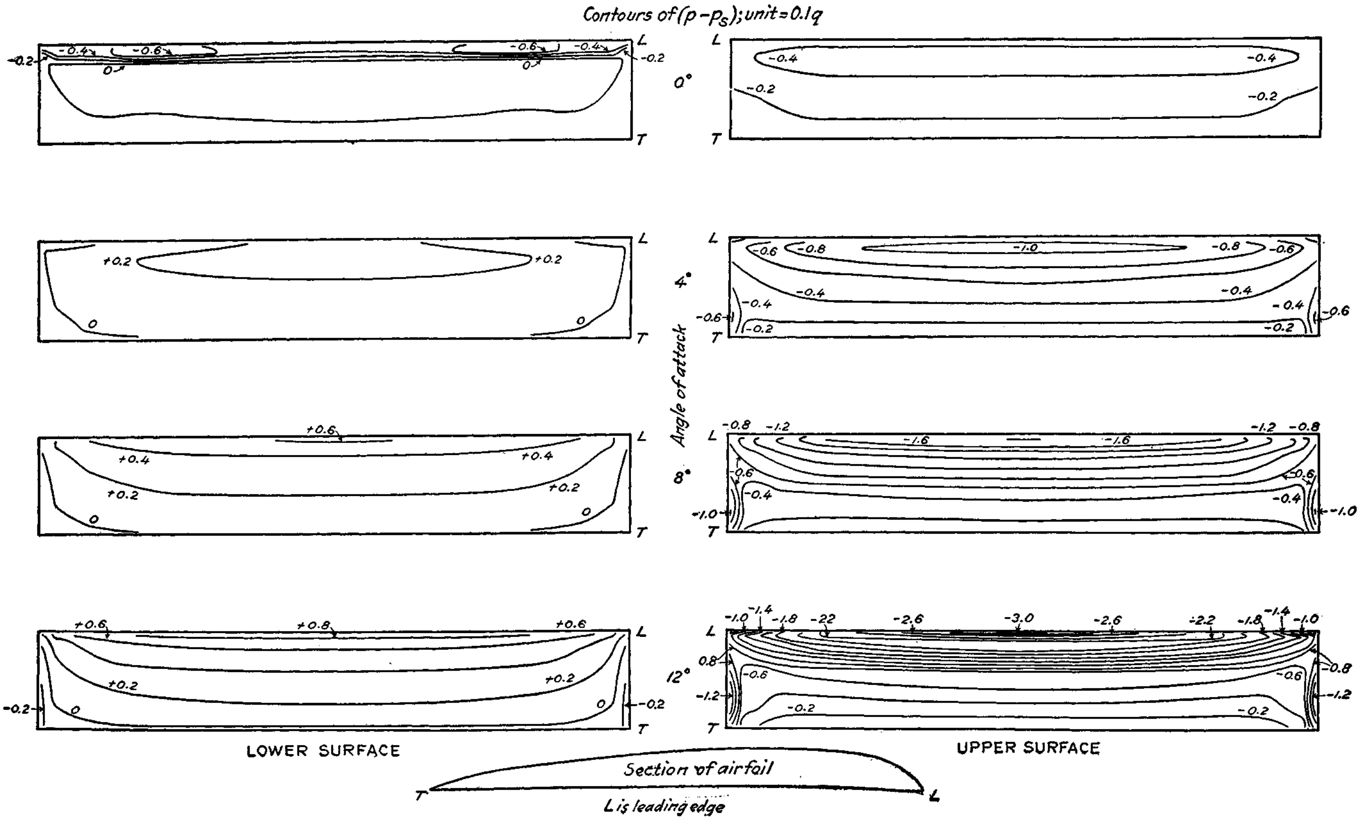
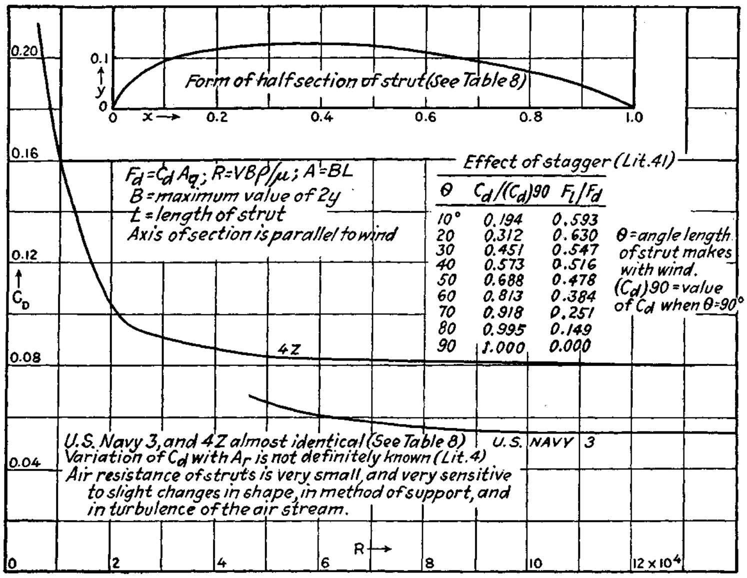


FIG. 15.—Pressure distribution: airfoil (30).



Effect of stagger (Lit. 41)

θ	$C_d/(C_d)90$	F_l/F_d
10°	0.194	0.593
20	0.312	0.630
30	0.451	0.547
40	0.573	0.516
50	0.688	0.478
60	0.813	0.384
70	0.918	0.251
80	0.995	0.149
90	1.000	0.000

FIG. 16.—Air force on long struts (40, 64, 78, 79).

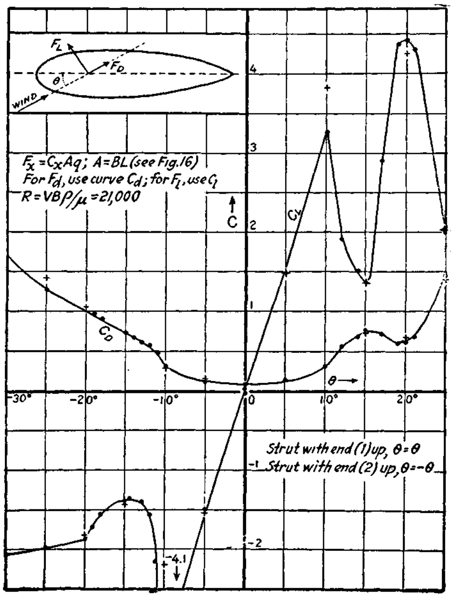


FIG. 17.—Air force on strut 4Z: inclined (85), see also (4).

TABLE 7.—CHARACTERISTICS OF AIRFOIL SECTIONS

$A_r = 6$; model 36 in. by 6 in.; $V = 40$ mi./hr; $R(= \rho Vc/\mu) = 181\,000$; tunnel diameter = 7.5 ft. (57). θ_A is measured from reference plane AB (see Figs. 22, 23, 24); x and y are rectangular coordinates of points on surface of airfoil (y_u, y_l refer to upper and lower surface, respectively); x is measured in plane AB. Unit of x and of y is 1% of chord. For additional data for these and other sections see (12, 13, 14, 34, 37, 68, 69, 70, 73, 80, 81).

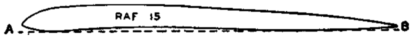
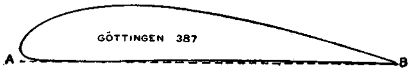
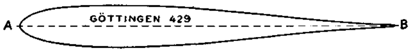
Form			Aerodynamical characteristics					
x	y_u	y_l	θ_A	C_l	C_d	F_l/F_d	x_c/c	C_M
0.00	0.30	+0.30						
1.25	1.90	−0.35	FIG. 22.					
2.50	2.85	−0.70	−4°	−0.18	0.025	−7.3	—	—
5.00	3.95	−1.05	−2°	−0.04	0.014	−2.8	—	—
7.50	4.65	−1.15	−1°	+0.03	0.013	+2.6	0.966	0.029
10.00	5.05	−1.20	0°	0.14	0.013	10.7	0.479	0.067
15.00	5.55	−0.85	1°	0.24	0.013	18.8	0.407	0.098
20.00	5.78	−0.55	2°	0.32	0.016	20.0	0.367	0.117
30.00	5.80	−0.10	4°	0.46	0.023	20.0	0.321	0.148
40.00	5.60	−0.03	6°	0.61	0.033	18.4	0.302	0.185
50.00	5.23	−0.24	8°	0.76	0.047	16.2	0.297	0.228
60.00	4.65	−0.50	10°	0.89	0.061	14.7	0.288	0.260
70.00	4.05	−0.65	12°	1.00	0.083	12.1	0.281	0.286
80.00	3.30	−0.65	14°	1.02	0.124	8.2	0.298	0.313
90.00	2.30	−0.30						
95.00	1.68	0.00						
100.00	0.65	+0.34						
0.00	0.00	0.00						
1.25	2.02	−1.65						
2.50	2.71	−2.45						
5.00	3.67	−3.46	FIG. 23.					
7.50	4.47	−4.10	−4°	−0.26	0.014	—	—	—
10.00	4.95	−4.57	−2°	−0.10	0.012	−8.8	—	—
15.00	5.37	−5.27	0°	+0.04	0.013	+3.1	0.197	0.008
20.00	5.69	−5.58	2°	0.18	0.015	12.4	0.224	0.040
30.00	5.69	−5.69	4°	0.33	0.020	17.2	0.229	0.076
40.00	5.32	−5.27	6°	0.50	0.028	17.5	0.241	0.121
50.00	4.68	−4.52	8°	0.65	0.040	16.2	0.242	0.159
60.00	3.72	−3.56	10°	0.78	0.054	14.6	0.244	0.193
70.00	2.61	−2.39	12°	0.88	0.076	11.6	0.246	0.220
80.00	1.60	−1.44	14°	0.73	0.170	4.3	0.234	0.181
90.00	0.69	−0.74	16°	0.70	0.239	2.9	0.382	0.293
95.00	0.37	−0.43						
100.00	0.16	−0.16						
								
0.00	3.61	3.61						
1.25	6.74	1.35	FIG. 24.					
2.50	7.98	0.80	−8°	−0.07	0.071	−0.9	—	—
5.00	9.86	0.35	−6°	+0.08	0.031	+2.6	1.410	0.109
7.50	11.32	0.18	−4°	0.22	0.024	9.4	0.684	0.150
10.00	12.40	0.09	−2°	0.37	0.026	14.3	0.507	0.188
15.00	13.83	0.00	0°	0.51	0.031	16.4	0.436	0.222
20.00	14.77	0.07	2°	0.66	0.039	16.9	0.396	0.261
30.00	15.36	0.21	4°	0.81	0.051	15.9	0.369	0.300
40.00	14.88	0.37	6°	0.96	0.067	14.3	0.348	0.336
50.00	13.47	0.54	8°	1.10	0.084	13.0	0.337	0.374
60.00	11.59	0.54	10°	1.23	0.104	11.8	0.323	0.403
70.00	9.27	0.54	12°	1.33	0.125	10.6	0.307	0.416
80.00	6.57	0.49	14°	1.42	0.148	9.6	0.312	0.454
90.00	3.61	0.27	16°	1.43	0.182	7.9	0.315	0.466
95.00	1.99	0.16	18°	1.42	0.213	6.7	0.327	0.486
100.00	0.36	0.00	20°	1.41	—	—		

TABLE 8.—FORM OF STRUTS; U. S. NAVY 3, BRITISH 4Z

(See Fig. 16) (These struts give as small a C_d as any)
Unit = axial length of section

x	$2y$		x	$2y$		x	$2y$	
	U.S.N. 3	4Z		U.S.N. 3	4Z		U.S.N. 3	4Z
0	0	0	0.250	0.240		0.700	0.184	0.182
0.025	0.092		0.300	0.247	0.250	0.750	0.164	
0.050	0.132	0.122	0.350	0.250		0.800	0.142	0.142
0.075	0.159		0.400	0.250	0.246	0.850	0.116	
0.100	0.180	0.182	0.450	0.250		0.900	0.085	0.094
0.125	0.197		0.500	0.240	0.234	0.950	0.049	
0.150	0.210		0.550	0.230		1.000	0.000	0.000
0.175	0.220		0.600	0.215	0.212			
0.200	0.229	0.240	0.650	0.201				

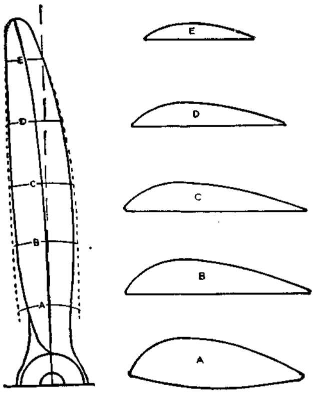


FIG. 18.—Durand's $F_2A_1S_1P_1$ propeller family. Pitch ratio constant. (Members differ only in pitch ratio.)

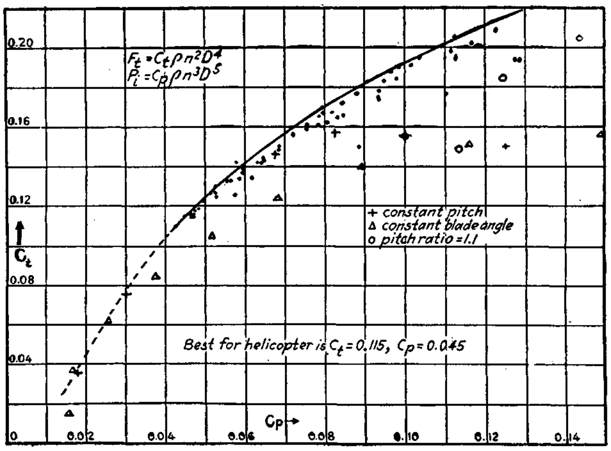


FIG. 19.—Characteristics of Durand propellers at a fixed point (8, 10).

Elongated stream-line solids of revolution have a small resultant drag, which varies greatly with turbulence of air stream, position of neighboring bodies, and slight changes in form. The area entering into the expression $F = CAq$, is generally taken either as the area of maximum section normal to the length, or as $(\text{volume})^{2/3}$. C varies with the Reynold's number. When $A = (\text{volume})^{2/3}$, the minimum value of C for large values of R, and for bodies which are 4 to 5 diameters long, is of the order of 0.014. When A = sectional area, the minimum value of C is of the order 0.03, and is obtained with bodies shorter than 4 diameters. Their equilibrium when parallel to the air stream is unstable; adding fins gives stability and greatly increases their drag (23, 35, 39).

Propellers.—Propellers are usually divided into families in which pitch-ratio and diameter are the only variables. Blade thickness and outline are usually determined largely by structural considerations; if the average thickness and width of blade are fixed, other variations have small effect upon attainable efficiency (**8, 9, 15, 19, 65, 66, 71, 76, 77**).

The characteristics of a propeller working at a fixed point may be expressed by two dimensionless coefficients, C_t and C_P, defined by the equations $F_t = C_t\rho n^2D^4$ and $P_i = C_P\rho n^3D^5$. For most propellers, there is, between C_t and C_P, a functional relation which is nearly independent of the design, provided large blade angles are not used (**33**). In Fig. 19, the curve indicates the most favorable results; marked departures from the curve occur mainly with propellers of high pitch ratio, or of constant blade angle.

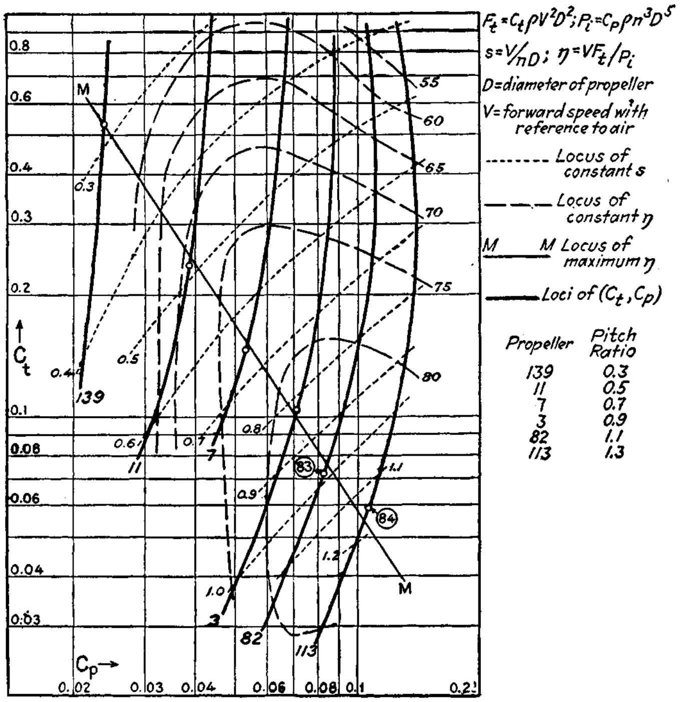


Fig. 20.—Characteristics of advancing Durand $F_2A_1S_1P_1$ propeller family (9).

The characteristics of propellers at various forward speeds (V) and speeds of rotation may be expressed by curves showing the relationships between three parameters. In Fig. 20, the parameters used are C_t, C_P, and s or η, defined by the equation $F_t = C_t\rho V^2D^2$, $P_i = C_P\rho n^3D^5$, $s = V/Dn$; $\eta = C_ts^3/C_P$, and D = diameter of the propeller. Useful range of C_t is 0.05 to 0.25; of C_P is 0.04 to 0.16. Data given are for propellers of two blades; increasing the number of blades, displaces the curves upwards and to the right.

Wind mills.—Quite different principles control the designing of wind mills which derive power from natural winds, and of those (such as the small wind mills used on airplanes for driving fuel pumps, etc.) which derive their power from the motion of a power driven craft. In the former, the controlling factor is the cost per unit of power developed; in the latter, it is the power consumed per unit of power, or torque load, developed.

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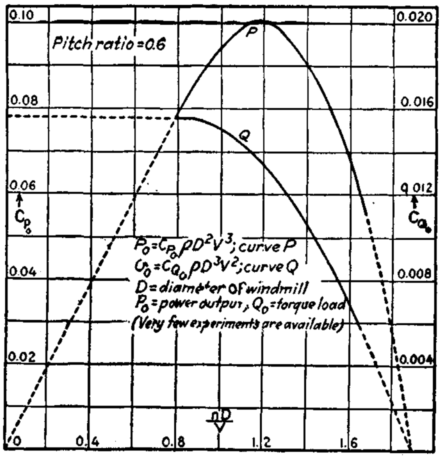

Fig. 21.—Characteristics of two blade windmill (17).

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INTERNATIONAL CRITICAL TABLES

STRENGTH AND RELATED PROPERTIES OF WOODS

Column Headings	Entêtes des Colonnes	Kopftitel	Titoli delle Colonne
Index number.	Nombre index.	Index Nummer.	Numeri indice.
Botanical name.	Nom botanique.	Botanischer Name.	Nome botanico.
Family; genus and species.	Famille; genres et espèces.	Familie; Genus und Art.	Famiglia; genere e specie.
Common name.	Nom commun.	Gebräuchlicher Name.	Nome comune.
Place of growth of material tested.	Lieu où a poussé le matériel soumis aux essais.	Ort an dem das untersuchte Material gewachsen ist.	Luogo di origine del materiale esaminato.
Seasoning condition.	Condition de séchage à l'air.	Trocknungsbedingungen.	Condizione di stagionatura.
Bulk density of wood substance; oven-dry weight divided by volume in condition stated.	Densité apparente du bois; poids du bois séché au four divisé par le volume dans la condition spécifiée.	Raumgewicht des Holzes; Gewicht nach der Ofentrocknung dividiert durch das Volumen im angegebenem Zustand.	Densità della sostanza legnosa: peso dopo seccata al forno diviso per il volume nella condizione stabilita.
Bulk density of piece; weight of sample divided by its volume in condition stated.	Densité apparente de la pièce; poids de l'éprouvette divisé par son volume dans la condition spécifiée.	Raumgewicht des Stückes: Gewicht der Probe dividiert durch das Volumen im angegebenem Zustand.	Densità del pezzo: peso del campione diviso per il suo volume nella condizione stabilita.
Oven-dry.	Séché au four.	Ofen trocken.	Seccato al forno.
Green.	Vert.	Frisch (grün).	Verde.
Air-dry.	Séché à l'air.	Luft trocken.	Seccato all'aria.
Moisture content.	Teneur en humidité.	Feuchtigkeitsgehalt.	Contenuto di umidità.
Shrinkage from green to oven-dry condition.	Retrait à partir du bois vert lorsque séché au four.	Schwinden vom frischen bis zum Ofen trockenem Zustand.	Contrazione dallo stato verde a quello di essiccamento nel forno.
Static and impact bending; compression parallel or perpendicular to grain.	Essai de flexion statique et au choc; compression parallèle et perpendiculaire à la fibre.	Statische und dynamische Biegefestigkeit; Druck parallel oder senkrecht zur Faser.	Incurvamento alla flessione statica e all'urto; compressione parallela o perpendicolare alla vena del legno.
Fiber stress at elastic limit.	Tension de la fibre à la limite élastique.	Faserspannung an der Elastizitätsgrenze.	Trazione della fibra al limite di elasticità.
Modulus of rupture.	Module de rupture.	Bruchfestigkeit.	Modulo di rottura.
Modulus of elasticity.	Module d'élasticité.	Elastizitätsmodulus.	Modulo di elasticità.
Work to elastic limit.	Travail jusqu'à la limite élastique.	Arbeit bis zur Elastizitätsgrenze.	Lavoro fino al limite di elasticità.
Work to maximum load.	Travail jusqu'à charge maximum.	Arbeit bis zur Höchstlast.	Lavoro fino al carico massimo.
Total work.	Travail total.	Gesamtarbeit.	Lavoro totale.
Height of drop causing complete failure.	Hauteur de chute occasionnant une rupture complète.	Fallhöhe die zum vollkommenem Bruch führt.	Altezza del peso causante completa rottura.
Maximum crushing strength.	Résistance maximum à l'écrasement.	Schlagfestigkeit.	Massima forza schiacciante.
Shear; tension perpendicular to grain; hardness; cleavage.	Cisaillement tension perpendiculaire à la fibre; dureté; clivage.	Scherung; Druck senkrecht zur Faser; Härte; Spaltbarkeit.	Taglio; tensione perpendicolare alla vena; durezza; fendimento.

I. NORTH AMER-

UNITED STATES FOREST

The following data on certain woods of North America are based on an extensive series of tests of small specimens free of defects. All the tests were conducted under a uniform procedure, so that the results are strictly comparable. Analysis of the test figures has made it possible to establish definite density-strength relations, which are represented by the equations given in the first section of the table (Table 1). These equations are all of the parabolic type, the degree being determined to the nearest quarter-unit. By substituting the appropriate specific gravity for a given species (columns 8 and 9) in the equation for any property, the value of the corresponding property may be obtained.

In most species, however, there is a very considerable departure of average test results from the general equation values, although very few species, thus far investigated, are either wholly above or wholly below normal, all properties considered. Since the deviation of a property from the normal value as determined by the equation often indicates the special fitness or unfitness of the species for a particular use, it becomes necessary to supplement the equations with departure factors, for the properties of each species. Such factors, expressed as *percentages* and listed in order below the respective equations, make up the second part of Table 1. By multiplying the value, F, computed by the equation, by the proper correction factor, the actual average value for the property and species in question may be determined.

Example: To find the modulus of rupture of air-dried shagbark hickory. The finding list shows this to be No. 62, *Hicoria ovata.* From the equation of column 15 we find $F = 18.1\ D_d^{1.25}$. For No. 62 we find (column 9) $D_d = 0.724$ and (column 15) correction factor = 119 %, whence

$$F = 1.19 \times 18.1 \times (0.724)^{1.25} = 14.4 \text{ kg/mm}^2 = 14.4 \times 1422 = 20\,500 \text{ lb./in.}^2$$

The test methods that were used conform to Tentative Standard D143-24T of the American Society for Testing Materials, as set forth in *Proc. A. S. T. M.* 939; 24. (General description in U. S. Dept. Agr., *Bull.* No. 556.) The principal data relating to the procedure for each kind of test are summarized as follows:

Shrinkage in Volume.—Specimen 5.08 × 5.08 × 15.24 cm (2 × 2 × 6 in.). Volume determined when green (unseasoned) and after oven-drying to constant weight at 100°C. Specimens thoroughly air-seasoned prior to drying in oven.

Shrinkage, Radial and Tangential.—Specimen 2.54 × 10.16 × 2.54 cm (1 × 4 × 1 in.). Width measured when green (unseasoned) and after oven-drying to constant weight at 100°C. Specimens thoroughly air-seasoned prior to drying in oven.

Static Bending.—Specimen 5.08 × 5.08 × 76.20 cm (2 × 2 × 30 in.). Center loading, 71.12 cm (28 in.) span. Load applied by testing machine head moving 0.254 cm (0.10 in.) per min. Total work is defined as that obtained by continuing the test until either a 15.24 cm (6 in.) deflection is reached or the load falls to 90.7 kg (200 lb.) or less.

Impact Bending.—Specimen and span as above. 22.7 kg (50 lb.) hammer dropped first from 2.54 cm (1 in.) height, next from 5.08 cm (2 in.) height, etc., up to 25.4 cm (10 in.), then from height increments of 5.08 cm (2 in.) until failure.

Compression Parallel to Grain.—Specimen 5.08 × 5.08 × 20.32 cm (2 × 2 × 8 in.). End load, testing machine head moving 0.061 cm (0.024 in.) per min.

Les données indiquées ici, relatives à certains bois de l'Amérique du Nord, sont basées sur une série d'expériences faites sur de petites éprouvettes exemptes de défauts. Tous les essais ayant été effectués suivant une procédure uniforme, les résultats sont donc strictement comparables. L'analyse des chiffres obtenus aux essais a permis d'établir des relations définies entre la densité et la résistance, qui sont représentées par les équations inscrites dans la première section de la table (Table 1). Ces équations sont toutes du type parabolique, le degré étant déterminé au quart d'unité le plus proche. En substituant le poids spécifique approprié pour une espèce donnée (colonnes 8 et 9) dans l'équation relative à une propriété donnée, on peut obtenir la valeur correspondante de la propriété.

Cependant pour la plupart des espèces il y a un écart considérable entre les résultats moyens des essais et les valeurs déduites de l'équation générale; pour autant que les expériences effectuées l'ont démontré, il n'y a qu'un petit nombre d'espèces qui sont, ou en entier au-dessus ou en entier au-dessous de la normale pour toutes les propriétés considérées. Comme l'écart d'une propriété de la valeur normale, ainsi qu'elle est déterminée par l'équation, indique souvent la convenance spéciale de l'espèce pour un usage particulier, ou sa non-convenance, il est nécessaire de compléter les équations par des facteurs de correction pour les propriétés de chaque espèce. Ces facteurs, exprimés en pourcentage et inscrits dans l'ordre au-dessous des équations respectives, constituent la deuxième partie de la Table 1. En multipliant la valeur F calculée au moyen de l'équation par le facteur de correction convenable, on peut déterminer la valeur moyenne de la propriété de l'espèce en question.

Exemple: Soit à déterminer le module de rupture du "shagbark hickory" séché à l'air. La liste de recherches montre qu'il s'agit du No. 62 *Hicoria ovata.* De l'équation de la colonne 15 on trouve $F = 18{,}1\ D_d^{1{,}25}$. On trouve pour le No. 62 (colonne 9) $D_d = 0{,}724$ et (colonne 15) le facteur de correction = 119 %, d'où

$$F = 1{,}19 \times 18{,}1 \times (0{,}724)^{1{,}25} = 14{,}4 \text{ kg/mm}^2 = 14{,}4 \times 1\,422 = 20\,500 \text{ lb./in.}^2$$

Les méthodes d'essais qui ont été utilisées sont conformes à l'examen type D143-24T de la société américaine pour l'essai des matériaux, ainsi qu'elles sont décrites dans *Proc. A. S. T. M.* 939: 24 (*cf.* U. S. Dept. Agr. *Bull.* 556). Les données principales relatives à la procédure pour chaque sorte d'essai sont rassemblées ci-dessous:

Retrait en volume.—Eprouvette 5,08 × 5,08 × 15,24 cm (2 × 2 × 6 pouces). Le volume est déterminé lorsque le bois est vert, puis, après séchage à poids constant au four à 100°C. Avant le séchage au four, les éprouvettes sont complètement séchées à l'air.

Retrait radial et tangentiel.—Eprouvette 2,54 × 10,16 × 2,54 cm (1 × 4 × 1 pouce). La largeur est mesurée sur le bois vert et après séchage à poids constant, au four à 100°C. Avant le séchage au four, les éprouvettes sont complètement séchées à l'air.

Essai de flexion statique.—Eprouvette 5,08 × 5,08 × 76,20 cm (2 × 2 × 30 pouces); charge centrale; portée 71,12 cm (28 pouces). La charge est appliquée par une machine à essai dont la pièce mobile se déplace de 0,254 cm (0,10 pouces) à la minute. Le travail total est défini par celui qu'on obtient en continuant l'essai jusqu'à ce qu'une flèche de 15,25 cm soit obtenue, ou que la charge tombe à 90,7 kg (200 lb.) ou moins.

ICAN WOODS

PRODUCTS LABORATORY

Die hier angegebenen Werte bestimmter nordamerikanischer Hölzer ergeben sich aus einer ausgedehnten Serie von Prüfungen an einer kleinen Zahl von fehlerfreien Arten. Alle Prüfungen sind bei einheitlichem Vorgange ausgeführt worden, so, dass sie direkt vergleichbar sind. Die Analysen der Zahlenwerte der Prüfungsergebnisse machten es möglich gewisse Beziehungen zwischen Dichte und Festigkeit aufzustellen, die durch Gleichungen im ersten Abschnitt der Tafel 1 wiedergegeben sind. Diese Gleichungen sind alle vom parabolischen Typus, der Exponent in der Gleichung ist auf die nächste Viertel-Einheit bestimmt. Durch Einsetzung des entsprechenden spezifischen Gewichtes für eine bestimmte Art (Reihe 8 und 9) in die Gleichung für ihrgend eine Eigenschaft, erhält man den Wert für die entsprechende Eigenschaft.

Bei vielen Arten jedoch ist eine bemerkenswerte Abweichung des durchschnittlichen Wertes des Prüfungsergebnisses von dem Werte, der sich aus der allgemeinen Gleichung ergibt, vorhanden. Es gibt indessen nur sehr wenige Arten, so weit untersucht, deren berücksichtigten Eigenschaften zur Gänze entweder über oder unter dem normalen Werten liegen. Da die Abweichung einer Eigenschaft, von dem durch die Gleichung erhaltenen Wert, häufig die besondere Eignung oder Nichteignung einer Art für eine besondere Verwendung anzeigt, wird es notwendig, für die Eigenschaft jeder einzelnen Art die Gleichung durch einen Abweichungsfaktor zu ergänzen. Solche Faktoren, in *Prozenten* ausgedrückt, befinden sich geordnet unter den entsprechenden Gleichungen und machen den zweiten Teil der Tafel 1 aus. Durch Multiplikation des Wertes F, der nach der Gleichung gefunden ist, mit dem eigenen Korrektionsfaktor, erhält man richtige Mittelwerte für die Eigenschaft des fraglichen Musters.

Beispiel: Es ist die Bruchfestigkeit von lufttrockenem Hykorynussbaum zu finden. Die Nachschlagsliste zeigt, dass dies No. 62 *Hicoria ovata* ist. Aus der Gleichung der Reihe 15 findet man $F = 18{,}1\ D_d^{1{,}25}$. Für No. 62 findet man (Reihe 9) $D_d = 0{,}724$ und (Reihe 15) den Korrektionsfaktor = 119%, mithin

$$F = 1{,}19 \times 18{,}1 \times (0{,}724)^{1{,}25} = 14{,}4\ \text{kg/mm}^2$$

Die angewandten Prüfungsmethoden entsprechen der Standard Prüfung D143-24T der American Society for Testing Materials, wie es in *Proc. A. S. T. M.* 939; 24 (*cf.* U. S. Dep. Agr. *Bull.* 556) mitgeteilt wird. Die hauptsächlichsten Angaben, die den Vorgang bei jeder besonderen Prüfung bezeichnen, sind zusammengestellt, die folgenden:

Volumabnahme (Schwindung).—Muster 5,08 × 5,08 × 15,24 cm. Das Volumen wurde in unausgetrocknetem Zustande und dann nach der Trocknung im Ofen bei 100°C, bis zum konstantem Gewicht bestimmt. Die Proben waren vor der Ofentrocknung vollständig lufttrocken.

Volumabnahme, tangential und radial.—Muster 2,54 × 10,16 × 2,54 cm. Die Masse sind im ungetrocknetem Zustande abgenommen und dann nach der Ofentrocknung bei 100°C, bis zum konstantem Gewicht bestimmt. Die Proben waren vor der Ofentrocknung vollständig lufttrocken.

Statischer Biegeversuch.—Muster 5,08 × 5,08 × 76,20 cm, Mittelbelastung, 71,12 cm Spannweite, Belastung durch eine Festigkeitsmaschine, derart, dass die Durchbiegung 0,254 cm in der Minute beträgt. Die gesammt Arbeit ist diejenige, die bei

I valori qui riportati per certi legni dell'America del Nord sono il risultato di una estesa serie di prove eseguite sopra un piccolo numero di specie senza difetti. Tutti i saggi sono stati condotti con lo stesso metodo, per modo che i risultati sono strettamente confrontabili. L'esame dei valori numerici ha permesso di stabilire alcune relazioni fra densitá e resistenza, le quali sono rappresentate dalle equazioni riprodotte nella prima parte della tabella (Tabella 1). Queste equazioni sono tutte di tipo parabolico, e il grado è determinato con l'approssimazione del quarto dell'unità.

Introducendo nell'equazione per una data proprietà il peso specifico di una determinata specie (colonne 8 e 9) si ottiene il valore della proprietà corrispondente.

In molte specie la media dei risultati dei saggi scarta notevolmente dai valori che si ottengono dall'equazione generale; solo in poche però, tutti i valori sono sempre al di sopra e sempre al di sotto dei normali.

Siccome lo scarto di una proprietà dal valore risultante dall' equazione sta spesso ad indicare se una specie è adatta o no ad uno speciale impiego, è necessario completare le equazioni con dei fattori di correzione per le proprietà di ogni specie. Questi fattori, espressi in percento, sono riportati sotto le equazioni corrispondenti e costituiscono la seconda parte della Tabella 1. Moltiplicando il valore F dato dall'equazione per il rispettivo fattore di correzione, si ottengono valori medi esatti per la proprietà del campione in questione.

Esempio: Si debba trovare la resistenza alla rottura dello "shagbark hickory" seccato all'aria. Dall'elenco di riferimento si ricava che si tratta del No. 62, *Hicoria ovata.* Dall'equazione della colonna 15 si ha $F = 18{,}1\ D_d^{1{,}25}$. Per il No. 62 si trova $D_d = 0{,}724$ (colonna 9) e come fattore di correzione 119% (colonna 15), per modo che si ha

$$F = 1{,}19 \times 18{,}1 \times (0{,}724)^{1{,}25} = 14{,}4\ \text{kg/mm}^2$$

I metodi di prova adoperati corrispondono alle norme D143-24T della American Society for Testing Materials, quali si trovano indicate nei *Proc. A. S. T. M.* 939; 24 (*v.* U. S. Dep. Agr. *Bull.* 556). Le indicazioni principali riferentisi a ogni specie di saggio sono le seguenti:

Contrazione di volume.—Dimensioni della provetta 5,08 × 5,08 × 15,24 cm. Il volume viene determinato su legno non stagionato e su legno seccato in forno a 100°C fino a costanza di peso. I provini vengono seccati completamente all'aria prima che nel forno.

Diminuzione di volume, tangenziale e radiale.—Dimensioni della provetta 2,54 × 10,16 × 2,54 cm. La larghezza viene misurata su legno non stagionato e su legno seccato in forno a 100°C fino a costanza di peso. Le provette vengono seccate completamente all'aria prima che nel forno.

Flessione statica.—Dimensioni della provetta 5,08 × 5,08 × 76,20 cm. Carico centrale, distanza tra gli appoggi 71,12 cm. Il carico viene applicato con una macchina di prova in modo che la freccia di incurvamento cresca con la velocità di 0,254 cm al minuto. Il lavoro totale è quello che si ottiene prolungando il saggio finchè o si raggiunge una freccia di 15,24 cm o il carico si abbassa a 90,7 kg o meno.

Compression Perpendicular to Grain.—Specimen 5.08 × 5.08 × 15.24 cm (2 × 2 × 6 in.). Load applied to side through a steel plate 5.08 cm (2 in.) wide laid across center of piece and at right angles to its length, ⅓ of surface being thus directly subjected to compression; testing machine head moving 0.061 cm (0.024 in.) per min.

Shear Parallel to Grain.—Specimen 5.08 × 5.08 × 6.35 cm (2 × 2 × 2.5 in.). Undercut at one end to permit shear over area 5.08 × 5.08 cm (2 × 2 in.); testing machine head moving 0.038 cm (0.015 in.) per min.

Tension Perpendicular to Grain.—Specimen as above. Transverse recess bored at each end to permit gripping for tension over 5.08 × 2.54 cm (2 × 1 in.) area; testing machine head moving 0.635 cm (0.25 in.) per min.

Hardness.—Specimen 5.08 × 5.08 × 15.24 cm (2 × 2 × 6 in.). Load required to embed a steel ball having a maximum cross-sectional area of 1 cm^2 to ½ its diam.; testing machine head moving 0.635 cm (0.25 in.) per minute.

Cleavage Parallel to Grain.—Specimen 5.08 × 5.08 × 9.525 cm (2 × 2 × 3¾ in.). Transverse recess bored at one end to permit gripping for cleavage of specimen over 5.08 cm (2 in.) width and along a 7.62 cm (3 in.) length; testing machine head moving 0.635 cm (0.25 in.) per min.

Conversion Factors

Multiply	By	To obtain
Kg per mm^2	1422	lb. per in.^{2}
Kg-mm per mm^3	1422	in.-lb. per in.^{3}
Meters	39.37	in.
Kg	2.205	lb.
Kg per mm of width	56	lb. per in. of width

WOODS OF THE PHILIPPINE ISLANDS

The Bureau of Forestry and the Bureau of Science of the Philippine Islands

Introduction

Density and strength values for five woods of commerce have been determined. The testing methods used and manner of displaying the results are identical with those used by the U. S. Forest Products Laboratory and the results have therefore been incorporated at the end of Table 1 below.

CANADIAN WOODS

A number of the species listed in Table 1 below have also been tested by the Canadian Forest Products Laboratory, using samples obtained from trees grown in Canada. As far as can be definitely determined, these woods are substantially the same in properties as like species grown in the United States.

Essai de flexion par choc.—Eprouvette et portée comme ci-dessus. Un marteau de 22,7 kg (50 lb.) tombe premièrement d'une hauteur de 2,54 cm (1 pouce), ensuite de 5,08 cm (2 pouces) de haut, etc., jusqu'à 25,4 cm (10 pouces), ensuite par augmentations successives de hauteur de 5,08 cm (2 pouces) jusqu'à rupture.

Compression parallèle à la fibre.—Eprouvette 5,08 × 5,08 × 20,32 cm (2 × 2 × 8 pouces). Charge finale, machine à essai dont la pièce mobile se déplace de 0,061 cm par minute.

Compression perpendiculaire à la fibre.—Eprouvette 5,08 × 5,08 × 15,24 cm (2 × 2 × 6 pouces). Charge appliquée sur le côté par l'intermédiaire d'une plaque d'acier de 5,08 cm de largeur disposée au milieu de la pièce et normalement à sa longueur, de façon que ⅓ de la surface soit soumis à la compression; machine à essai dont la pièce mobile se déplace de 0,061 cm (0,024 pouce) par minute.

Cisaillement parallèle à la fibre.—Eprouvette 5,08 × 5,08 × 6,35 cm (2 × 2 × 2½ pouce). Ecrénée à une extrémité pour permettre le cisaillement sur une surface de 5,08 × 5,08 cm (2 × 2 pouces); machine à essai dont la pièce mobile se déplace de 0,038 cm (0,015 pouce) par minute.

Traction perpendiculaire à la fibre.—Eprouvette comme ci-dessus. Niche transversale découpée à chaque extrémité de façon à permettre la traction sur une surface de 5,08 × 2,54 cm (2 × 1 pouce). Machine à essai dont la pièce mobile se déplace de 0,635 cm (0,25 pouce) par minute.

Dureté.—Eprouvette 5,08 × 5,08 × 15,24 cm (2 × 2 × 6 pouces). Charge nécessaire pour enfoncer une bille d'acier ayant une section maximum de 1 cm^2, de la moitié de son diamètre. Machine à essai dont la pièce mobile se déplace de 0,635 cm (0,25 pouce) par minute.

Clivage parallèle à la fibre.—Eprouvette 5,08 × 5,08 × 9,525 cm (2 × 2 × 3¾ pouces). Niche transversale découpée à une extrémité de façon à permettre le clivage de l'éprouvette sur une largeur de 5,08 cm (2 pouces) et le long de 7,62 cm (3 pouces); machine à essai dont la pièce mobile se déplace de 0,635 cm (0,25 pouce) par minute.

BOIS DES ILES PHILIPPINES

Bureau de Sylviculture et Bureau de Science des Iles Philippines

Introduction

Les valeurs de densité et de résistance ont été déterminées pour cinq bois du commerce. Les méthodes d'essais utilisées, et la façon de disposer les résultats sont identiques à celles utilisées par le U. S. Forest Products Laboratory (voir ci-dessus); c'est pourquoi les résultats ont été incorporés à la fin de la Table 1.

BOIS CANADIENS

Un certain nombre d'espèces mentionnées au bas de la Table 1 ont aussi été essayées par le "Laboratoire des Produits Forestiers Canadiens" qui employa des échantillons provenant d'arbres ayant poussé au Canada. Pour autant qu'on peut le déterminer d'une façon définie, ces bois sont les mêmes, au point de vue de leurs propriétés, que ceux des mêmes espèces croissant aux États-Unis.

fortgesetzter Prüfung entweder eine 15,24 cm Durchbiegung erreicht, oder das Gewicht fällt auf 90,7 kg oder weniger.

Schlagbiegeversuch.—Muster und Grösse wie oben. Ein 22,7 kg Hammer fällt zuerst von 2,54 cm dann von 5,08 cm u. s. w. Höhe herunter, bis 25,4 cm, von hier an, in Höhenzunahmen um 5,08 cm bis zum Bruch.

Druckversuch parallel zur Faserrichtung.—Muster 5,08 × 5,08 × 20,32 cm. Endlast, Festigkeitsmaschine derart, dass Zusammendrückung in der Minute 0,061 cm beträgt.

Druck senkrecht zur Faserrichtung.—Muster 5,08 × 5,08 × 15,24 cm. Das Gewicht an die Seite drückt auf eine Stahlplatte von 5,08 cm Weite, die um die Mitte des Stückes in rechten Winkeln zu seiner Länge angelegt ist, wodurch ⅓ der Oberfläche dem Drucke ausgesetzt wird, derart, dass die Zusammendrückung 0,061 cm in der Minute beträgt.

Scherversuch, parallel zur Faserrichtung.—Muster 5,08 × 5,08 × 6,35 cm. An einem Ende unterschnitten, um eine Scherung über eine Fläche von 5,08 × 5,08 cm zu gestatten; Scherung 0,038 cm in der Minute.

Zugversuch senkrecht zur Faserrichtung.—Muster so wie oben. Kreuzweise an jedem Ende gebohrt um die Zugkraft auf eine Fläche von 5,08 × 2,54 cm wirken zu lassen. Zug der Maschine 0,635 cm in der Minute.

Härte.—Muster 5,08 × 5,08 × 15,24 cm. Das notwendige Gewicht um eine Stahlkugel von einem maximalen Querschnitt von 1 cm bis zur Hälfte seines Durchmessers einzudrücken. Bewegung der Maschine 0,635 cm in der Minute.

Spaltung parallel zur Faserrichtung.—Muster 5,08 × 5,08 × 9,525 cm. Kreuzweise an einem Ende gebohrt für die Fassung des Musters zur Spaltung über eine Weite von 5,08 cm und 7,62 cm der Länge nach. Spaltung 0,635 cm in der Minute.

HÖLZER DER PHILIPPINEN

The Bureau of Forestry and the Bureau of Science of the Philippine Islands

Einleitung

Dichte und Festigkeit von fünf Hölzern des Handels sind bestimmt worden. Die angewendeten Prüfungsmethoden und der Vorgang bei der Darstellung der Ergebnisse sind dieselben, welche von U. S. Forest Products Laboratory angewandt werden und schon oben verzeichnet sind. Es sind daher die Ergebnisse am Ende der Tafel 1 (unten) angegeben.

CANADISCHE HÖLZER

Eine Anzahl der in der Liste Tabelle 1 unten vorhandenen Arten sind ebenso vom Canadian Forest Products Laboratory untersucht worden, indem Proben von in Canada gewachsenen Bäumen, verwendet wurden. Soweit man ein abschliessendes Urteil abgeben kann, sind diese Hölzer im wesentlichen von gleicher Eigenschaft wie diejenigen, die in den Vereinigten Staaten gewachsen sind.

Flessione per urto.—Dimensioni come sopra. Un martello di 22,7 kg cade prima di una altezza di 2,54 cm, poi di 5,08 cm ecc. fino a 25,4 cm; da 25,4 in poi l'aumento di altezza è di 5,08 cm fino a rottura.

Compressione parallela alla fibra.—Dimensioni della provetta, 5,08 × 5,08 × 20,32 cm. Carico finale, spostamento della macchina 0,061 cm al minuto.

Compressione perpendicolare alla fibra.—Dimensioni della provetta 5,08 × 5,08 × 15,24 cm. Il carico è applicato lateralmente a mezzo di una piastra di acciaio di 5,08 cm di larghezza, e questa è disposta nel mezzo del pezzo ad angolo retto rispetto alla lunghezza, per modo che ⅓ della superficie viene sottoposta a pressione. Lo spostamento della macchina deve essere di 0,061 cm al minuto.

Taglio nel senso della fibra.—Dimensioni della provetta 5,08 × 5,08 × 6,35 cm. Adattato ad una estremità in maniera da permettere il taglio sopra un'area di 5,08 × 5,08 cm. Spostamento della macchina 0,038 cm al minuto.

Trazione perpendicolare al senso della fibra.—Dimensioni come sopra. Forato in croce ad ogni estremità per fare agire lo sforzo sopra una superficie di 5,08 × 2,54 cm. Spostamento della macchina 0,635 cm al minuto.

Durezza.—Dimensioni della provetta, 5,08 × 5,08 × 15,24 cm. Carico necessario per far penetrare fino a metà spessore una sfera di acciaio avente una sezione massima di 1 cm.^{2} Spostamento della macchina 0,635 cm al minuto.

Sfaldatura parallela alla fibra.—Dimensioni delle provette 5,08 × 5,08 × 9,525. Forato a croce ad una estremità per sollecitare la provetta allo scorrimento per una larghezza di 5,08 cm e una lunghezza di 7,62 cm. Spostamento della macchina 0,635 cm al minuto.

LEGNI DELLE FILIPPINE

The Bureau of Forestry and the Bureau of Science of the Philippine Islands

Introduzione

Sono state determinate densità e tenacità di cinque legni del commercio. I metodi di saggio adoperati e la rappresentazione dei risultati sono gli stessi impiegati dall' U. S. Forest Products Laboratory (*v.* sopra). I risultati sono stati perciò incorporati nella Tabella 1 e riportati in fondo.

LEGNI DEL CANADÀ

Un certo numero delle specie elencate nella Tabella 1 in basso è stato esaminato dal Canadian Forest Products Laboratory, il quale ha eseguito i saggi su campioni di alberi cresciuti nel Canadà. Questi legni hanno dimostrato di possedere proprietà eguali a quelle delle stesse specie crescente negli Stati Uniti.

TABLE 1.—STRENGTH AND RELATED PROPER-

Index No.	Botanical name: Family	Botanical name: Genus and species	Common name	Place of growth of material tested*	Seasoning condition	Density based on weight when oven-dry and volume: When oven-dry D_o	Density based on weight when oven-dry and volume: When green (D_g)	Density based on weight when oven-dry and volume: When air-dry (D_d)	Moisture content
						g/cm³			% of oven dry-weight
1	2	3	4	5	6	7	8	9	10
I. Equations expressing strength proper-									
Green									
Green to oven-dry									
Air-dry									
II. Values as determined by tests—strength and shrink-									
1	*Aceraceae*	*Acer macrophyllum*	Maple, bigleaf	Washington	Green	0.513	0.440		72
					Air-dry			0.483	12
2		*Acer nigrum*	Maple, black	Indiana	Green	0.620	0.520		65
					Air-dry			0.568	12
3		*Acer pennsylvanicum*	Maple, striped	Vermont	Green		0.438		35
					Air-dry			0.464	12
4		*Acer rubrum*	Maple, red	Wisconsin, Pennsylvania, New Hampshire	Green	0.546	0.488		63
					Air-dry			0.538	12
5		*Acer saccharinum*	Maple, silver	Wisconsin	Green	0.506	0.439		66
					Air-dry			0.470	12
6		*Acer saccharum*	Maple, sugar	Ind., Pa., Vt., Wis.	Green	0.676	0.568		57
					Air-dry			0.630	12
7	*Anacardiaceae*	*Rhus hirta*	Sumach, staghorn	Wisconsin	Green		0.449		45
					Air-dry			0.473	12
8		*Rhus metopium*	Poisonwood	Florida	Green	0.553	0.511		71
					Air-dry			0.533	12
9	*Aquifoliaceae*	*Ilex opaca*	Holly	Tennessee	Green	0.606	0.503		82
					Air-dry			0.569	12
10	*Betulaceae*	*Alnus rubra*	Alder, red	Washington	Green	0.434	0.368		98
					Air-dry			0.407	12
11		*Betula alaskana*	Birch, Alaska	Alaska	Green	0.594	0.488		58
					Air-dry				
12		*Betula lenta*	Birch, sweet	Pennsylvania New Hampshire	Green	0.714	0.601		53
					Air-dry			0.654	12
13		*Betula lutea*	Birch, yellow	Wis., Pa.	Green	0.668	0.550		68
					Air-dry			0.617	12
14		*Betula papyrifera*	Birch, paper	Wis., N. H.	Green	0.600	0.484		65
					Air-dry			0.552	12
15		*Betula populifolia*	Birch, gray	New Hampshire	Green	0.552	0.448		63
					Air-dry			0.506	12
16		*Carpinus caroliniana*	Beech, blue	Massachusetts	Green	0.717	0.575		48
					Air-dry			0.694	12
17		*Ostrya virginiana*	Hornbeam	Wisconsin	Green	0.762	0.632		52
					Air-dry			0.708	12
18	*Burseraceae*	*Bursera simaruba*	Gumbo, limbo	Florida	Green	0.320	0.305		99
					Air-dry			0.307	12
19	*Caprifoliaceae*	*Sambucus glauca*	Elderberry, blue	Oregon	Green	0.570	0.464		124
					Air-dry			0.518	12
20	*Combretaceae*	*Conocarpus erecta*	Buttonwood, Florida	Florida	Green	0.851	0.694		47
					Air-dry			0.709	12

*All material tested was grown in the United States. The State or States in which grown are listed in column 5.

ties of Certain North American Woods

Shrinkage from green to oven-dry condition			Static bending						Impact bending 22.7 kg hammer				Compression parallel to grain			Compression perpendicular to grain	Shear		Tension perpendicular to grain		Hardness: load to embed a steel ball of 1 sq. cm maximum cross section to one-half its diameter			Cleavage	
In volume	Radial	Tangential	Fiber stress at elastic limit	Modulus of rupture	Modulus of elasticity	Work to elastic limit	Work to maximum load	Total work	Fiber stress at elastic limit	Modulus of elasticity	Work to elastic limit	Height of drop causing complete failure	Fiber stress at elastic limit	Maximum crushing strength	Modulus of elasticity		Radial	Tangential	Radial	Tangential	End	Radial	Tangential	Radial	Tangential
% of dimension when green			kg/mm²			kg-mm/mm³			kg/mm²		kg-mm/mm³	m	kg/mm²			kg/mm²	kg/mm²		kg/mm²		kg			kg/mm of width	
11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
ties and shrinkage in terms of density																									
…. $S = 26.5D_g^{1.00}$ ….	… $S = 9.10D_g^{1.00}$ …	… $S = 16.3D_g^{1.00}$ …	$F = 11.74D_d^{1.25}$ $F = 7.17D_g^{1.25}$	$F = 18.1D_d^{1.25}$ $F = 12.4D_g^{1.25}$	$F = 1969D_d^{1.00}$ $F = 1660D_g^{1.00}$	$F = 0.00389D_d^{1.50}$ $F = 0.00172D_g^{1.50}$	$F = 0.0228D_d^{1.75}$ $F = 0.0250D_g^{1.75}$	$F = 0.0511D_d^{2.00}$ $F = 0.0724D_g^{2.00}$	$F = 21.9D_d^{1.25}$ $F = 16.7D_g^{1.25}$	$F = 2380D_d^{1.00}$ $F = 2070D_g^{1.00}$	$F = 0.0112D_d^{1.50}$ $F = 0.00745D_g^{1.50}$	$F = 2.40D_d^{1.75}$ $F = 2.90D_g^{1.75}$	$F = 6.15D_d^{1.00}$ $F = 3.69D_g^{1.00}$	$F = 8.58D_d^{1.00}$ $F = 4.73D_g^{1.00}$	$F = 2380D_d^{1.00}$ $F = 2050D_g^{1.00}$	$F = 3.26D_d^{2.25}$ $F = 2.11D_g^{2.25}$	$F = 2.22D_d^{1.25}$ $F = 1.73D_g^{1.25}$	$F = 2.40D_d^{1.25}$ $F = 1.85D_g^{1.25}$	$F = 1.31D_d^{2.00}$ $F = 1.27D_g^{2.00}$	$F = 1.60D_d^{2.00}$ $F = 1.62D_g^{2.00}$	$F = 2180D_d^{2.25}$ $F = 1700D_g^{2.25}$	$F = 1690D_d^{2.25}$ $F = 1530D_g^{2.25}$	$F = 1730D_d^{2.25}$ $F = 1570D_g^{2.25}$	$F = 20.4D_d^{2.00}$ $F = 19.3D_g^{2.00}$	$F = 22.9D_d^{2.00}$ $F = 22.5D_g^{2.00}$
age values expressed in percentage of equation values																									
99	92	99	119	116	105	144	102	76	100	114	90	85	103	109	97	118	120	123	143	154	129	118	114	134	150
			99	104	108	91	87	68		98		107	122	103	87	104	123	145	101	120	147	120	115	125	158
101	102	109	90	101	108	77	112	117	96	99	95	132	104	93	88	107	97	103	118	136	109	112	101	128	140
			101	105	102	103	104	106	88	95	83	112	90	97	92	97	108	118	65	128	128	115	110	109	105
105			99	115	104	97	130	67	103	141	75	134	79	99	109	106	123	130			86	95			
			80	109	103	62	135	117	95	88	102	108		97		97		108			113	104			
101	89	102	92	107	120	78	113	97	101	103	101	97	95	100	123	85	101	107	126	119	105	104	100	100	106
			111	112	109	129	115	128	106	108	108	99	98	99	92	107	119	128	107	160	120	101	101	147	135
103	75	100	85	92	91	86	131	112	80	79	84	107	84	84	83	97	111	120	140	144	115	111	110	133	135
			98	90	87	111	95	90	103	84	137	99	108	93	70	110	114	127	83	131	133	99	106	122	131
99	92	99	101	108	115	99	100	109	104	106	104	95	105	105	102	95	106	116	110	123	102	102	98	110	119
			101	108	104	102	114	95	119	121	117	93	102	103	94	108	125	135	120	102	111	109	112	121	150
			80	90	76	92	123	204						89		97					109	107	103		
			123	102	91	167	97	119						106		121					100	105	91		
85	89	86	71	67	34	153	50	27	78	76	85	43	39	63	96	136	73	91	68	64	49	43	36	67	53
			71	91	86	59	59	31						74		72									
121	98	116	77	87	75	83	101	127	88	71	116	148	74	78	58	95	96	113	102	128	108	108	109	105	136
			75	81	70	83	89	64	82	72	101	93	71	83	60	89	94	118	123	85	107	95	100	99	
129	129	122	127	129	134	130	129	101	117	129	108	110	136	119	135	99	104	107	148	136	141	119	125	128	143
			130	119	120	133	125	74	115	115	117	102	130	120	143	90	97	109	102	140	156	117	125	130	136
128			90	98	117	72	113	136	101	103	103	113	77	92	96	73	84	92	48	33	74	85	80	67	59
98	118	87	88	100	116	83	107	116	83	114	64	102	85	92	127	62	90	94	58	59	90	87	90	71	69
			103	111	118	95	117	76	137	135	126	105	106	107	106	76	122	116	112	98	106	105	98	119	115
115	148	100	94	103	119	81	133	128	103	106	105	100	95	93	106	58	92	93	80	74	84	85	82	89	82
			118	120	122	120	141	123	115	115	114	136	123	112	98	76	92	102	102	106	90	98	94	77	116
126	143	109	72	89	102	55	162	180	84	94	74	153	66	73	83	58	80	82	67	65	64	81	86	79	73
			89	102	103	83	139	157	84	96	74	115	81	87	96	63	80	78			72	95	94	149	142
124	127		49	76	38	64	159	182	85	87	82	211	42	62	33	61					71	75	96		
			76	89	80	73	110	162	78	98	61	122	69	79	88	95					66	100	90		
125			62	77	73	58	141	177	85	85	86	245	46	69	62	85	98	85	76	32	83	95	95	73	59
			36	74	55	24	213	217	52	61	46		51	66	48	95	112	116	116		76	108	105	125	102
111	144	92	78	86	77	84	83	96	79	98	65	143	78	84	73	69	96	95	63	48	87	98	94	77	66
			89	87	86	95	80	85	70	80	62	94	93	94	70	74	93	78			103	111	110		
106	82	72	84	82	77	110	79	42	93	70	128	92	49	73	56	139	103	100	187	210	111	96	95	166	140
			88	81	86	92	72	45	88	98	86	73	67	85	95	177	110	105	204	170	111	106	101	169	172
126	105	118	86	97	82	94	95	156	87	92	85	128	100	97	109	98	116	107	144	113	114	119	117	151	104
			79	83	71	80	98		77	70	87	108	76	82	81	73					79	94	102		
79	86	75	70	66	73	71	33	33	93	79	110	66	84	88	118	86	75	77	44	51	66	74	74	68	62
			62	60	79	51	34							90		76									

1	2	3	4	5	6	7	8	9	10
21	*Cornaceae*	*Cornus florida*	Dogwood (flowering)	Tennessee	Green	0.796	0.638		62
					Air-dry			0.735	12
22		*Cornus nuttallii*	Dogwood, Pacific	Oregon	Green	0.701	0.578		52
					Air-dry			0.644	12
23		*Nyssa aquatica*	Gum, tupelo	Louisiana, Missouri	Green	0.524	0.455		97
					Air-dry			0.496	12
24		*Nyssa sylvatica*	Gum, black	Tennessee	Green	0.552	0.462		55
					Air-dry			0.507	12
25	*Ebenaceae*	*Diospyros virginiana*	Persimmon	Missouri	Green	0.776	0.639		59
					Air-dry			0.748	12
26	*Ericacae*	*Arbutus menziesii*	Madroña	Oregon, California	Green	0.694	0.575		69
					Air-dry			0.653	12
27		*Kalmia latifolia*	Laurel, mountain	Tennessee	Green	0.744	0.616		62
					Air-dry			0.684	12
28		*Oxydendrum arboreum*	Sourwood	Tennessee	Green	0.593	0.504		69
					Air-dry			0.550	12
29		*Rhododendron maximum*	Rhododendron, great	Tennessee	Green	0.601	0.501		99
					Air-dry			0.576	12
30	*Fagaceae*	*Castanea dentata*	Chestnut	Tennessee, Maryland	Green	0.454	0.396		122
					Air-dry			0.433	12
31		*Castanopsis chrysophylla*	Chinquapin, golden	Oregon	Green	0.483	0.417		134
					Air-dry			0.459	12
32		*Fagus grandifolia*	Beech	Ind., Pa.	Green	0.655	0.544		62
					Air-dry			0.624	12
33		*Quercus alba*	Oak, white	La., Ark., Ind.	Green	0.710	0.595		68
					Air-dry			0.683	12
34		*Quercus bicolor*	Oak, swamp white	Indiana	Green	0.792	0.637		74
					Air-dry			0.720	12
35		*Quercus borealis*	Oak, red	La., Ark., Ind., Tenn., N. H.	Green	0.657	0.564		80
					Air-dry			0.628	12
36		*Quercus californica*	Oak, California black	Oregon, California	Green	0.578	0.510		106
					Air-dry			0.571	12
37		*Quercus chrysolepis*	Oak, canyon live	California	Green	0.838	0.702		62
					Air-dry			0.778	12
38		*Quercus coccinea*	Oak, scarlet	Massachusetts	Green	0.709	0.603		65
					Air-dry				
39		*Quercus gambelii*	Oak, Gambel	Arizona	Green	0.701	0.617		61
					Air-dry			0.735	12
40		*Quercus garryana*	Oak, Oregon white	Oregon	Green	0.748	0.644		72
					Air-dry			0.724	12
41		*Quercus laurifolia*	Oak, laurel	Louisiana	Green	0.703	0.564		84
					Air-dry			0.632	12
42		*Quercus macrocarpa*	Oak, bur	Wisconsin	Green	0.671	0.583		70
					Air-dry			0.644	12
43		*Quercus montana*	Oak, chestnut	Tennessee	Green	0.674	0.573		72
					Air-dry			0.658	12
44		*Quercus nigra*	Oak, water	Louisiana	Green	0.685	0.556		81
					Air-dry			0.633	12
45		*Quercus rubra pagodaefolia*	Oak, swamp red	Louisiana	Green	0.708	0.607		78
					Air-dry			0.680	12
46		*Quercus palustris*	Oak, pin	Massachusetts	Green	0.677	0.577		75
					Air-dry				
47		*Quercus phellos*	Oak, willow	Louisiana	Green	0.688	0.556		94
					Air-dry			0.696	12
48		*Quercus prinus*	Oak, swamp chestnut	Louisiana	Green	0.756	0.595		76
					Air-dry			0.674	12
49		*Quercus rubra*	Oak, southern red	Louisiana	Green	0.624	0.521		90
					Air-dry			0.588	12
50		*Quercus stellata*	Oak, post	Arkansas, Louisiana	Green	0.738	0.596		69
					Air-dry			0.675	12
51		*Quercus velutina*	Oak, black	Arkansas, Wisconsin	Green	0.669	0.564		78
					Air-dry			0.610	12
52		*Quercus virginiana*	Oak, live	Florida	Green	0.977	0.810		50
					Air-dry			0.888	12
53	*Hamamelidaceae*	*Hamamelis virginiana*	Witch-hazel	Tennessee	Green	0.714	0.558		70
					Air-dry			0.614	12
54		*Liquidambar styraciflua*	Gum, red	Missouri	Green	0.530	0.441		81
					Air-dry			0.487	12
55	*Hippocastanaceae*	*Aesculus octandra*	Buckeye, yellow	Tennessee	Green	0.383	0.326		141
					Air-dry			0.363	12
56	*Juglandaceae*	*Hicoria alba*	Hickory, mockernut	Pa., Miss.	Green		0.642		60
					Air-dry			0.725	12
57		*Hicoria aquatica*	Hickory, water	Mississippi	Green		0.606		80
					Air-dry			0.621	12
58		*Hicoria cordiformis*	Hickory, bitternut	Ohio	Green		0.604		66
					Air-dry			0.663	12
59		*Hicoria glabra*	Hickory, pignut	W. Va., Miss., Ohio, Pa.	Green		0.661		54
					Air-dry			0.754	12
60		*Hicoria laciniosa*	Hickory, bigleaf shagbark	Ohio, Miss.	Green		0.622		61
					Air-dry			0.692	12
61		*Hicoria myristicae formis*	Hickory, nutmeg	Mississippi	Green		0.556		74
					Air-dry			0.605	12

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
117	122	109	82	87	78	90	130	127	52	44	65	111		84		95	104	106			104	115	112		
			82	87	75	94	103	99	71	66	77	79		89		85		103			103	119	114		
112	121	101	81	92	80	86	124	113	81	89	77	129	75	93	91	100	97	105	114	102	105	101	95	81	90
			78	71	82	74	72	107	58	76	45	76	77	99	91	99	90	96		123	108	101	98	71	95
103	103	103	110	111	97	132	92	94	101	105	100	104	115	110	102	117	119	132	147	165	127	120	123	117	160
			107	91	91	132	73	63	97	91	107	82	101	101	88	117	114	122	172	134	125	111	119	102	136
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127			101	97	84	127	152	176	108	83	143	97		90		77	89	92			101	106	107		
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			91	122	101	80	188							95		133	110								

1	2	3	4	5	6	7	8	9	10
62		*Hicoria ovata*	Hickory, shagbark	Miss., Ohio, W. Va., Pa.	Green		0.637		60
					Air-dry			0.724	12
63		*Hicoria pecan*	Hickory, pecan	Missouri	Green	0.694	0.601		63
					Air-dry			0.666	12
64		*Juglans cinerea*	Butternut	Wisconsin, Tennessee	Green	0.404	0.359		104
					Air-dry			0.383	12
65		*Juglans nigra*	Walnut, black	Kentucky	Green	0.562	0.513		81
					Air-dry			0.552	12
66		*Juglans rupestris*	Walnut, Mexican	Arizona	Green	0.613	0.532		67
					Air-dry			0.570	12
67	*Lauraceae*	*Sassafras sassafras*	Sassafras	Tennessee	Green	0.473	0.424		67
					Air-dry			0.451	12
68		*Umbellularia californica*	Myrtle, Oregon	Oregon	Green	0.589	0.512		71
					Air-dry			0.556	12
69	*Leguminosae*	*Gleditsia triacanthos*	Locust, honey	Indiana, Missouri	Green	0.666	0.596		63
					Air-dry			0.636	12
70		*Robinia pseudacacia*	Locust, black	Tennessee	Green	0.708	0.659		41
					Air-dry			0.694	12
71	*Magnoliaceae*	*Liriodendron tulipifera*	Poplar, yellow	Tennessee, Kentucky	Green	0.427	0.376		64
					Air-dry			0.401	12
72		*Magnolia acuminata*	Magnolia, cucumber	Tennessee	Green	0.516	0.440		80
					Air-dry			0.480	12
73		*Magnolia fraseri*	Magnolia, Fraser's	Tennessee	Green	0.477	0.400		89
					Air-dry			0.446	12
74		*Magnolia grandiflora*	Magnolia, evergreen	Louisiana	Green	0.530	0.460		117
					Air-dry			0.502	12
75	*Moraceae*	*Toxylon pomiferum*	Orange, osage	Indiana	Green	0.838	0.761		31
					Air-dry				
76		*Ficus aurea*	Fig, golden	Florida	Green		0.438		88
					Air-dry			0.444	12
77	*Myrtaceae*	*Eucalyptus globulus*	Gum, blue	California	Green	0.796	0.625		79
					Air-dry			0.750	12
78		*Eugenia garberi*	Stopper, Garber's	Florida	Green	0.918	0.831		40
					Air-dry			0.877	12
79	*Oleaceae*	*Fraxinus americana*	Ash, white	Ark., N. Y., W. Va.	Green	0.638	0.542		42
					Air-dry			0.593	12
80		*Fraxinus biltmoreana*	Ash, Biltmore white	Tennessee	Green	0.584	0.507		42
					Air-dry			0.550	12
81		*Fraxinus pennsylvanica lanceolata*	Ash, green	Louisiana, Missouri	Green	0.610	0.526		48
					Air-dry			0.566	12
82		*Fraxinus nigra*	Ash, black	Wisconsin, Michigan	Green	0.526	0.457		84
					Air-dry			0.493	12
83		*Fraxinus oregona*	Ash, Oregon	Oregon	Green	0.575	0.497		48
					Air-dry			0.550	12
84		*Fraxinus profunda*	Ash, pumpkin	Missouri	Green	0.551	0.485		51
					Air-dry			0.520	12
85		*Fraxinus quadrangulata*	Ash, blue	Kentucky	Green	0.603	0.532		39
					Air-dry			0.568	12
86	*Palmaceae*	*Sabal palmetto*	Palmetto, cabbage	Florida	Green	0.453	0.372		133
					Air-dry			0.387	12
87	*Pinaceae*	*Abies amabilis*	Fir, silver	Washington	Green	0.415	0.351		66
					Air-dry			0.385	12
88		*Abies balsamea*	Fir, balsam	Wisconsin	Green	0.414	0.335		117
					Air-dry			0.366	12
89		*Abies concolor*	Fir, white	California, New Mexico	Green	0.397	0.348		115
					Air-dry			0.371	12
90		*Abies grandis*	Fir, lowland white	Montana, Oregon	Green	0.419	0.370		94
					Air-dry			0.398	12
91		*Abies lasiocarpa*	Fir, alpine	Colorado	Green	0.321	0.306		47
					Air-dry			0.327	12
92		*Abies magnifica*	Fir, red	California	Green	0.421	0.372		108
					Air-dry			0.388	12
93		*Abies nobilis*	Fir, noble	Oregon	Green	0.403	0.351		36
					Air-dry			0.375	12
94		*Chamaecyparis lawsoniana*	Cedar, Port Orford	Oregon	Green	0.440	0.399		43
					Air-dry			0.416	12
95		*Chamaecyparis nootkatensis*	Cedar, Alaska	Oregon	Green	0.439	0.399		40
					Air-dry			0.422	12
96		*Chamaecyparis thyoides*	Cedar, southern white	New Hampshire, North Carolina	Green	0.352	0.310		35
					Air-dry			0.323	12
97		*Juniperus pachyphloea*	Juniper, alligator	Arizona	Green	0.545	0.477		40
					Air-dry			0.511	12
98		*Juniperus virginiana*	Cedar, eastern red	Vermont	Green	0.492	0.442		35
					Air-dry			0.471	12
99		*Larix laricina*	Tamarack	Wisconsin	Green	0.558	0.491		52
					Air-dry			0.528	12
100		*Larix occidentalis*	Larch, western	Montana, Washington	Green	0.587	0.482		58
					Air-dry			0.520	12
101		*Libocedrus decurrens*	Cedar, incense	Oregon, California	Green	0.365	0.346		108
					Air-dry			0.368	12

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
99	121	101	101	110	104	103	146	181	106	96	119	143	102	107	93	96	119	92							
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44			106	109	74	156	172	170	92	67	126	169	99	113	60	139					91	126	94		
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			64	77	65	64	88	77						82											
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83	81	75	122	119	98	155	125	137	103	88	119	113	126	117	84	275	139	128	100	101	126	124	124	100	111
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253			64	73	55	82	64	96	72	48	112	73	58	69	33	58					83				
			59	60	51	72	73	125	65	58	76	90	25	47	74	32					53				
150	141	172	127	118	151	120	105	101	121	146	100	115	128	112	150	102	100	95	82	104	103	91	101	102	99
			123	122	142	110	155	160	121	120	128	133	131	120	140	93	133	93		86	113	98	100	99	124
121	93	120	114	108	122	111	90	67	113	118	110	95	118	106	129	82	96	93	81	72	91	97	103	102	94
			111	105	122	106	91	128	88	104	76	124	127	105	128	80	75	79	76	53	105	104	105		
102	100	123	140	120	125	168	90	89	132	135	133	120	120	105	119	134	111	110	115	121	109	103	107	118	120
			133	124	133	140	118	84	118	129	114	114	101	119	118	121	97	99	91	91	142	109	112	93	93
108	94	120	121	118	147	105	89	104	117	129	108	110	137	120	170	106	106	101	87	81	105	96	103	98	89
			112	115	147	92	119	207	123	128	120	150	137	115	152	110	92	89	47	69	112	96	115	140	62
111	89	142	101	110	119	95	98	76	97	109	88	62	105	100	99	148	102	109			108	86	96	127	113
			137	106	98	194	65	68	89	110	75	113	123	102	103	155	127	145			120	103	149	111	106
119	112	113	138	116	121	173	105	89	125	130	117	107		112		137	125	124	113	124	96	104	102	111	123
			136	137	143	138	151		124	136	114	126		112		154	112	98	105	119	190	121	116	98	109
134	141	143	131	121	152	122	105	124	133	138	132	105	127	115	167	119	106	110	83	98	94	87	90	94	110
			136	134	151	129	152	168	122	148	105	139	153	123	169	129	103	104	78	76	133	97	105	72	81
95	128	106	121	110	151	107	104	148	121	135	111	93	128	116	159	94	103	104	60	50	99	92	92	56	57
			138	133	148	135	132	198	130	146	116	137	160	129	144	122	96	102	108	117	111	110	105	98	113
74	53	77	109	110	102	126	134	144	114	113	118	118	114	107	91	109	98	105	87	74	110	92	97	79	73
			117	115	107	139	124	104	114	100	132	135	143	112	98	107	86	93	98	95	102	102	93		
102	100	102	106	116	103	121	127	136	108	102	118	121	103	114	105	141	120	115	97	86	152	121	119	115	104
			116	108	103	117	90	71	100	103	101	102	104	117	122	140	97	104	98	108	139	121	113	106	101
61	63	46	89	94	40	209	137	69	72	49	111	67	96	116	45	181	128	125			136	121	132		56
			75	60	45	138	64		42	44	43	40		66		168	75				123	142	140		
66	78	65	92	110	62	152	175	166	81	81	87	126	112	120	53	182	116	104	82	82	128	124	114	80	73
			57	86	66	57	100		69	56	87	88		102		133			177		101		124	73	115
105	82	92	100	99	107	100	70	120	79	87	72	85	117	105	111	80	87	78	54	49	53	56	53	64	52
			107	101	111	105	67	88	89	91	88	75	107	111	114	91	93	87	79	62	59	68	67	71	61
103	95	102	112	105	118	123	72	77	98	115	103	75	128	117	107	97	93	87	47	48	65	68	69	59	57
			104	103	116	117	78	109	109	121	118	105	151	118	103	100	95	94	54	56	99	93	82	55	45
83	103	100	144	132	103	192	114	64	116	126	111	96	151	135	111	167	127	120	126	107	167	124	125	123	107
			125	109	102	140	95	73	108	107	111	103	151	119	99	152	93	94	95	99	168	118	120		

1	2	3	4	5	9	7	8	9	10
102		*Picea engelmanni*	Spruce, Engelmann	Colorado	Green	0.347	0.312		100
					Air-dry			0.332	12
103		*Picea glauca*	Spruce, white	Wis., N. H.	Green	0.431	0.366		50
					Air-dry			0.391	12
104		*Picea mariana*	Spruce, black	New Hampshire	Green	0.428	0.376		38
					Air-dry			0.402	12
105		*Picea rubra*	Spruce, red	Tennessee, New Hampshire	Green	0.413	0.379		43
					Air-dry			0.406	12
106		*Picea sitchensis*	Spruce, Sitka	Wash., Oregon	Green	0.397	0.355		44
					Air-dry			0.384	12
107		*Pinus banksiana*	Pine, jack	Wisconsin	Green	0.461	0.394		105
					Air-dry			0.428	12
108		*Pinus caribaea*	Pine, slash	Florida	Green	0.756	0.638		40
					Air-dry			0.682	12
109		*Pinus clausa*	Pine, sand	Florida	Green	0.506	0.451		36
					Air-dry			0.481	12
110		*Pinus contorta*	Pine, lodgepole	Wyo., Mont., Colo.	Green	0.434	0.380		65
					Air-dry			0.410	12
111		*Pinus echinata*	Pine, shortleaf	Ark., La.	Green	0.584	0.494		64
					Air-dry			0.542	12
112		*Pinus edulis*	Piñon	Arizona	Green	0.567	0.502		63
					Air-dry			0.530	12
113		*Pinus flexilis*	Pine, limber	New Mexico	Green	0.420	0.374		68
					Air-dry			0.401	12
114		*Pinus jeffreyi*	Pine, Jeffrey	California	Green	0.425	0.371		101
					Air-dry			0.402	12
115		*Pinus lambertiana*	Pine, sugar	California	Green	0.378	0.348		137
					Air-dry			0.360	12
116		*Pinus monticola*	Pine, western white	Montana, Idaho	Green	0.418	0.363		54
					Air-dry			0.385	12
117		*Pinus palustris*	Pine, longleaf	La., Miss., Fla.	Green	0.638	0.551		47
					Air-dry			0.592	12
118		*Pinus ponderosa*	Pine, western yellow	Colo., Wash., Ariz., Cal., Mont.	Green	0.420	0.379		91
					Air-dry			0.402	12
119		*Pinus pungens*	Pine, mountain	Tennessee	Green	0.549	0.494		75
					Air-dry			0.523	12
120		*Pinus resinosa*	Pine, red	Wisconsin	Green	0.507	0.440		54
					Air-dry			0.479	12
121		*Pinus rigida*	Pine, pitch	Tennessee	Green	0.542	0.470		85
					Air-dry			0.505	12
122		*Pinus rigida serotina*	Pine, pond	Florida	Green	0.580	0.501		56
					Air-dry			0.539	12
123		*Pinus strobus*	Pine, eastern white	Wis., Minn., N. H.	Green	0.373	0.344		68
					Air-dry			0.362	12
124		*Pinus taeda*	Pine, loblolly	Florida	Green	0.593	0.504		72
					Air-dry			0.550	12
125		*Pseudotsuga taxifolia*	Douglas fir (coast type)	Lewis Co., Chehalis Co., Clark Co., Wash.; Lane Co., Clatsop Co., Wash. Co., Ore.; Humboldt Co., Cal.	Green	0.512	0.448		36
					Air-dry			0.482	12
126		*Pseudotsuga taxifolia*	Douglas fir (mountain type)	Johnson Co., Wyo.; Missoula Co., Mont.	Green	0.446	0.405		39
					Air-dry			0.426	12
127		*Sequoia sempervirens*	Redwood	California	Green	0.436	0.410		113
					Air-dry			0.427	12
128		*Taxodium distichum*	Cypress, southern	Louisiana, Missouri	Green	0.482	0.425		91
					Air-dry			0.458	12
129		*Thuja occidentalis*	Cedar, northern white	Wisconsin	Green	0.315	0.293		55
					Air-dry			0.310	12
130		*Thuja plicata*	Cedar, western red	Montana, Washington	Green	0.344	0.310		39
					Air-dry			0.330	12
131		*Tsuga canadensis*	Hemlock, eastern	Wis., Tenn., N. H.	Green	0.431	0.375		110
					Air-dry			0.398	12
132		*Tsuga heterophylla*	Hemlock, western	Washington, Oregon	Green	0.432	0.377		77
					Air-dry			0.406	12
133		*Tsuga mertensiana*	Hemlock, mountain	Montana	Green	0.480	0.418		70
					Air-dry			0.450	12
134	*Platanaceae*	*Platanus occidentalis*	Sycamore	Indiana, Tennessee	Green	0.539	0.456		83
					Air-dry			0.494	12
135	*Polygonaceae*	*Coccolobis laurifolia*	Plum, pigeon	Florida	Green	0.851	0.771		52
					Air-dry			0.786	12
136	*Rhamnaceae*	*Rhamnidium ferreum*	Ironwood, black	Florida	Green	1.077	1.045		32
					Air-dry			1.147	12
137		*Rhamnus purshiana*	Cascara	Oregon	Green	0.548	0.496		61
					Air-dry			0.516	12
138	*Rhizophoraceae*	*Rhizophora mangle*	Mangrove	Florida	Green	1.063	0.886		39
					Air-dry			0.964	12
139	*Rosaceae*	*Amelanchier canadensis*	Serviceberry	Tennessee	Green	0.791	0.656		48
					Air-dry			0.747	12
140		*Crataegus tomentosa*	Haw, pear	Wisconsin	Green		0.623		63
					Air-dry			0.680	12
141		*Prunus pennsylvanica*	Cherry, wild red	Tennessee	Green	0.425	0.361		46
					Air-dry			0.394	12

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
125	121	129	103	101	113	102	106	62	105	108	101	94	105	95	109	133	100	100			93	95	99	113	113
			133	122	121	138	119	96	112	116	111	107	115	109	103	156	121	118			108	89	105	158	138
153	112	122	114	110	118	120	99	110	99	110	83	101	107	101	87	87	97	92	76	69	66	78	66	90	81
			116	114	130	117	116	114	100	113	89	111	115	108	138	89	95	92	119	103	107	95	119	100	104
113	121	110	96	103	120	80	115	139	97	130	72	114	81	102	150	53	93	84	36	35	104	103	92	77	64
			107	125	135	94	159	183	134	122	151	118	138	110	144	116	102	95	87		114	112	106	99	68
117	109	126	112	110	132	102	106	93	101	111	92	80	128	104	126	102	102	100	58	85	99	89	93	83	90
			125	122	134	121	125	98	116	119	115	129	139	119	135	95	100	103	107	97	101	96	102	83	90
121	134	128	117	113	147	102	106	141	130	130	136	130	113	108	164	106	109	106	76	89	118	100	103	89	92
			129	124	142	117	150	179	126	137	121	138	122	112	114	132	122	118	122	142	133	109	110	102	117
100	94	102	93	98	99	92	84	127	105	94	127	134	108	97	91	103		91	94	98	83	85	89	106	88
			89	91	103	82	73	75	104	106	107	164		107		124		96	105	103	95	111	104	88	94
75	100	79	97	96	104	113	52	66	96	98	98	70	101	110	115	65	83	70	54	43	51	60	60	51	43
			94	99	110	101	67	59	94	114	80	71	112	119	96	87	98	82	65	49	60	68	76		41
83	95	99	109	115	96	128	108	104	111	89	144	88	108	113	103	112	125	118	102	80	75	83	85	95	
			101	114	106	101	107	105	99	102	103	72	96	119	148	116	84	82	73	52	104	104	100	85	
114	128	108	99	104	120	86	86	82	100	111	92	96	105	102	131	92	93	88	80	69	77	84	88	101	81
			124	112	117	142	102	94	94	100	92	100	128	110	113	124	87	79	102	68	84	93	98	96	79
95	113	101	106	109	124	94	84	140	113	123	108	117	139	114	131	78	92	77	67	65	64	77	83	76	73
			111	111	126	102	87	86	105	124	92	113	127	119	132	100	96	84	80	50	67	81	86	82	55
74	100	63	60	64	55	70	72	88	81	63	110	62	61	76	122	75	86	85	93	85	65	81	83		68
			75	68	77	89	43		60	77	48	39		101		143	99		66		81	96	96		
83	71	84	128	101	90	193	81	61	102	97	108	88	99	96	109	97	102	96	94	92	73	86	82	99	108
			125	112	104	158	103	78	114	109	127	96		111		123	81	74	73	56	85	94	88	148	120
100	130	110	106	97	112	109	75	108	103	103	108	104	104	95	104	110	94	94	90	92	80	91	95	93	99
			138	116	110	180	100	85	125	123	129	141	123	116	100	137	120	116	121	109	102	100	106	129	126
86	91	98	123	107	114	140	96		116	113	120	96	127	108	101	126	102	97	111	108	91	94	100	128	127
			122	112	118	129	101	87	123	118	130	111	145	108	124	126	125	110	126	129	111	104	101	120	123
123	124	125	116	104	136	106	83	139	114	121	113	98	124	108	150	96	90	87	96	96	81	88	90	106	98
			123	123	140	115	146	138	126	137	118	132	145	121	162	101	105	85	101	82	79	86	86	87	88
84	106	83	110	104	125	100	64	98	95	115	79	85	132	118	117	76	96	82	50	44	56	66	67	57	50
			116	116	124	112	83	89	95	111	82	86	135	124	114	99	99	82	59	50	68	79	78	61	47
95	112	102	101	95	108	104	78	92	95	92	102	94	104	93	103	106	91	90	99	97	72	82	81	99	99
			118	112	112	133	101	97	98	103	98	88	120	109	102	125	113	111	120	124	91	94	93	110	112
83	76	84	106	103	109	111	78	110	103	108	103	87	114	106	97	91	96	86	75	56	62	72	70	76	65
			108	104	106	114	84	86	104	105	107	95	90	110	118	115	87	78			66	80	73	62	58
98	115	100	102	101	133	83	68	139	87	110	70	103	106	104	128	76	92	78	51	46	60	65	62	77	63
			140	122	134	153	112	98	126	125	126	95	139	124	136	94	112	88	95	111	74	77	85	82	68
94	112	96	91	97	101	96	89	139	98	92	100	95	85	96	86	93	100	92	93	66	67	76	78	89	81
			90	96	97	93	88	95	108	99	137	98	84	99	96	94	99	97	84	104	68	80	77	92	82
84	111	87	105	100	108	88	71	98	93	103	84	97	113	108	95	86	95	80	55	54	58	71	70	66	60
			110	99	116	106	78	62	93	104	81	88	129	119	117	102	104	85	67	55	67	85	76	74	64
90	74	107	114	107	125	110	95	93	106	117	104	95	116	108	135	106	99	97	98	100	90	97	102	105	102
			128	123	126	135	124	116	108	116	106	116	122	111	127	119	100	90	109	113	103	105	106	105	102
94	120	90	107	101	120	102	75	99	93	108	82	93	108	108	102	86	92	76	58	52	51	61	63	66	60
			115	106	125	116	76	94	89	106	76	83	124	122	110	101	109	77	64	47	64	75	70	68	53
99	122	107	127	117	146	116	78	90	112	131	100	87	145	129	162	104	103	97	59	59	82	84	85	67	69
			123	116	143	110	96	137	103	129	86	114	163	129	144	103	93	81	64	66	84	92	95	64	72
98	97	94	110	111	123	103	93	76	117	128	113	87	117	110	126	115	108	104	108	98	92	89	90	93	78
			109	108	117	105	89	106	113	122	109	122	125	118	116	123	101	84	85	89	105	112	116	73	72
58	73	63	163	137	120	255	99		125	122	132	89		158		135	104	104	78	49	124	99	100	88	68
			136	121	114	171	103		103	115	96	87		126		149	103	91	75	57	125	97	91	76	69
93	100	87	119	109	118	136	83	100	107	109	110	98	137	125	121	114	97	89	94	72	82	76	80	90	76
			114	109	112	126	98	113	88	105	78	100	130	114	112	113	86	78	64	61	80	79	79	64	67
90	78	98	117	111	93	158	136	107	103	90	121	113	91	100	88	153	116	108	156	118	137	106	105	157	129
			126	109	93	182	114	79	98	98	100	99	100	105	98	115	114	121	122	124	131	115	126	126	132
99	89	100	137	128	131	152	109	91	128	128	86	116	152	136	125	147	127	118	122	99	161	105	107	133	103
			122	119	126	126	130	122	114	126	107	115	153	128	131	150	107	105	82	87	163	108	113	87	99
98	88	108	129	124	122	143	97	117	110	113	112	100	126	124	113	140	119	110	82	84	122	113	108	101	87
			116	106	108	131	99	102	113	106	125	112	115	115	117	144	97	98	54	50	130	105	98	65	62
117	132	127	116	116	136	105	95	92	115	127	104	97	115	115	159	103	107	108	86	96	128	106	115	98	103
			120	111	127	121	97	131	116	114	117	122	147	118	112	102	99	99	72	70	133	104	113	91	104
97	116	104	101	101	95	118	120	176	109	97	124	145	117	102	98	95	106	100	93	106	110	97	96	95	99
			102	104	90	127	114	90	119	104	140	154	98	111	97	134	94	99	61	98	136	100	105	68	71
117	121	101	85	97	99	80	83	71	99	99	100	92	100	95	90	88	98	110	133	158	109	104	104	119	150
			93	95	103	89	92	71	81	97	70	96	87	91	99	92	96	116	120	157	94	97	105	103	160
77	63	62	68	77	71	71	51	40	93	91	94	56	103	95	141	90	73	90	51	84	83	87	94	57	57
			61	67	59	69	51						77	73	83	110						81	103		
42	65	47	93	88	89	101	33	64	74	82	67	285	103	107	72	105		93	51						40
			38	61	93	17	18	36	46	75	28	129		71	93	48		63							17
58	71	57	78	86	54	122	128	209	88	79	97	155	72	98	68	109	120	98	117	89	88	108	100	90	89
			84	78	68	108	74		75	72	157	41	82	99	64	132	121	109			120	123	127		
67	67		110	100	110	113	50	50	100	109	92	56	112	108	108	108	73	91	89		71	91	81	68	
			88	89	110	73	58	96				36	66	92	91	77	93	92				80	79		
107	112	101	93	92	105	84	94	90	87	108	72	115	92	92	79	68	80	87	87	79	87	95	93	75	84
			97	96	90	101	97	121	99	104	96	104	108	98	64	76	69	73			86	96	90		
			68	78	65	74	146	109						74		95	95	96			94	105	98		
			75	94	67	84	143	97						83		83	90				100	98	101		
133	85	175	100	102	122	89	103	126	98	110	91	115	96	89	102	88	90	99	114	108	116	111	112	115	113
			111	108	115	116	132	194	104	110	102	171	116	99	99	94	101	105	101	101	128	113	110	120	127

1	2	3	4	5	6	7	8	9	10
142		*Prunus serotina*	Cherry, black	Pennsylvania	Green	0.534	0.471		55
					Air-dry			0.506	12
143		*Pyrus malus*	Applewood or wild apple	Virginia	Green	0.745	0.606		47
					Air-dry			0.668	12
144	*Salicaceae*	*Populus balsamifera*	Poplar, balsam	Vermont	Green	0.331	0.301		121
					Air-dry			0.316	12
145		*Populus deltoides*	Cottonwood, eastern	Missouri	Green	0.433	0.372		111
					Air-dry			0.408	12
146		*Populus grandidentata*	Aspen, large tooth	Wisconsin, Vermont	Green	0.412	0.348		99
					Air-dry			0.386	12
147		*Populus tremuloides*	Aspen	Wisconsin, New Mexico	Green	0.401	0.351		94
					Air-dry			0.380	12
148		*Populus trichocarpa*	Cottonwood, black	Washington	Green	0.368	0.315		132
					Air-dry			0.348	12
149		*Salix lasiandra*	Willow, western black	Oregon	Green	0.473	0.394		105
					Air-dry			0.441	12
150		*Salix nigra*	Willow, black	Wisconsin, Missouri	Green	0.408	0.338		139
					Air-dry			0.372	12
151	*Sapindaceae*	*Exothea paniculata*	Inkwood	Florida	Green	0.917	0.731		56
					Air-dry			0.800	12
152	*Sapotaceae*	*Dipholis salicifolia*	Bustic	Florida	Green		0.861		44
					Air-dry			0.885	12
153		*Sideroxylon mastichodendron*	Mastic	Florida	Green	1.034	0.886		39
					Air-dry			0.932	12
154	*Simaroubaceae*	*Simarouba glauca*	Paradise-tree	Florida	Green	0.359	0.332		81
					Air-dry			0.345	12
155	*Styracaceae*	*Mohrodendron carolinum*	Silverbell-tree	Tennessee	Green	0.475	0.418		70
					Air-dry			0.453	12
156	*Taxaceae*	*Taxus brevifolia*	Yew, Pacific	Washington	Green	0.673	0.601		44
					Air-dry			0.626	12
157	*Tiliaceae*	*Tilia glabra*	Basswood	Wisconsin, Pennsylvania	Green	0.398	0.325		103
					Air-dry			0.368	12
158	*Ulmaceae*	*Celtis laevigata*	Sugarberry	Missouri	Green	0.545	0.473		62
					Air-dry			0.515	12
159		*Celtis occidentalis*	Hackberry	Indiana, Wisconsin	Green	0.558	0.486		65
					Air-dry			0.531	12
160		*Ulmus americana*	Elm, American	Wisconsin, Pennsylvania, New Hampshire	Green	0.554	0.458		89
					Air-dry			0.507	12
161		*Ulmus fulva*	Elm, slippery	Indiana, Wisconsin	Green	0.568	0.485		85
					Air-dry			0.528	12
162		*Ulmus racemosa*	Elm, rock	Wisconsin	Green	0.658	0.574		49
					Air-dry			0.634	12
163	*Verbenaceae*	*Avicennia nitida*	Blackwood	Florida	Green	0.963	0.830		42
					Air-dry			0.830	12

TABLE 1A.—STRENGTH AND RELATED PROPERTIES OF

I. Equations expressing strength properties

1	2	3	4	5	6	7	8	9	10	11	12	13	14
													$F = 12.08D_a^{1.25}$

II. Values as determined by tests—strength values

1	2	3	4	5	6	7	8	9	10	11	12	13	14
170	*Dipterocarpaceae*	*Dipterocarpus grandiflorus*	Apitong	P. I.	*d*	0.687							97
171		*Pentacme contorta*	White Lauan	P. I.	*d*	0.485							112
172		*Shorea negrosensis*	Red Lauan	P. I.	*d*	0.523							89
173		*Shorea polysperma*	Tangile	P. I.	*d*	0.538							102
174	*Sterculiaceae*	*Tarrietia javanica*	Lumbayau	P. I.	*d*	0.571							95

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
92	86	92	104	116	117	101	135	136	109	106	117	108	118	112	112	81	112	115	120	130	110	111	101	122	130
			128	114	105	166	115	77	103	110	95	101	142	118	110	87	115	132	107	105	146	110	128	125	96
109	102	102	66	78	73	65	106	78	60	65	60	69	62	73	98	88	120	120	117	122	86	100	97	112	108
			66	82	68	76	146	95	84	66	91	91	54	75	115	71	92	84	81		112	117	112	102	
100			93	102	112	80	97	91	116	108	126	129	75	85	103	78	89	95	96	100	105	111	110	132	129
			98	111	115	94	132	104	104	115	100	113	105	99	104	111	103	113	162	150	112	102	123	160	170
142	115	151	96	102	115	89	116	124	103	117	96	103	90	90	118	75	87	96	149	139	95	93	94	133	139
			108	104	121	103	110	187	71	99	57	99	99	102	101	80	82	94	147	184	93	89	86	125	149
127	103	139	106	114	136	88	100	105	116	123	113	102	104	106	124	91	103	112	133	120	115	115	118	136	131
			110	116	131	97	126	119	120	119	127	126	116	114	123	104	105	113	132	120	112	96	94	117	126
124	109	116	114	107	103	135	112	100	107	100	123	123	89	90	106	79	95	96	101	84	79	93	93	99	88
			115	112	112	122	130	122	97	108	93	122	98	94	114	90	89	90	113	68	97	85	80	116	123
148	124	165	118	116	144	102	106	122	121	129	116	132	107	102	124	92	97	103	129	138	100	100	100	133	156
			120	123	129	113	131	127	118	121	115	145	120	106	113	89	119	113	115	144	124	102	101	147	150
131	81	141	97	102	110	97	154	155	103	115	96	147	87	88	117	91	104	113	112	111	107	122	117	121	111
			95	93	107	89	119	168	100	98	104	137	90	88	112	89	99	102	130	136	115	106	107	119	127
153	81	142	67	83	70	75	204	156	83	77	95	208	54	66	65	82	92	98	180	183	107	118	123	163	181
			82	84	70	116	137	103	86	77	106	114	63	78	66	99	112	115	162	157	108	111	110	148	193
97	100	91	104	90	89	124	78	116	95	88	102	76	84	91	93	108	101	102		71	72	85	86	82	63
			71	77	85	59	47	48				45	62	86	78	91	85	98			108	100	96		57
			68	84	91	51	63						83	92	90	79									
													58	89	100										
50	76	52	80	68	76	88	28	26	88	82	98	56	101	98	70	118	71	81	60	67	59	72	63	46	47
			43	43	68	28	21	11	49	72	34	28	45	61	64	71	36	61	34	42	51	46	54	30	38
98	73	96	74	78	89	85	35	21	90	87	95	44	71	81	103	106	121	100	150	123	112	82	89	130	101
			88	78	88	79	62	43	66	93	48	47	75	72	84	96	72	71	140	129	139	109	101		
113	100	112	102	109	118	94	113	103	113	113	114	109	95	100	102	102	110	108	126	130	106	99	97	133	140
			94	90	104	90	84	88	117	109	124	102	88	95	110	89	97	98	114	110	111	93	97	118	142
61	73	55	120	108	69	218	138	174	104	88	124	81	106	115	54	109	123	118	61	60	113	112	99	63	54
			101	107	78	133	131	101	70	72	69	74	81	108	59	135	120	132		47	123	139	108	43	42
184	220	176	107	114	134	93	105	95	105	111	102	104	100	101	136	89	96	100	122	131	96	92	89	118	121
			125	118	142	120	130	109	110	120	107	98	111	108	145	96	112	118	94	147	104	104	105	139	150
101	116	95	79	94	73	98	125	138	88	86	91	107	78	88	64	105	105	105	158	130	121	119	113	145	140
			88	90	80	113	110	128	86	79	95	120	90	93	69	124	90	92	138		122	120	109	113	119
107	109	111	70	90	83	70	144	150	81	78	86	148	80	81	66	83	103	104	135	123	102	104	102	129	120
			79	95	81	83	120	141	98	83	116	137	79	86	64	100	107	112	89	107	97	96	101	91	101
120	100	127	101	108	103	108	130	130	95	102	91	130	78	94	102	85	103	107	145	132	105	105	106	142	126
			107	109	95	130	132	154	103	90	121	134	93	90	83	88	113	108	137	115	109	101	105	122	109
111	111	113	97	112	108	99	152	182	95	96	94	145	111	101	93	87	113	102	151	118	102	99	98	146	128
			104	114	101	115	160	211	111	98	126	147	101	101	94	93	115	110	111	73	99	95	97	109	96
93	92	86	89	107	88	93	146	136	98	100	94	124	92	97	75	88	111	106	212	128	92	93	95	161	112
			85	103	87	91	130	154	95	92	99	131	86	93	94	94	103	106	90	95	89	100	97	77	99
71	83	71	68	80	79	63	48	55	84	85	84	50	81	88	74	95	72	64	58	38	64	74	78	36	33
			65	80	89	49	76	135						82		77									

CERTAIN WOODS OF THE PHILIPPINE ISLANDS

of air-dry wood in terms of density

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
$F = 20.90D_a^{1.25}$	$F = 2750D_a^{1.00}$	$F = 0.00416D_a^{2}$							$F = 7.38D_o^{1.25}$	$F = 8.37D_o^{1.00}$		$F = 2.71D_o^{2.25}$	$F = 2.17D_o^{1.33}$	$F = 2.17D_o^{1.33}$			$F = 1466D_o^{2.25}$	$F = 1365D_o^{2.25}$	$F = 1365D_o^{2.25}$		

expressed in percentage of equation values

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
95	102	98							103	109		84	99	99			87	89	89		
112	109	107	For other Philippine woods, *see* Bulletins Nos. 4 and 14, Bureau of Forestry, Philippine Islands 1907 and 1916.						116	102		113	110	110			135	135	135		
85	85	90							106	99		92	108	108			95	96	96		
107	103	114							96	96		109	98	98			108	106	106		
101	103	108							92	84		108	95	95			104	111	111		

BUILDING STONES

D. W. KESSLER

CONVERSION FACTORS

$1\ \text{kg cm}^{-2} = 14.22\ \text{lb. in.}^{-2} = 1.024\ \text{ton* ft.}^{-2}$

$1\ \text{dyne cm}^{-2} = 1.020 \times 10^{-5}\ \text{kg cm}^{-2} = 1.450 \times 10^{-5}\ \text{lb. in.}^{-2}$
$= 1.044 \times 10^{-6}\ \text{ton* ft.}^{-2}$

$1\ \text{kg}^{-1}\ \text{cm}^{2} = 1.020 \times 10^{6}\ \text{dyne}^{-1}\ \text{cm}^{2} = 0.0703\ \text{lb.}^{-1}\ \text{in.}^{2}$
$= 1.033\ \text{atm}^{-1}$

$1\ \text{g cm}^{-3} = 1000\ \text{kg m}^{-3} = 62.4\ \text{lb. ft.}^{-3} = 0.843\ \text{ton* yd.}^{-3}$

$1\ \text{joule cm}^{-2}\ \text{sec}^{-1}\ (°\text{C, cm}^{-1})^{-1} = 0.239\ \text{g-cal cm}^{-2}\ \text{sec}^{-1}\ (°\text{C, cm}^{-1})^{-1}$
$= 9.48 \times 10^{-4}\ \text{BTU ft.}^{-2}\ \text{sec}^{-1}\ (°\text{F, in.}^{-1})^{-1}$

per deg C = 0.556 per deg F.

* 1 ton = 2000 lb.

COMPRESSIVE STRENGTH

$\text{kg cm}^{-2} \times 10^{-3}$

Example: For basalt from Limburg, 3200 kg per sq. cm (4).

Basalt, Av. Range—2.0 to 3.5

Near Linz a. R.	4.7	(6)
Limburg, Nassau	3.2	(4)
Ortenberg, Hesse	2.7	(4)
Lauterbach, Hesse	2.0	(4)

Phonolite

Rothweil, Baden	3.4	(12)
Aschaffenburg, L. Franconia	3.0	(4)

Porphyry, Av. Range—2.0 to 3.0

Quartz, Beutengrund, Silesia	3.2	(12)
Quartz, Reinsdorf, Silesia	2.2	(12)
Alpirsbach, Black Forest	2.0	(4)

Quartzite, Av. Range—1.0 to 2.0

Kugelberg, Alsace	3.2	(4)
Sierk near Metz	2.9	(4)
Pipestone, Minn	2.0	(45)
White Haven, Pa	1.1	(21)

Felsite

Rohrschweger, Alsace	2.9	(4)
Kerzheim, Alsace	2.0	(4)

Diabase

Ochenkopf, Bavaria	2.7	(4)
Hasselfelde, Harz Mts	2.1	(12)
Taylors Falls, Minn	1.8	(13)

Diorite, Av. Range—1.0 to 2.5

Freiburg, Baden	2.6	(4)
Aschaffenburg, L. Franconia	2.4	(4)
Boulder Canyon, Ariz	2.0	(21)
Quartz mica, Monson, Mass	1.1	(23)

Aplite

Hingham, Mass	2.5	(41)

Syenite, Av. Range—1.0 to 2.0

Fine grained, East St. Cloud, Minn	2.0	(13)
Porphyry, Pulaski Co., Ark	2.0	(34)
Red, Beaver Bay, Minn	1.9	(13)
Gray quartzose, East St. Cloud, Minn	1.9	(13)
Coarse, Watab, Minn	1.8	(13)
Fine grained, Sauk Rapids, Minn	1.5	(13)
Cape Ann, Mass	1.1	(13)
Weinheim, Baden	1.0	(4)

Serpentine, Av. Range—0.9 to 2.0

Hollysprings, Ga	2.0	(21)
Auburn, Calif	1.8	(38)
Roxbury, Vt	1.7	(21)
Einseidel, Bohemia	1.4	(15)
Zoblitz, Saxony	0.8	(16)

Granite, Av. Range—1.0 to 2.8

Quartz-monzonite, Westerly, R. I.	2.0	(41)
Muscovite, Stone Mountain, Ga	1.9	(32)
Hornblende, Mosquito Mt., Maine	1.6	(46)
Gneiss, Branford, Conn	1.6	(41)
Biotite, Milford, Mass	1.6	(41)
Biotite gneiss, Port Deposit, Md	1.6	(21)
Riebeckite-aegirite, Quincy, Mass	1.5	(20)
Hornblende, Rockport, Maine	1.4	(41)

Granite.—(*Continued*)

Coarse biotite, Stony Creek, Conn	1.1	(13)
Gneiss, Monson, Mass	1.1	(41)
Biotite, Aberdeen, Scotland	0.8	(13)

Gabbro

Rice Pt., Duluth, Minn	1.9	(13)
Randauthal, Hanover	1.0	(4)

Lava

Niedermendig, Rhine	1.9	(6)
Fremont Co., Colo	0.7	(18)

Marble, Av. Range—0.8 to 1.5

Hematitic dolomite, Swanton, Vt	1.9	(21)
Coarse dolomite, Pleasantville, N. Y	1.6	(13)
Carbonaceous, Isle LaMotte, Vt	1.5	(21)
Dolomite, South Dover, N. Y	1.4	(21)
Dolomite, Lee, Mass	1.4	(21)
Pink fossiliferous, Knoxville, Tenn	1.2	(21)
Saccharoidal calcite, Carrara, Italy	1.1	(15)
Saccharoidal calcite, Plattsburg, N. Y	1.0	(21)
Magnesian, Gouverneur, N. Y	1.0	(21)
Dolomite, Beaverdam, Md	0.9	(21)
Graphitic dolomite, Florence, Vt	0.9	(21)
Carbonaceous, Glens Falls, N. Y	0.8	(13)
Coarse calcite, Ball Ground, Ga	0.8	(21)
Saccharoidal calcite, Rutland, Vt	0.7	(21)
Actinolitic calcite, South Dorset, Vt	0.6	(21)

Dolomite, Av. Range—0.8 to 1.5

Compact, Lemont, Ill	1.9	(13)
Compact, Red Wing, Minn	1.6	(13)
Arenaceous, Kasota, Minn	0.9	(21)
Bituminous, Marblehead, Ohio	.8	(21)
Pitted, Jefferson City, Mo	.8	(21)
Vesicular, Stone City, Iowa	.4	(3)

Essexite

Mt. Johnson, Quebec	1.8	(1)

Granodiorite

Rocklin, Calif	1.5	(43)

Labradorite

Beaver Bay, Minn	1.5	(13)

Sandstone, Av. Range—0.5 to 1.5

Quartzitic, Potsdam, N. Y	1.5	(21)
Argillaceous, Warsaw, N. Y	1.4	(41)
Calcareous, Horst, Schleswig-Holstein	1.2	(12)
Calcareous, Craigleith, Scotland	0.9	(13)
Triassic, Hummelstown, Pa	.8	(21)
Triassic, Bellville, N. J	.8	(13)
Triassic, Portland, Conn	.7	(21)
Triassic, East Long Meadow, Mass	.7	(21)
Calcareous, Dorchester, N. B	.7	(13)
Feldspathic, Vitzenberg, Thuringia	.6	(12)
Calcareous, Warrensburg, Mo	.4	(8)
Feldspathic, Aquia Creek, Va	.4	(21)
Ferruginous, Chitwood, Ore	.4	(41)

Limestone, Av. Range—0.4 to 1.4

Argillaceous, St. Paul, Minn	1.4	(13)
Compact, Lias, France	1.4	(36)
Jurassic, Chatillon, France	1.4	(36)
Aluminous, Minneapolis, Minn	1.2	(13)
Compact, earthy, Cassville, Mo	0.9	(21)
Fine-grained oolite, Marshalltown, Iowa	.9	(3)
Vesicular, Mantorville, Minn	.7	(13)
Magnesian, Andalusia, Ill	.4	(35)
Oolitic, Bedford, Ind	.4	(21)
Jurassic, Isle of Portland	.3	(33)
Oolitic, Caen, Normandy	.25	(13)
Oolitic, Bath, England	.09	(29)

Conglomerate

Wilkesbarre, Pa	1.3	(18)
Königssee, Thuringia	1.2	(12)

Breccia (Volcanic)

Boulder Canyon, Ariz	1.0	(21)

Tufa

Lilliwaup, Wash	0.8	(31)

Slate

Pen Argyl, Pa	0.7	(11)

Trachyte

Köln, Rhine	0.7	(6)

Steatite

Arrington, Va	0.6	(21)

Tuff

Oregon	0.2	(21)
Grafenberg, Bavaria	0.1	(4)

SHEARING STRENGTH

The shearing values given in this table were determined by three types of apparatus, one of which appears to give results which are too low, due to the fact that bending stresses are produced. The values determined by authority No. 41 are probably low for this reason.

$kg\ cm^{-2}$

Marble, Av. Range—100 to 300

Hematitic dolomite, Swanton, Vt	450	(21)
Dolomitic, Lee, Mass	320	(21)
Impure calcite, Carthage, Mo	310	(21)
Graphitic calcite, Albertson, Vt	260	(21)
Pink fossiliferous, Knoxville, Tenn	250	(21)
Karstmarmor, Nabresina, Istria	110	(15)
Dolomitic, Tuckahoe, N. Y	105	(41)
Siliceous, Neubeuern, Bavaria	100	(4)
Saccharoidal calcite, Carrara, Italy	90	(15)
Fine-grained, Laas, Tyrol	60	(15)

Serpentine

Weisen, Tyrol	340	(15)
Hollysprings, Ga	320	(21)
Einsiedel, Bohemia	180	(15)

Granite, Av. Range—150 to 300

Muscovite, Stone Mountain, Ga	300	(21)
Biotite, Millbridge, Maine	200	(18)
Biotite, Milford, Mass	180	(41)
Hornblende, Rockport, Mass	170	(41)
Hornblende, Cape Ann, Mass	170	(22)
Muscovite-biotite, Troy, N. H	160	(41)
Fine-grained biotite, Schwarzwasser, Poland	140	(15)
Fine-grained biotite, Mauthausen, Austria	140	(4)
Biotite, Hauzenberg, Bavaria	130	(4)
Biotite, Baveno, Italy	90	(15)

Steatite

Arrington, Va	280	(21)

Slate

Calcareous mica, Pen Argyl, Pa	250	(21)
Siliceous mica, Monson, Maine	150	(27)

Limestone, Av. Range—100 to 200

Earthy dolomite, Quincy, Ill	210	(21)
Aluminous dolomite, Mantorville, Minn	200	(21)
Gray oolitic, Bedford, Ind	170	(10)
Buff oolitic, Bedford, Ind	150	(10)
Flinty, Buffalo, N. Y	150	(41)
Oolitic, Rockwood, Ala	150	(21)
Pure white oolitic, Kehlheim, Bavaria	30	(4)

Sandstone, Av. Range—50 to 150

Triassic, East Longmeadow, Mass	190	(21)
Fine-grained variegated, Murgtal, Baden	40	(4)
Argillaceous, Hochberg, Bavaria	30	(4)
Glauconitic, Ihrlerstein, Bavaria	20	(4)

TRANSVERSE STRENGTH

Modulus of Rupture
$kg\ cm^{-2}$

Serpentine, Av. Range—100 to 350

Weisen, Tyrol	780	(15)
Hollysprings, Ga	340	(21)
Roxbury, Vt	310	(21)
Einsiedel, Bohemia	160	(15)
Auburn, Calif	90	(38)

Quartzite

White Haven, Pa	330	(21)

Marble, Av. Range—100 to 200

Hematitic dolomite, Swanton, Vt	300	(21)
Carbonaceous, Isle LaMotte, Vt	250	(21)
Fine-grained calcite, Laas, Tyrol	190	(15)
Pink fossiliferous, Knoxville, Tenn	180	(21)
Graphitic, Albertson, Vt	170	(21)
Saccharoidal calcite, Carrara, Italy	170	(15)
Karstmarmor, Nabresina, Istria	170	(15)
Fossiliferous, Plattsburg, N. Y	150	(21)
Dolomitic, Beaverdam, Md	150	(21)
Dolomitic, Lee, Mass	130	(21)
Coarse calcite, Ball Ground, Ga	110	(21)
Saccharoidal calcite, West Rutland, Vt	80	(21)

Granite, Av. Range—100 to 200

Fine-grained biotite, Mauthausen, Austria	230	(4)
Fine-grained biotite, Schwarzwasser, Poland	180	(15)
Hornblende, Cape Ann, Mass	170	(22)
Biotite, Millbridge, Maine	140	(18)
Biotite, Baveno, Italy	110	(15)
Biotite, Gefrees, Franconia	80	(4)

Sandstone, Av. Range—25 to 125

Flagstone, Lacyville, Pa	160	(21)
Quartzitic, Potsdam, N. Y	130	(21)
Triassic, Hummelstown, Pa	80	(21)
Feldspathic, McDermott, Ohio	80	(21)
Berea grit, Amherst, Ohio	50	(21)

Limestone, Av. Range—75 to 125

Arenaceous dolomite, Kasota, Minn	150	(21)
Compact earthy, Cassville, Mo	140	(21)
Flinty, Buffalo, N. Y	100	(41)
Pure white oolitic, Kehlheim, Bavaria	90	(4)
Oolitic, Bedford, Ind	80	(21)
Muschelkalk, Randersacker, Bavaria	70	(4)

TENSILE STRENGTH

$kg\ cm^{-2}$

Slate

Pen Argyl, Pa	250	(11)

Marble, Av. Range—30 to 90

Hematitic dolomite, Swanton, Vt	160	(21)
Carbonaceous, Isle LaMotte, Vt	90	(21)
Graphitic calcite, Albertson, Vt	90	(21)
Pink fossiliferous, Plattsburg, N. Y	90	(21)
Karstmarmor, Nabresina, Istria	90	(15)
Fine-grained, Laas, Tyrol	60	(15)
Coarse gr. calcite, Ball Ground, Ga	50	(21)
Dolomite, Parsberg, Bavaria	50	(4)
Saccharoidal calcite, Carrara, Italy	40	(15)
Dolomite, S. Dover, N. Y	30	(21)
Saccharoidal calcite, W. Rutland, Vt	30	(21)
Dolomite, Rehburg, Franconia	20	(4)

Serpentine

Roxbury, Vt	110	(21)
Einsiedel, Bohemia	100	(15)
Hollysprings, Ga	100	(21)
Weisen, Tyrol	60	(15)

Limestone, Av. Range—30 to 60

Compact earthy, Cassville, Mo	90	(21)
Compact earthy, Phenix, Mo	80	(21)
Arenaceous dolomite, Kasota, Minn	50	(21)
Buff oolitic, Bedford, Ind	30	(10)
Oolitic, Rockwood, Ala	30	(21)
Aluminous dolomite, Mantorville, Minn	20	(21)

Granite, Av. Range—30 to 50

Gneissoid, St. Gothard Tunnel	40	(4)
Biotite, Hausenberg, Bavaria	40	(4)
Fine-grained, Schwarzwasser, Poland	40	(15)
Biotite, Baveno, Italy	40	(15)

Sandstone, Av. Range—10 to 30

Feldspathic, McDermott, Ohio	40	(21)
Asphaltic, Liberal, Mo	20	(8)
Fine-grained variegated, Murgtal, Baden	20	(4)
Triassic, E. Longmeadow, Mass	20	(21)
Variegated, Kronach, Bavaria	10	(4)
Argillaceous, Hochberg, Bavaria	10	(4)
Glauconitic, Ihrlerstein Bavaria	10	(4)

Trachyte

Spitzberg, Bohemia	40	(15)

RESISTANCE TO ABRASION ("HARDNESS") (19)

The hardness values were determined by subjecting cylindrical specimens 2.5 cm in diameter to the abrasive action of crushed and graded quartz which is fed upon a revolving steel disc. The coefficient of hardness equals $20 - (\frac{1}{3})w$, where w is the weight of specimen worn away by 1000 revolutions of the disc.

Rhyolite, Av. Range—18 to 20

Adams Co., Pa	≮20
Milton, Calif	≮20
Boise, Idaho	15

Basalt, Av. Range—17 to 19

Nephelite, Austin, Texas	19
Olivine, Cliffs, Wash	18

Diabase, Av. Range—17 to 19

Upper Nyack, N. Y	19
Ansonia, Conn	18

Quartzite, Av. Range—16 to 19

Roanoke, Va	19
Greenbank, Del	18

Gabbro, Av. Range—16 to 18

St. Peters, Pa	19
York Haven, Pa	18

Trachyte

Colorado Springs, Colo	19

Chert

Chockie, Okla	19
Provo, Utah	17

Amphibolite

Wilmington, Del	19

Granite, Av. Range—17 to 19

Biotite, Vinal Haven, Maine	19
Biotite, Barre, Vt	19
Hornblende, Beverly, Mass	19
Aplitic, Richmond, Va	18
Biotite, Mt. Airy, N. C	18
Quartz monzonite, Milford, N. H	18

Slate, Av. Range—12 to 18

Clay, Berks Co., Pa	19
Siliceous, Montgomery Co., Pa	18
Calcareous, Waynesboro, Va	12
Heber Springs, Ark	9

Diorite, Av. Range—16 to 19

Bakersfield, Calif	19
Granite Falls, Wash	18
Glen Mills, Pa	17

Gneiss, Av. Range—16 to 19

Hornblende, Middle Valley, N. J	19
Sericite, Atlanta, Ga	18
Biotite, Hanover, N. H	18
Diorite, Derwood, Md	18
Pyroxene, Little Falls, N. Y	17

Schist, Av. Range—15 to 18

Quartz hornblende, Havre de Grace, Md	19
Sericite, Atlanta, Ga	18
Quartzite, Haverhill, N. H	18
Muscovite, Charlottesville, Va	17

Andesite

Elbe, Wash	18

Syenite

Vera Cruz, Pa	18
Charlottesville, Va	17

Sandstone, Av. Range—12 to 18

Argillaceous, Culpeper, Va	18
Ferruginous, Manassas, Va	18
Calcareous, Huntington, W. Va	16
Argillaceous, Salford, Pa	16
Chloritic, Warren, R. I	15
Ferruginous, Shreveport, La	14
Feldspathic, Parkersburg, W. Va	12
Bituminous, Provo, Utah	6
Ferruginous, Marshall, Texas	3

Serpentine, Av. Range—12 to 16

Rockville, Md	18
Blue Mountain, Pa	15
Newark, Calif	12

Limestone, Av. Range—12 to 17

Siliceous, Coyote, Calif	17
Carbonaceous, Petersburg, Ind	17
Fossiliferous, East Smithfield, Pa	16
Dolomitic, Huntington, W. Va	15
Crystalline, New Decatur, Ala	15
Dolomite, Joliet, Ill	14
Travertine, Damascus, Va	12
Argillaceous, Pontoosuc, Ill	9
Bituminous, Ravia, Okla	3

Marble, Av. Range—10 to 16

Hematitic dolomite, Burlington, Vt	17
Dolomitic, Port Kennedy, Pa	15
Graphitic calcite, Regal, N. C	14
Calcite, Ball Ground, Ga	11
Siliceous, Texas, Md	8

Tuff

Andesite, Petaluma, Calif	5

Steatite

New London, N. C	4

Impact Hardness ("Toughness") (19)

The toughness values were determined by subjecting cylindrical specimens 2.5 cm high by 2.5 cm diameter to the impact produced by the fall of a 2 kg hammer upon a steel plunger, the lower end of which is spherical and rests on the test piece. The weight is first dropped from a height of 1 cm which is increased 1 cm for each blow until the specimen breaks. The toughness is recorded as the height of the last hammer fall.

Slate, Av. Range—10 to 25

Clay, Berks Co., Pa	56
Indurated, Green Lane, Pa	40
Micaceous, Green Lane, Pa	17
Heber Springs, Ark	16
Siliceous, Montgomery Co., Pa	11
Calcareous, Waynesboro, Va	10

Sandstone, Av. Range—5 to 20

Ferruginous, Manassas, Va	47
Feldspathic, Little Rock, Ark	37
Ferruginous, Berks Co., Pa	35
Argillaceous, Culpeper, Va	24
Chloritic, Warren, R. I	24
Calcareous, Monroe, N. Y	19
Argillaceous, Hughesville, Pa	13

Sandstone.—(*Continued*)

Calcareous, Harrisburg, Pa	13
Ferruginous, Shreveport, La	8
Conglomerate, Sullivan Co., Pa	8
Calcareous, Huntington, W. Va	7
Feldspathic, Parkersburg, W. Va	6
Argillaceous, Salford, Pa	6
Bituminous, Provo, Utah	6
Ferruginous, Marshall, Texas	3

Rhyolite, Av. Range—5 to 25

Adams Co., Pa	42
Milton, Calif	20
Boise, Idaho	6

Diorite, Av. Range—8 to 25

Bakersfield, Calif	36
Granite Falls, Wash	17
Glen Mills, Pa	12

Schist, Av. Range—8 to 25

Chlorite epidote, Haw River, N. C	34
Quartz hornblende, Havre de Grace, Md	19
Sericite, Atlanta, Ga	10
Quartzite, Haverhill, N. H	10
Muscovite, Charlottesville, Va	7
Biotite, Leominster, Mass	6

Diabase, Av. Range—5 to 30

Ansonia, Conn	32
Upper Nyack, N. Y	23

Granite, Av. Range—5 to 18

Hornblende, Beverly, Mass	31
Coarse biotite, Vinal Haven, Maine	12
Biotite, Barre, Vt	9
Quartz monzonite, Milford, N. H	8
Aplitic, Richmond, Va	8
Biotite, Mt. Airy, N. C	7
Muscovite, Stone Mountain, Ga	7

Quartzite, Av. Range—5 to 25

Greenbank, Del	30
Courtland, Minn	22
Rockville, Pa	20
Roanoke, Va	14

Basalt, Av. Range—5 to 30

Hoquiam, Wash	27
Nephelite, Austin, Texas	24
Olivine, Cliffs, Wash	18
Lind, Wash	14

Gneiss, Av. Range—5 to 15

Hornblende, Middle Valley, N. J	26
Pyroxene, Little Falls, N. Y	18
Plagioclase, Clinton Co., N. Y	10
Sericite, Atlanta, Ga	8
Chlorite, East Providence, R. I	8
Diorite, Derwood, Md	7
Biotite, Hanover, N. H	6

Chert

Chockie, Okla	25
Provo, Utah	6

Limestone, Av. Range—5 to 15

Dolomite, Springfield, Mo	21
Carbonaceous, Petersburg, Ind	20
Dolomitic, Washington, Pa	14
Fossiliferous, East Smithfield, Pa	10
Siliceous, Coyote, Calif	8
Dolomitic, Huntington, W. Va	8
Dolomite, Joliet, Ill	8
Crystalline, New Decatur, Ala	7
Cherty, Akron, N. Y	7
Bituminous, Ravia, Okla	6
Shell, Fort Myers, Fla	6
Argillaceous, Pontoosuc, Ill	4
Travertine, Damascus, Va	4

Trachyte

Colorado Springs, Colo	21

Tuff

Basalt, Rio Piedras, Porto Rico	20
Andesite, Petaluma, Calif	5

Amphibolite

Wilmington, Del	18

Marble, Av. Range—2 to 10

Hematitic dolomite, Burlington, Vt	18
Dolomitic, Port Kennedy, Pa	5
Graphitic calcite, Regal, N. C	4
Siliceous, Texas, Md	3
Calcite, Ball Ground, Ga	2

Serpentine, Av. Range—8 to 15

Rockville, Md	17
Blue Mountain, Pa	11
Newark, Calif	6

Gabbro, Av. Range—8 to 22

St. Peters, Pa	17
York Haven, Pa	15

Syenite, Av. Range—10 to 15

Vera Cruz, Pa	16
Spartanburg, S. C	10
Charlottesville, Va	10

Andesite

Augite, Elbe, Wash	9

Steatite

New London, N. C	6

ELASTICITY

Young's Modulus

(Dynes cm^{-2}) $\times 10^{-11}$

Example: For oolitic Bedford limestone, 180,000,000,000 dyne per sq. cm (10).

Schist

Chlorite, Chichibu, Japan	12	(24)

Limestone, Av. Range—3 to 6

Schalstein, Rickuchyu, Japan	11	(24)
Fossiliferous, Montreal, Canada	6.4	(1)
Impure calcite, Carthage, Mo	5.4	(21)
Arenaceous dolomite, Kasota, Minn	4.0	(21)
Oolitic, Rockwood, Ala	3.8	(21)
Aluminous, Mantorville, Minn	3.0	(21)

Limestone.—(*Continued*)

Oolitic, Russelville, Ala	2.9	(21)
Oolitic, Bedford, Ind	1.8	(10)

Gabbro

New Glasgow, Quebec	11	(1)

Marble, Av. Range—5 to 7

Carbonaceous, Isle LaMotte, Vt	10	(21)
Belgian black, Dinant, Belgium	7.2	(1)
Hematitic dolomite, Swanton, Vt	7.0	(21)
Graphitic calcite, Albertson, Vt	6.3	(21)
Fossiliferous, Knoxville, Tenn	6.2	(1)
Saccharoidal calcite, Carrara, Italy	5.5	(1)
Saccharoidal calcite, Rutland, Vt	5.2	(1)
Pink fossiliferous, Plattsburg, N. Y	5.0	(21)

Diabase

Sudbury, Ontario	9.5	(1)

Slate, Av. Range—6 to 9

Siliceous, Granville, N. Y	9.0	(21)
Sandy, Rickuchyu, Japan	8.2	(24)
Calcareous, Pen Argyl, Pa	6.2	(11)
Clay, Tanba, Japan	3.2	(24)

Anorthosite

New Glasgow, Quebec	8.2	(1)

Essexite

Mt. Johnson, Quebec	6.7	(1)

Serpentine (Peridotite)

Kuzi, Japan	6.6	(24)
Roxbury, Vt	5.8	(21)
Hollysprings, Ga	3.3	(21)

Syenite (Nephelite)

Montreal, Canada	6.3	(1)

Granite, Av. Range—4 to 6

Biotite, Peterhead, Scotland	5.7	(1)
Biotite, Lake Lilly, N. B	5.6	(1)
Light gray hornblende, Rockport, Mass	5.5	(41)
Quartz monzonite, Westerly, R. I	5.1	(1)
Riebeckite aegirite, Quincy, Mass	5.0	(1)
Biotite, Aberdeen, Scotland	5.0	(5)
Biotite, Baveno, Italy	4.7	(1)
Biotite muscovite, Sanstead, Canada	3.9	(1)

Steatite

Arrington, Va	3.9	(21)

Dolomite

Yellow, Anston, Yorkshire	3.4	(5)
Siliceous, Mansfield, Nottingham	2.3	(5)

Rhyolite

Izu, Japan	2.5	(24)
Kozuke, Japan	1.9	(24)

Tuff

Rhyolite, Iyo, Japan	2.1	(24)
Rhyolite, Mikawa, Japan	1.8	(24)
Andesite, Echizen, Japan	1.3	(24)
Rhyolite, Iwashiro, Japan	1.1	(24)
Izu, Japan	0.67	(24)
Rhyolite, Tochigi, Japan	0.20	(24)

Sandstone

Feldspathic, Cleveland, Ohio	1.6	(1)
Triassic, East Longmeadow, Mass	1.6	(21)
Bluestone, McDermott, Ohio	1.3	(21)

BULK DENSITY

$g\ cm^{-3}$

Basalt, Nephelite

Austin, Texas	3.19	(19)
Debus, Bohemia	3.06	(12)
Lind, Wash	2.94	(19)

Gabbro

York Haven, Pa	3.04	(19)
Rice Pt., Duluth, Minn	2.79	(9)

Gneiss, Av. Range—2.7 to 2.95

Hornblende, Port Deposit, Md	3.04	(19)
Diorite, Amherst Co., Va	2.94	(19)
Pyroxene, Little Falls, N. Y	2.90	(19)
Chlorite, E. Providence, R. I	2.80	(19)
Sericite, Havre de Grace, Md	2.69	(19)
Biotite, Ansonia, Conn	2.69	(19)
Chloritic sericite, Potomac, Md	2.69	(19)

Breccia

Basalt, Culpeper, Va	3.00	(19)
Volcanic, Boulder Canyon, Ariz	2.46	(21)
Rhyolite, Silver Cliff, Calif	2.14	(19)

Diabase

Taylors Falls, Minn	3.00	(13)

Schist, Av. Range—2.7 to 2.95

Chlorite, Chichibo, Japan	2.97	(24)
Talc, Prov. Awa, Japan	2.94	(40)
Chlorite epidote, Haw River, N. C	2.80	(19)
Hornblende, Port Deposit, Md	2.73	(19)
Biotite, Atlanta, Ga	2.72	(19)
Sericite, Leominster, Mass	2.69	(19)
Quartzite, San Pedro, Calif	2.64	(19)

Steatite

Arrington, Va	2.97	(21)
New London, N. C	2.85	(19)

Marble, Av. Range—2.7 to 2.85

Coarse-grained dolomite, Texas, Md	2.86	(28)
Dolomitic, Lee, Mass	2.86	(21)
Small crystal dolomite, South Dover, N. Y	2.86	(21)
Hematitic dolomite, Swanton, Vt	2.83	(21)
Carbonaceous, Isle LaMotte, Vt	2.76	(21)
Magnesian, Gouverneur, N. Y	2.74	(21)
Coarse-grained calcite, Marblehill, Ga	2.72	(21)
Saccharoidal calcite, Rutland, Vt	2.71	(21)
Graphitic calcite, Albertson, Vt	2.71	(21)
Carbonaceous, Glens Falls, N. Y	2.70	(13)
Red and white, Cerfontaine, Belgium	2.21	(2)

Serpentine—Av. Range—2.7 to 2.8

Hollysprings, Ga	2.84	(21)
Peridotite, Kuzi, Japan	2.82	(24)
Roxbury, Vt	2.80	(21)
Rockville, Md	2.69	(19)
Auburn, Calif	2.54	(38)

Limestone, Av. Range—2.3 to 2.7

Dolomite, Springfield, Mass	2.80	(19)
Compact dolomite, Red Wing, Minn	2.75	(9)
Argillaceous, Clarksburg, W. Va	2.75	(19)
Argillaceous, St. Paul, Minn	2.71	(9)
Aluminous, Minneapolis, Minn	2.71	(9)
Travertine, Damascus, Va	2.69	(19)
Compact earthy, Cassville, Mo	2.66	(21)
Vesicular, Mantorville, Minn	2.65	(21)
Siliceous, Petersburg, Ind	2.64	(19)
Lithographic, Solenhofen, Bavaria	2.60	(7)
Arenaceous dolomite, Kasota, Minn	2.57	(21)
Pitted dolomite, Jefferson City, Mo	2.55	(8)
Compact, hard, Lias, France	2.40	(36)
Bituminous, Marblehead, Ohio	2.40	(13)
Magnesian, impure, Andalusia, Ill	2.34	(35)
Gray oolitic, Bedford, Ind	2.32	(21)
Buff oolitic, Bedford, Ind	2.28	(21)
Oolitic, Caen, Normandy	1.90	(13)

Slate, Av. Range—2.7 to 2.8

Calcareous, Pen Argyl, Pa	2.80	(11)
Siliceous, Granville, N. Y	2.76	(11)
Sandy, Rikuchyu, Japan	2.64	(24)
Clay, Mikawa, Japan	2.44	(24)

Diorite

Boulder Canyon, Ariz	2.77	(21)

Anorthosite

Au Sable Forks, N. Y	2.75	(26)

Quartzite

Pipestone, Minn	2.73	(45)
White Haven, Pa	2.67	(21)
E. Sioux Falls, S. D	2.64	(21)

Syenite, Av. Range—2.6 to 2.7

Coarse light-colored, Watab, Minn	2.73	(9)
Fine-grained gray, Sauk Rapids, Minn	2.71	(9)
Fine-grained gray, East St. Cloud, Minn	2.70	(9)
Porphyry, Pulaski Co., Ark	2.69	(34)
Fine-grained red, Beaver Bay, Minn	2.65	(9)
Red, East St. Cloud, Minn	2.63	(9)
Gray quartzose, East St. Cloud, Minn	2.63	(9)

Granite, Av. Range—2.65 to 2.7

Coarse biotite, Vinal Haven, Maine	2.72	(13)
Riebeckite-aegirite, Quincy, Mass	2.70	(13)
Biotite gneiss, Port Deposit, Md	2.68	(21)
Anorthosite, Au Sable Forks, N. Y	2.65	(13)
Coarse biotite, Vinal Haven, Maine	2.65	(21)
Coarse biotite, Stony Creek, Conn	2.65	(13)
Muscovite, Stone Mountain, Ga	2.63	(21)
Hornblende, Bay of Fundy, N. B	2.60	(13)

Chert

Provo, Utah	2.69	(19)

Felsite

Beaver Bay, Minn	2.69	(9)

Sandstone, Av. Range—2.2 to 2.6

Chloritic, Warren, R. I	2.69	(19)
Feldspathic, Portsmouth, R. I	2.68	(19)
Brown Potsdam, Fond du Lac, Wis	2.52	(9)
Ferruginous, Manassas, Va	2.52	(19)
Argillaceous, Logan, Ohio	2.50	(19)
Triassic, Belleville, N. J	2.26	(13)
Brownstone, Edinburgh, Scotland	2.26	(13)
Calcareous, Warrensburg, Mo	2.21	(8)
Triassic, East Longmeadow, Mass	2.17	(21)

Rhyolite

Dunbarton, Calif	2.69	(19)
Kozuke, Japan	2.46	(24)
Izu, Japan	2.10	(24)

Tuff

Rhyolite, Lake Shore, Calif	2.63	(19)
Rhyolite, Iyo, Japan	2.33	(24)
Basalt, Holcomb, Wash	2.29	(19)
Rhyolite, Douglas Co., Colo	2.19	(25)
Andesite, Petaluma, Calif	1.84	(19)
Rhyolite, Tochigi, Japan	1.37	(24)

Andesite

Echizen, Japan	2.42	(24)

POROSITY

Per cent of pore space

Diabase

Hohenberg, Bavaria	0.2	(2)
Hohenberg, Bavaria, green	0.5	(12)
Wiesbaden, Germany	1.2	(12)

Granite, Av. Range—0.5 to 1.5%

Biotite, Peterhead, Scotland	0.3	(2)
Biotite, Lysekil, Sweden	0.8	(12)
Biotite, Karlskrana, Sweden	1.0	(12)
Biotite, Malmö, Sweden	1.3	(12)
Hornblende, Pontresina, Switzerland	2.6	(39)

Basalt

Lichtenau, Westphalia, blue	0.4	(12)
Debus, Bohemia	0.5	(12)

Marble, Av. Range—0.5 to 1.0%

Graphitic calcite, Albertson, Vt	0.4	(21)
Saccharoidal calcite, Rutland, Vt	0.4	(21)
Carbonaceous, Isle LaMotte, Vt	0.5	(21)
Hematitic dolomite, Swanton, Vt	0.5	(21)
Dolomitic, Beaverdam, Md	0.6	(21)
Dolomitic, Lee, Mass	0.7	(21)
Black, Dinant, Belgium	0.7	(2)
Fossiliferous, Meadow, Tenn	0.8	(21)
Saccharoidal calcite, Carrara, Italy	0.8	(2)
Red and white, Cerfontaine, Belgium	0.9	(2)
Breccia, Besazio, Switzerland	1.5	(39)
Magnesian, Ollon, Switzerland	1.8	(39)

Limestone, Av. Range—3.0 to 15%

Glauconitic, Sachseln, Switzerland	1.0	(39)
Compact, earthy, Cassville, Mo	2.0	(21)
Oolitic, St. Ursanne, Switzerland	4.8	(39)
Pitted dolomite, Jefferson City, Mo	8.3	(8)
Compact fossiliferous, Derbyshire	8.4	(2)
Oolitic, Bowling Green, Ky	16.0	(21)
Oolitic, Bedford, Ind	16.0	(21)
Schaumkalk, La Coudre, Switzerland	17.0	(39)
Bath oolite, Monks Park, Somerset	20.0	(2)

Porphyry

Quartz, Beutengrund, Silesia	1.4	(12)

Quartzite

White, E. Sioux Falls, S. Dak.	1.5	(21)
Red, White Haven, Pa.	1.6	(21)
Pink, Ashby-de-la-Zouch, England	2.9	(2)

Sandstone, Av. Range—5 to 20%

Calcareous, Beckenried, Switzerland	1.9	(39)
Graywacke, Huttensteinach, S. Coburg-Gotha.	3.7	(12)
Flagstone, Lacyville, Pa.	5.6	(21)
Quartzitic, Potsdam, N. Y.	6.7	(21)
Yellow grit, Leeds, England	12.0	(2)
Calcareous, Hummelstown, Pa.	13.0	(21)
Brownstone, Portland, Conn.	13.0	(21)
Calcareous, Mansfield, Nottingham	15.0	(2)
Calcareous, Warrensburg, Mo.	17.0	(8)
Feldspathic, McDermott, Ohio	17.0	(21)
Triassic, East Longmeadow, Mass.	19.0	(21)
Berea grit, Amherst, Ohio	20.0	(21)
Coarse grit, Glenmont, Ohio	22.0	(21)

Gneiss

Two mica, Cresciano, Switzerland	2.5	(39)
Biotite, Castaneda, Switzerland	3.7	(39)
Muscovite, Osogna, Switzerland	4.4	(39)

Gabbro

Randauthal, Hanover	3.0	(12)

Breccia

Quartz, Mels, Switzerland	3.7	(39)

Diorite

Quartz, Pontresina, Switzerland	4.3	(39)

Serpentine

Peridotite, Hospenthal, Switzerland	6.0	(39)

Tuff

Calcareous, Oberdorf, Switzerland	17.0	(39)

Compressibility

$$\frac{1}{v}\frac{dv}{dP},\ \text{kg}^{-1} \times 10^{-6}$$

Example: For granite, the compressibility at a pressure of 2 000 kg cm^{-2} is 0.000 0021 or 0.000 21% per kg.

Granite	at 2 000 kg per sq. cm.	2.1	(44)
	at 10 000 kg per sq. cm.	1.8	(44)
Basalt	at 2 000 kg per sq. cm.	1.8	(44)
	at 10 000 kg per sq. cm.	1.5	(44)
Marble	at 2 000 kg per sq. cm.	1.4	(44)
	at 10 000 kg per sq. cm.	1.4	(44)
Limestone 0 to 12 000 kg per sq. cm			
Lithographic	at 75°C.	1.4	(7)
	at 30°C.	1.3	(7)
Diabase	at 2 000 kg per sq. cm.	1.2	(44)
	at 10 000 kg per sq. cm.	1.2	(44)

Thermal Expansion

$$\frac{1}{l}\frac{\Delta l}{\Delta t},\ \text{deg}^{-1}\ \text{C} \times 10^{-6}$$

Example: For Bedford limestone between 25 and 100°, 0.000 009 or 0.000 9% per °C.

Limestone

Semi-crystalline, Somersetshire, England	20° to 100°	22	(2)
Semi-crystalline, Somersetshire, England	100 to 200	26	(2)
Semi-crystalline, Somersetshire, England	200 to 300	27	(2)
Oolitic, Bedford, Ind.	25 to 100	9	(37)
Oolitic, Bedford, Ind.	100 to 200	17	(37)

Limestone.—(*Continued*)

Oolitic, Bedford, Ind.	200 to 300	22	(37)
Dense fossiliferous, Derbyshire, England	20 to 100	9	(2)
Dense fossiliferous, Derbyshire, England	100 to 200	16	(2)
Derbyshire, England	200 to 300	21	(2)
Mt. Vernon, Ky.	0 to 100	8.3	(41)
Dense fossiliferous, Mt. Vernon, Ky.	100 to 200	8.8	(41)
Oolitic, Bath, England	20 to 100	4.2	(2)
Oolitic, Bath, England	100 to 200	9.6	(2)
Oolitic, Bath, England	200 to 300	19	(2)

Marble

Blue calcite, Rutland, Vt.	25 to 100	16	(37)
Blue calcite, Rutland, Vt.	100 to 200	25	(37)
Blue calcite, Rutland, Vt.	200 to 300	29	(37)
White magnesian calcite, Pittsford, Vt.	25 to 100	14	(37)
White magnesian calcite, Pittsford, Vt.	100 to 200	23	(37)
White magnesian calcite, Pittsford, Vt.	200 to 300	25	(37)
Gray fossiliferous, Knoxville, Tenn.	25 to 100	10	(37)
Gray fossiliferous, Knoxville, Tenn.	100 to 200	22	(37)
Gray fossiliferous, Knoxville, Tenn.	200 to 300	27	(37)
Fine-grained, Couillet, Belgium	20 to 100	9.2	(2)
Fine-grained, Couillet, Belgium	100 to 200	19	(2)
Fine-grained, Couillet, Belgium	200 to 300	19	(2)
Saccharoidal calcite, Carrara, Italy	20 to 100	8.8	(2)
Saccharoidal calcite, Carrara, Italy	100 to 200	18	(2)
Saccharoidal calcite, Carrara, Italy	200 to 300	24	(2)
Dolomitic, Lee, Mass.	0 to 100	8.1	(41)
Dolomitic, Lee, Mass.	100 to 200	13	(41)
Dense black, Dinant, Belgium	20 to 100	4.9	(2)
Dense black, Dinant, Belgium	100 to 200	10	(2)
Dense black, Dinant, Belgium	200 to 300	14	(2)
Coarse calcite, Marble Hill, Ga.	0 to 100	3.6	(41)
Coarse calcite, Marble Hill, Ga.	100 to 200	19	(41)

Quartzite

Pink, Ashby-de-la-Zouch, England	20 to 100	16	(2)
Pink, Ashby-de-la-Zouch, England	100 to 200	20	(2)
Pink, Ashby-de-la-Zouch, England	200 to 300	20	(2)

Sandstone

Yellow grit, Leeds, England	20 to 100	12	(2)
Yellow grit, Leeds, England	100 to 200	16	(2)
Yellow grit, Leeds, England	200 to 300	19	(2)
Calcareous, Nottingham, England	20 to 100	10	(2)
Calcareous, Nottingham, England	100 to 200	15	(2)
Calcareous, Nottingham, England	200 to 300	19	(2)
Triassic, Kibbe, Mass.	0 to 100	10	(41)
Triassic, Kibbe, Mass.	100 to 200	14	(41)
Triassic, Seneca Creek, Md.	0 to 100	5	(41)

Slate

Mica slate, Hydeville, Vt.	0 to 100	12	(14)
Mica slate, Monson, Maine	0 to 100	9.4	(41)
Mica slate, Monson, Maine	100 to 200	9.7	(41)

Granite

Quartz monzonite, Westerly, R. I.	20 to 100	9	(42)
Quartz monzonite, Westerly, R. I.	100 to 200	14	(42)
Quartz monzonite, Westerly, R. I.	200 to 300	20	(42)
Biotite, Milford, Mass.	0 to 100	7.6	(41)
Biotite, Milford, Mass.	100 to 200	13	(41)
Gneissoid, Branford, Conn.	0 to 100	7.2	(41)
Gneissoid, Branford, Conn.	100 to 200	17	(41)
Muscovite-biotite, Troy, N. H.	0 to 100	6.1	(41)
Muscovite-biotite, Troy, N. H.	100 to 200	12	(41)

Diabase

20 to 100	6.3	(42)
100 to 200	9	(42)
200 to 300	12	(42)

SPECIFIC HEAT

The heat capacity of building stones, irrespective of type, varies within the rather narrow limits of 0.7–0.95 joule per g or 0.18–0.23 cal, per g or BTU per lb. for the dry stone. An occasional higher value, such as 0.28 cal per g for a serpentine from Cornwall, Eng., has been reported (17, 40).

THERMAL CONDUCTIVITY

Joules cm^{-2} sec^{-1} (°C, cm^{-1})
Room temperatures

Quartzite

Variegated, Prov. Bungo, Japan	0.054	(40)
Prov. Hizen, Japan	.031	(40)

Gneiss

Osogna, Turin	.034	(48)

Schist

Talc, Prov. Awa, Japan	.033	(40)
Granite, Simplon Tunnel	.027†§	(48)
Epidote, Prov. Awa, Japan	.018	(40)
Piedmontite, Prov. Awa, Japan	.009	(40)

Marble, Av. Range—0.02 to 0.03 (*See also infra*)

Black, Golzines, Belgium	.032	(30)
Dense fossiliferous, Knoxville, Tenn	.032	(30)
Saccharoidal, Japan	.030	(47)
Fine-grained yellow, Monte Arenti, Italy	.028	(30)
Breccia, Seravezza, Italy	.028	(30)
Carbonaceous, Isle LaMotte, Vt	.028	(30)
Yellow marble, Estremoz, Portugal	.028	(30)
Red marble, Devonshire, England	.023	(17)
Onyx, Mexico	.023	(30)
Green marble, Ireland	.023	(17)
Saccharoidal calcite, Carrara, Italy	.021	(30)
Vermont	.021	(30)

Serpentine

Prov. Hitachi, Japan	.030	(40)
Red, Cornwall, England	.020	(17)

Gabbro

Hornblende, Prov. Chikuzen, Japan	.030	(40)
Hornblende, Prov. Awadi, Japan	.018	(40)

Sandstone, Av. Range—0.025 to 0.03 (*See also* p. 315)

Hard grit, Linton, England	.029*	(17)
Hard grit, Linton, England	.026†	(17)
Flagstone, Loch Rannoch	.027‡	(17)
Flagstone, Loch Rannoch	.021§	(17)
Feldspathic, Bristol, England	.027	(17)

* Stone wet.
† Stone dry.
‡ Perpendicular to cleavage.
§ Parallel to cleavage.

Limestone, Av. Range—0.02 to 0.025 (*See also* p. 315)

Dolomite, Mansfield, Nottingham	.029	(17)
Magnesian, South Shields, England	.024	(17)
Oolitic, Musashi, Japan	.022	(40)
Oolite, Caen, Normandy	.020	(17)
Dolomite, Prov. Buzen, Japan	.018	(40)
Gritty, Boniss Island	.015	(40)
Coral, Boniss Island	.009	(40)

Conglomerate

Nagelfiue, St. Gallen	0.025	(48)
Calumet & Hecla Mine, Mich	.020	(48)

Granite

Porphyry, Prov. Omi, Japan	.024	(40)
Biotite, Aberdeen, Scotland	.023	(17)
Biotite, Prov. Yamashiro, Japan	.022	(40)

Diorite

Prov. Tanba, Japan	.023	(40)

Gneiss

Prov. Yamashiro, Japan	.021	(40)

Amphibolite

	.020	(40)

Porphyrite

Hornblende, Prov. Omi, Japan	.018	(40)
Augite, Prov. Kai, Japan	.016	(40)
Prov. Higo, Japan	.012	(40)

Tuff

Liparite, Prov. Bitchu, Japan	.017	(40)
Liparite, Prov. Harima, Japan	.014	(40)
Prov. Yamato, Japan	.007	(40)
Breccia, Prov. Yamato, Japan	.007	(40)

Rhyolite

Prov. Etchu, Japan	.015	(40)

Basalt (*See also* p. 315)

Prov. Tanba, Japan	.014	(40)

Andesite

Olivine pyroxene, Prov. Idzu, Japan	.013	(40)
Pyroxene, Prov. Satsuma, Japan	.006	(40)

Travertine

Campagna Romana	.011	(48)

Lava

Mt. Vesuvius	.008	(48)

Shale

	.008	(40)

Marble

Alabama white marble of density 2.7 g cm^{-3}, and sp. ht. 0.213 cal g^{-1}/°C gave (49), 50–100°C, 0.0257: 100–200°C, 0.0206.

THERMAL DIFFUSIVITY (40)

cm^2 sec^{-1}

Quartzite

Variegated, Prov. Bungo, Japan	0.031
Red, Prov. Bungo, Japan	.023

Schist

Piedmontite, Prov. Awa, Japan	.027
Talc, Prov. Awa, Japan	.014
Epidote, Prov. Awa, Japan	.008

Sandstone

Compact, Prov. Kawachi, Japan	.014
Feldspathic, Prov. Awa, Japan	.012

Granite	
Biotite, Prov. Yamashiro, Japan	0.013
Porphyritic, Prov. Omi, Japan	.012
Hornblende, Prov. Mikawa, Japan	.009
Two mica, Prov. Mikawa, Japan	.006
Gneiss	
Granite, Prov. Yamashiro, Japan	.013
Serpentine	
Peridotite, Prov. Hitachi, Japan	.013
Diorite	
Prov. Tanba, Japan	.012
Limestone	
Oolitic, Prov. Musashi, Japan	.011
Dolomite, Prov. Buzen, Japan	.008
Gritty, Boniss Island	.007
Coral, Boniss Island	.005
Marble (*See also infra*)	
White calcite, Prov. Mino, Japan	.011
White, Alabama (49)	.0106
Tuff	
Liparite, Prov. Harima, Japan	.009
Breccia, Prov. Yamato, Japan	.005
Pumiceous, Prov. Ugo, Japan	.004
Gabbro	
Hornblende, Prov. Awadi, Japan	.008
Rhyolite	
Prov. Etchu, Japan	.008

Basalt	
Prov. Tanba, Japan	0.007
Andesite	
Olivine, Prov. Idzu, Japan	.006
Pyroxene, Prov. Satsuma, Japan	.005
Shale	.004

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(For a key to the periodicals see end of volume)

(1) Adams and Coker, *152*, No. **46**; 06. (2) Baldwin-Wiseman and Griffith, *153*, **179**: 290; 09. (3) Bain, *154*, **8**: 370; 98. (4) Bauschinger, *162*, **1884-1889**. (5) Beare, *153*, **107**: 341; 91. (6) Bohme, *161*, **10**: 188; 92. (7) Bridgman, *12*, **7**: 81; 24. (8) Buckley and Buehler, *155*, **2**; 04. (9) Dodge, *163*, **1**: 196; 72–82.

(10) Dutton, U. S. Bureau of Standards, *O*. (11) Fuller, *Tests of physical and electrical properties of slate*, Lehigh Univ., 1921. (12) Gary, *161*, 1895–8. (13) Gillmore, *Compressive strength, etc., of various kinds of building stones*, 1874. (14) Hallock, *156*, No. **78**: 109; 91. (15) Hanisch, *B26:* 79; 18. (16) Hermann, *B27;* 14. (17) Herschel, Lebour and Dunn, *133;* 1874–9. (18) Howard, *B33:* 111; 03. (19) Hubbard and Jackson, *157*, No. **370**: 13; 16.

(20) Johnson, *B28*. (21) Kessler, *32*, No. **123**: 35; 19. (22) Mass. Inst. Tech., *B33:* 121; 03. (23) Merrill, *B29:* 498. (24) Nagaoka, *3*, **50**: 53; 00. (25) Nettleton, *164;* 86; *cf. B29:* 498. (26) Newland, *158*, No. **181; 16**. (27) Norton, *B33:* 114; 03. (28) Page, *30th. Congress, U. S.*, Doc. No. **23**. (29) Parliamentary Comm. Gt. Brit., *in B30:* 481.

(30) Pierce and Willson, *65*, **34**: 1; 98. (31) Purdue Univ., *B33:* 194; 03. (32) Reilly, *B33:* 89; 03. (33) Rennie, *B28*. (34) Rensselaer Polytechnic Inst., *B33:* 67; 03. (35) Rock Island Arsenal, *156*, **17**: 544; 06. (36) Rondelt, *in B28*. (37) Souder and Hindert, *31*, No. **352**: 415; 19. (38) Stone, *B33:* 78; 03. (39) Schweizerische Geotechnische Kommission, *B31*.

(40) Tadakora, *159*, **10**: *339*; 21. (41) Watertown Arsenal, *B32:* 385; 94. (42) Wheeler, *69*, **4**: 19; 10. (43) Williams, *160*, **1890**: 130. (44) Williamson, *143*, **193**: 491; 22. (45) Winchell, *163*, **1**: 142; 72. (46) Woolson, *The quarry industry in 1903*, p. 109 (U. S. Geol. Sur.). (47) Yamagawa, *J. Coll. Sci., Imp. Univ. Japan*, **2**: 263; 89. (48) Schulz, *308*, **9**: 345; 24. (49) Carman and Nelson, *86*, No. **122**: 29; 21.

CLAYS

H. RIES

Granite

Biotite, Prov. Yamashiro, Japan	0.013
Porphyritic, Prov. Omi, Japan	.012
Hornblende, Prov. Mikawa, Japan	.009
Two mica, Prov. Mikawa, Japan	.006

Gneiss

Granite, Prov. Yamashiro, Japan	.013

Serpentine

Peridotite, Prov. Hitachi, Japan	.013

Diorite

Prov. Tanba, Japan	.012

Limestone

Oolitic, Prov. Musashi, Japan	.011
Dolomite, Prov. Buzen, Japan	.008
Gritty, Boniss Island	.007
Coral, Boniss Island	.005

Marble (*See also infra*)

White calcite, Prov. Mino, Japan	.011
White, Alabama (49)	.0106

Tuff

Liparite, Prov. Harima, Japan	.009
Breccia, Prov. Yamato, Japan	.005
Pumiceous, Prov. Ugo, Japan	.004

Gabbro

Hornblende, Prov. Awadi, Japan	.008

Rhyolite

Prov. Etchu, Japan	.008

Basalt

Prov. Tanba, Japan	0.007

Andesite

Olivine, Prov. Idzu, Japan	.006
Pyroxene, Prov. Satsuma, Japan	.005
Shale	.004

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(10) Dutton, U. S. Bureau of Standards, *O.* (11) Fuller, *Tests of physical and electrical properties of slate*, Lehigh Univ., 1921. (12) Gary, *161*, 1895–8. (13) Gillmore, *Compressive strength, etc., of various kinds of building stones*, 1874. (14) Hallock, *156*, No. **78**: 109; 91. (15) Hanisch, *B26:* 79; 18. (16) Hermann, *B27;* 14. (17) Herschel, Lebour and Dunn, *133;* 1874–9. (18) Howard, *B33:* 111; 03. (19) Hubbard and Jackson, *157*, No. **370**: 13; 16.

(20) Johnson, *B28.* (21) Kessler, *32*, No. **123**: 35; 19. (22) Mass. Inst. Tech., *B33:* 121; 03. (23) Merrill, *B29:* 498. (24) Nagaoka, *3*, **50**: 53; 00. (25) Nettleton, *164;* 86; *cf. B29:* 498. (26) Newland, *158*, No. **181; 16.** (27) Norton, *B33:* 114; 03. (28) Page, *30th. Congress, U. S.*, Doc. No. **23.** (29) Parliamentary Comm. Gt. Brit., *in B30:* 481.

(30) Pierce and Willson, *65*, **34**: 1; 98. (31) Purdue Univ., *B33:* 194; 03. (32) Reilly, *B33:* 89; 03. (33) Rennie, *B28.* (34) Rensselaer Polytechnic Inst., *B33:* 67; 03. (35) Rock Island Arsenal, *156*, **17**: 544; 06. (36) Rondelt, *in B28.* (37) Souder and Hindert, *31*, No. **352**: 415; 19. (38) Stone, *B33:* 78; 03. (39) Schweizerische Geotechnische Kommission, *B31.*

(40) Tadakora, *159*, **10**: 339; 21. (41) Watertown Arsenal, *B32:* 385; 94. (42) Wheeler, *69*, **4**: 19; 10. (43) Williams, *160*, **1890**: 130. (44) Williamson, *143*, **193**: 491; 22. (45) Winchell, *163*, **1**: 142; 72. (46) Woolson, *The quarry industry in 1903*, p. 109 (U. S. Geol. Sur.). (47) Yamagawa, *J. Coll. Sci., Imp. Univ. Japan*, **2**: 263; 89. (48) Schulz, *308*, **9**: 345; 24. (49) Carman and Nelson, *86*, No. **122**: 29; 21.

CLAYS

H. RIES

LIST OF CLAYS AND THEIR INDEX NUMBERS

For properties, *v.* Figs. 1, 2, 3

Index No.	Type of clay	Index No.	Type of clay
1	Allophane	40	Laclede Christy raw flint clay
2	Atlas	41	Maryland flint clay
3	American ball clay	42	Ohio flint clay
4	Dorset ball clay	43	Semi-flint clay
5	English blue ball clay	44	Gibbsite
6	English white ball clay	45	Glass pot clay
7	Tennessee ball clay	46	Glenboig fire clay
8	Ayrshire bauxitic clay	47	Halifax clay
9	Bentonite	48	Halloysite
10	Refractory bond clay	49	Helmstadt clay
11	Brazil, Ind., clay	50	Kaolinite
12	Brick clay	51	Kaolin
13	Common brick clay	52	Albsheim kaolin
14	Face brick clay	53	Amberg kaolin
15	Paving brick clay	54	Australian kaolin
16	Plastic clay for No. 1 fire brick, Md.	55	Crude kaolin
17	Plastic clay for No. 2 fire brick, Md.	56	Eger kaolin
18	Bunzlau clay	57	Geisenheim kaolin
19	Cornwall china clay	58	Georgia kaolin
20	English china clay	59	Halle kaolin
21	Crucible clay	60	North Carolina kaolin
22	Czechoslovakia clay	61	St. Yrieix kaolin
23	Diaspore clay	62	Texas kaolin
24	English fire clay	63	Washed kaolin
25	Farnley fire clay	64	White sedimentary kaolin
26	Grossalmerode fire clay	65	Zettlitz kaolin
27	Halle Saxony fire clay	66	Lower Kittanning clay
28	Kittanning No. 2 fire	67	Lower Mercer clay
29	Lischwitz fire	68	Sagger clay
30	Löthian fire	69	Sewer pipe clay
31	Maryland fire	70	Aluminous shale
32	Meissen fire	71	Galesburg, Ill. shale
33	Ohio fire	72	Illinois shale
34	Ohio plastic fire	73	Ohio shale
35	Vallendar fire	74	Stoneware clay
36	Flint clay for No. 1 fire brick, Ky.	75	Cleveland surface clay
37	Flint clay for No. 1 fire brick, Md.	76	Georgia surface clay
		77	Ohio surface clay
38	Flint clay for No. 2 fire brick, Md.	78	Tionesta clay
		79	Velten clay
39	Flint clay for No. 1 fire brick, Md. and Ky.	80	Plastic fire clay
		81	Flint clay

EFFECT OF FIRING ON TRANSVERSE STRENGTH OF CLAY (10)

Clay	*	Modulus of rupture			
		Dried at 110°C, lb. in.$^{-2}$	Fired clay, hundred lb./in.^{2}		
			Cone 6	Cone 8	Cone 10
Tionesta clay: Ellis, Muskingum County, Ohio.	R	390	46	67	38
	W	468	72	83	53
Tionesta clay: Crooksville, Perry County, Ohio.	R	179	20	30	20
	W	315	66	71	37
Lower Kittanning clay (unweathered): Roseville, Muskingum County, Ohio.	R	219	32	34	27
	W	320	86	87	75
Lower Kittanning clay: Toronto, Jefferson Co., Ohio.	R	384	28	23	23
	W	532	79	48	57
New Brighton, Beaver County, Pa.	R	194	29	31	19
	W	191	49	58	34
New Brighton, Beaver County, Pa.	R	195	26	33	15
	W	321	51	52	47
Fire brick, Lawrence County, Ohio.	R	325	41	51	30
	W	499	104	72	62
Nelsonville, Hocking County, Ohio.	R	247	16	35	20
	W	350	47	62	50
Lower Mercer clay: White Cottage, Muskingum County, Ohio.	R	132	30	32	17
	W	251	57	73	47
Mogadore, Summit County, Ohio.	R	143	20	23	22
	W	259	46	48	34
Semi-flint clay: Scioto Furnace, Scioto County, Ohio.	R	94	16	21	20
	W	270	37	74	27

* R indicates run of mine, ground to pass a 20 mesh sieve. W indicates washed clay passing a 150 mesh sieve.

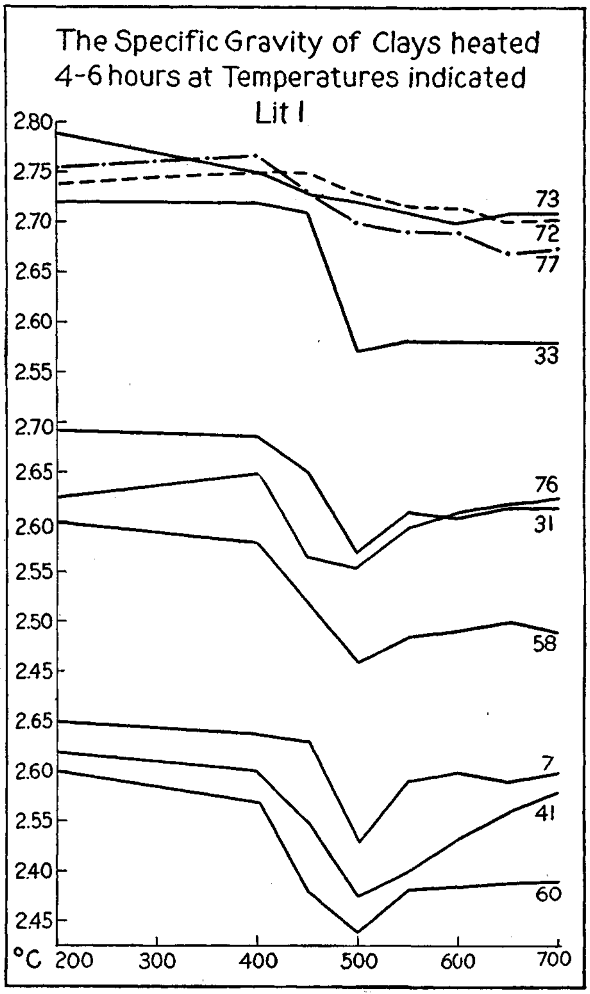


FIG. 4.

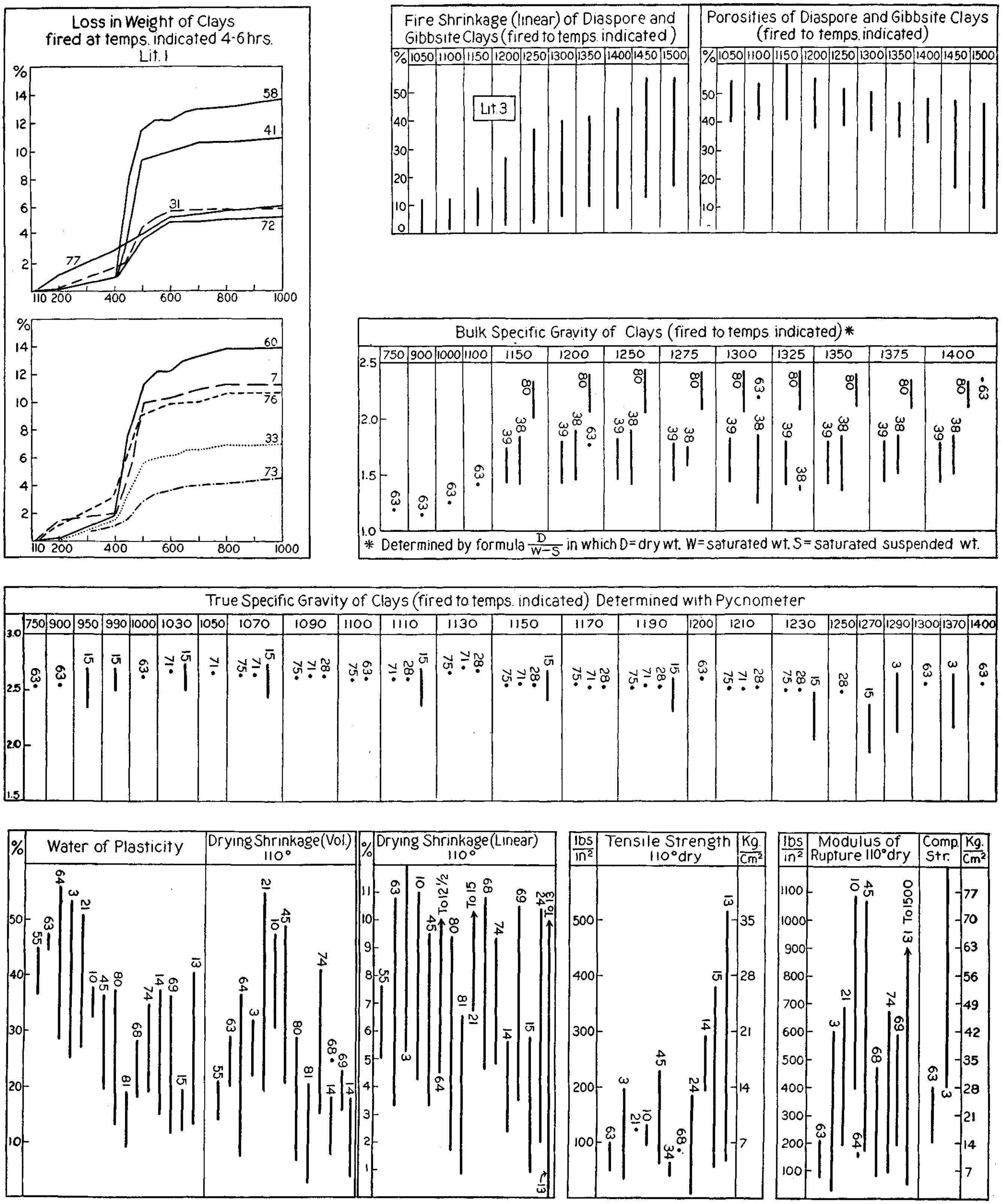

Loss in Weight of Clays fired at temps. indicated 4-6 hrs. Lit. 1
%
14
12
10
8
6
4
2
110 200 400 600 800 1000
58
41
31
72
77
60
7
76
33
73
Fire Shrinkage (linear) of Diaspore and Gibbsite Clays (fired to temps. indicated)
% 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500
Lit. 3
Porosities of Diaspore and Gibbsite Clays (fired to temps. indicated)
Bulk Specific Gravity of Clays (fired to temps. indicated)*
750 900 1000 1100 1150 1200 1250 1275 1300 1325 1350 1375 1400
2.5
2.0
1.5
1.0
* Determined by formula $\frac{D}{W-S}$ in which D = dry wt. W = saturated wt. S = saturated suspended wt.
True Specific Gravity of Clays (fired to temps. indicated) Determined with Pycnometer
750 900 950 990 1000 1030 1050 1070 1090 1100 1110 1130 1150 1170 1190 1200 1210 1230 1250 1270 1290 1300 1370 1400
3.0
2.5
2.0
1.5
% Water of Plasticity
Drying Shrinkage (Vol.) 110°
% Drying Shrinkage (Linear) 110°
To 12½
To 15
To 13
lbs/in² Tensile Strength 110° dry Kg/Cm²
lbs/in² Modulus of Rupture 110° dry
Comp. Str.
Kg/Cm²
To 1500 13

Fig. 1.

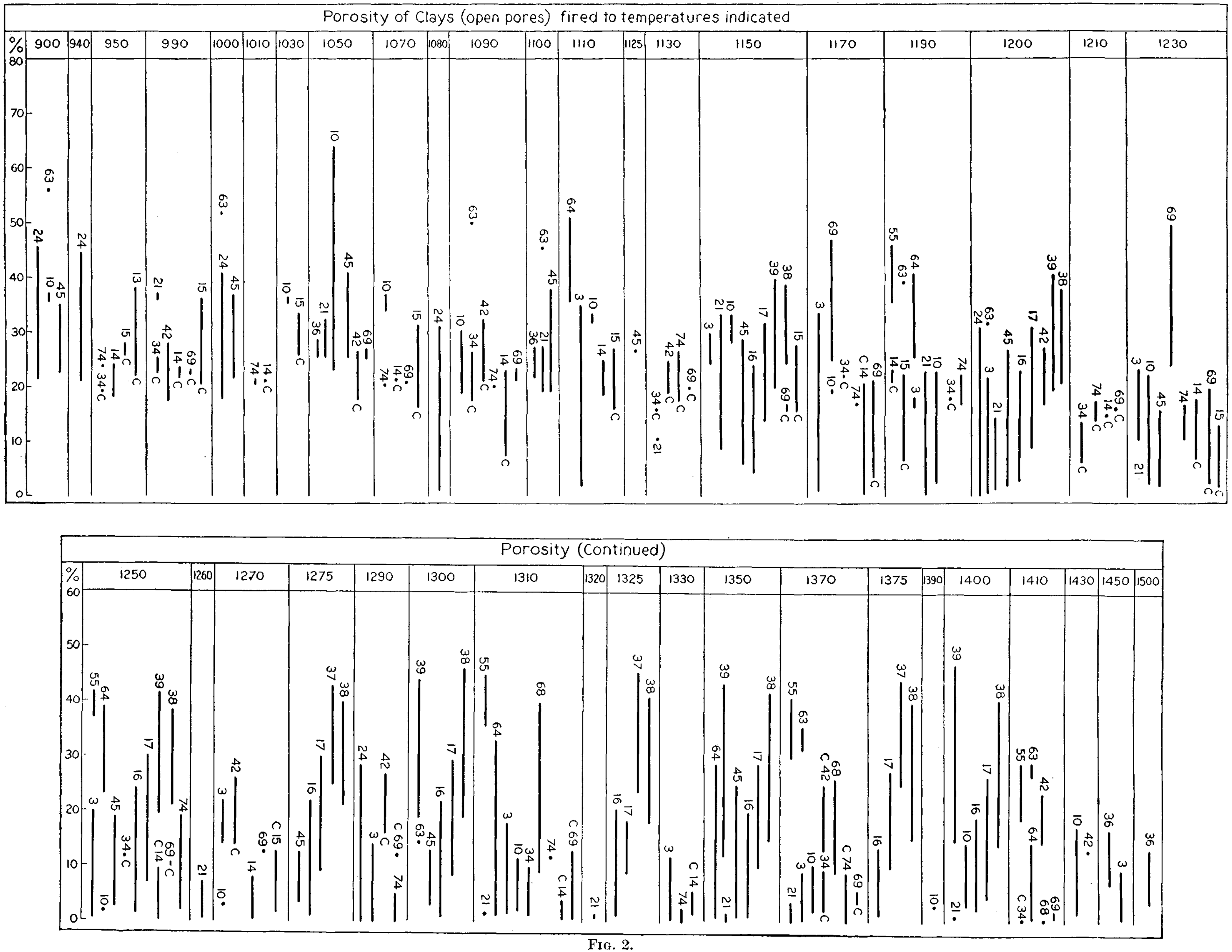
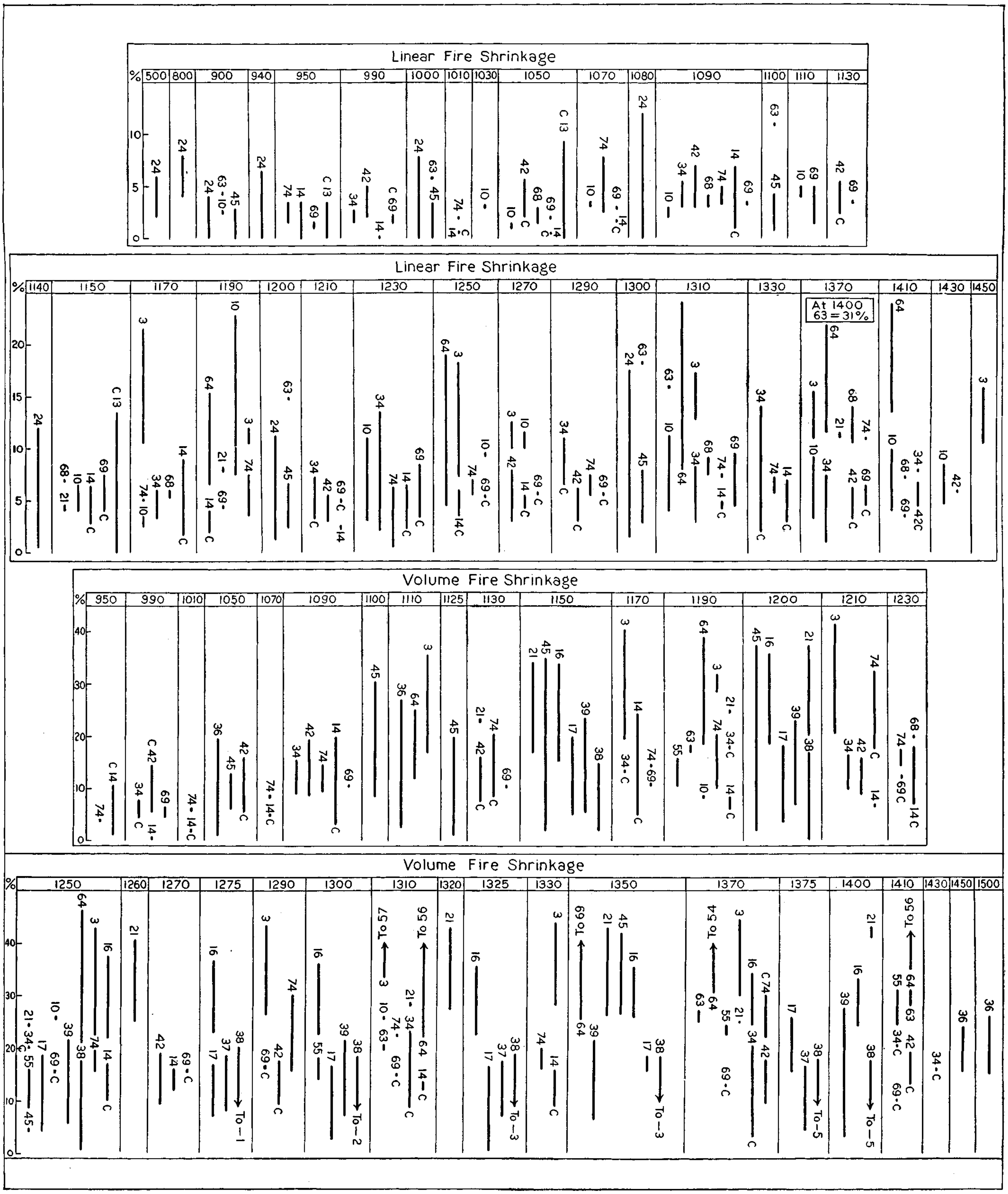

Porosity of Clays (open pores) fired to temperatures indicated
%
80
70
60
50
40
30
20
10
0
900
940
950
990
1000
1010
1030
1050
1070
1080
1090
1100
1110
1125
1130
1150
1170
1190
1200
1210
1230
Porosity (Continued)
%
60
50
40
30
20
10
0
1250
1260
1270
1275
1290
1300
1310
1320
1325
1330
1350
1370
1375
1390
1400
1410
1430
1450
1500

FIG. 2.



Linear Fire Shrinkage

Linear Fire Shrinkage

Volume Fire Shrinkage

Volume Fire Shrinkage

FIG. 3.

Linear Fire Shrinkage and Porosities of Diaspore and Gibbsite Clays (³)

B. T. = burning temperature. S = shrinkage. Por. = Porosity

B. T., °C	% S	% Por.	B. T., °C	% S	% Por.
1050	0–13	39–54	1300	5–40	36–50
1100	1–13	40–53	1350	9–42	34–48
1150	2–18	40–60	1400	9–44	32–49
1200	2–27	37–55	1450	12–55	16–48
1250	4–38	38–51	1500	17–55	9–46

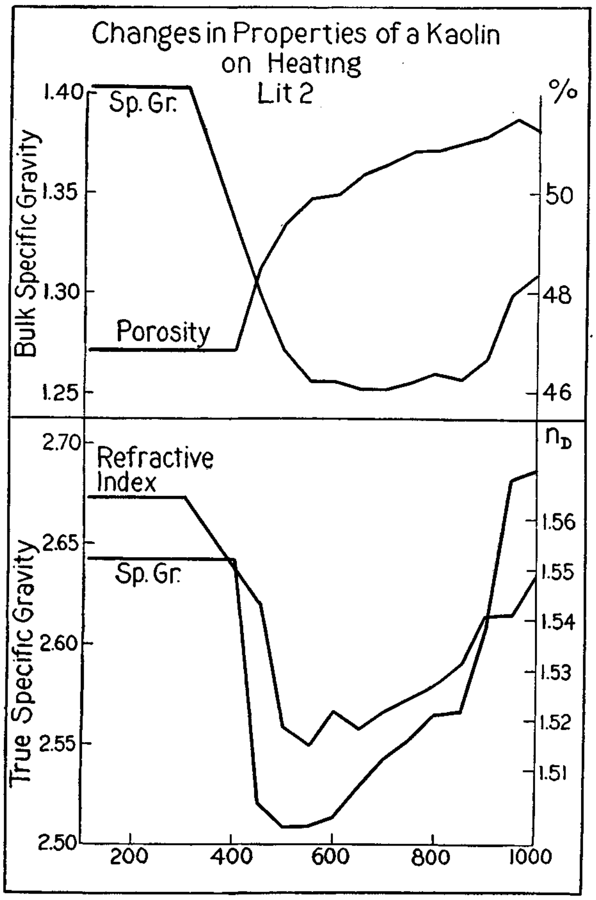


Fig. 5.

Water Ratios to Clay Volume and Weight

Clay	Ratio of pore water to shrinkage water	% water in terms true clay volume	% shrinkage water in terms true clay volume	% pore water in terms true clay volume
Ball clays	0.64–1.10			
Crucible clays	0.56–1.36	69.5–132.5	37.2–84.8	40.5–55.1
Refractory bond clay			15.5	
Glass pot clays	0.65–1.54	53.4–132.5	26.8–77.4	26.6–59.4
Plastic fire clay, Md.				
No. 1 fire brick	1.09–2.08			
No. 2 fire brick	1.13–4.15			
Stoneware clay	0.61–1.16	75–90.6	37.1–55.6	34.0–45.0

Fusion Point in Cones

Clay	Seger cone
Kaolin, washed	33 –35
White sedimentary, Ga. and S. C.	34 –35
Ball clays	30 –35
Crucible clays	30 –
Refractory bond clays	28 –33
Glass pot clays	21½–32
Stoneware clays	18 –32
Plastic fire clays, various localities	27 –35
Md., bond in No. 2 fire brick	31 –32
Flint clays, Md	32 –35
Md., No. 2 fire brick	28 –31
Ohio	31 –32½
Sagger clays	27 –28
Face brick clays	17 –30½
Common brick clays	1 –10

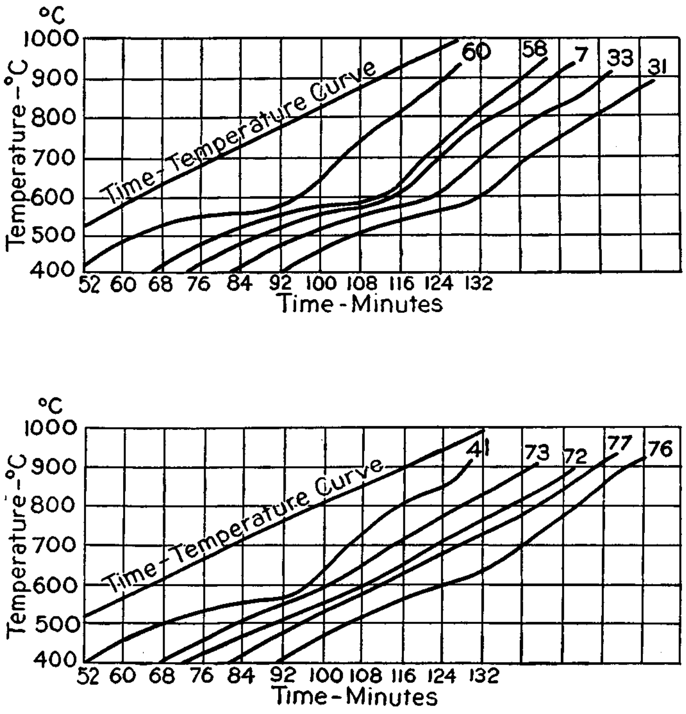


Fig. 6.—Heating curves of clays (¹).

Thermal Reactions in Clay with Temperatures at Which Reactions Have Been Noted (²), *cf.* (⁷)

Clay	Endothermic, °C	Exothermic, °C
Kaolin	500	950
Ayrshire bauxitic clay	530	950
Dorset ball clay	110 500	920
Farnley fire clay	90 510	910
Atlas clay	80 490	930
Aluminous shale	90 510	920
Halifax clay after experimental electro-osmosis	90 520	915

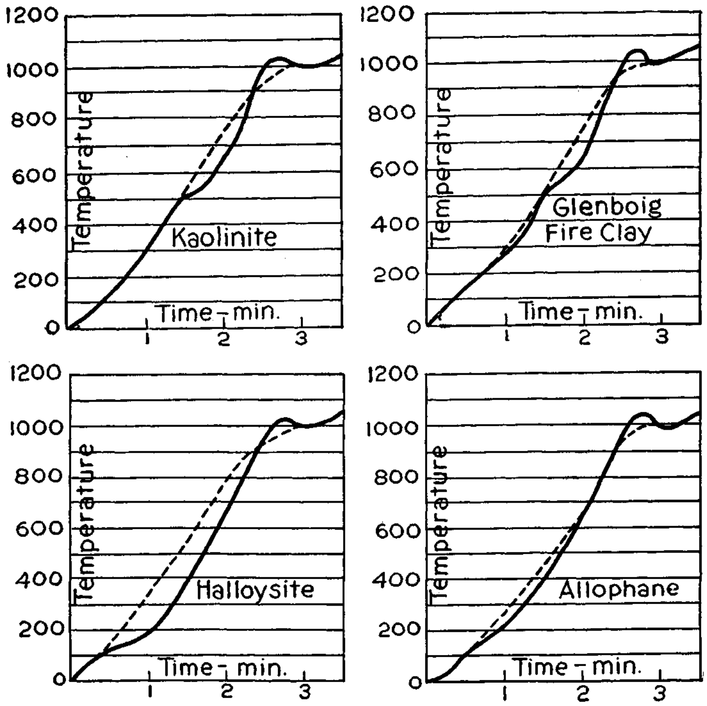


FIG. 7.—Heating curves of air-dried clays (4).

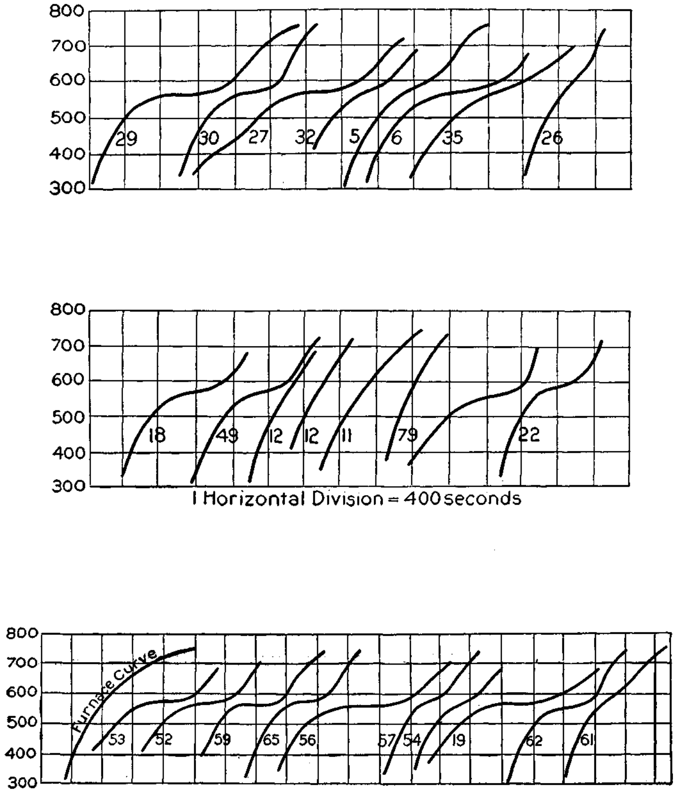


FIG. 8.—Heating curves of various clays (8).

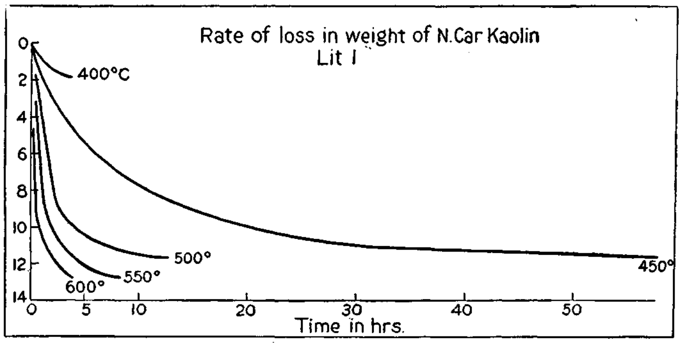


FIG. 9.

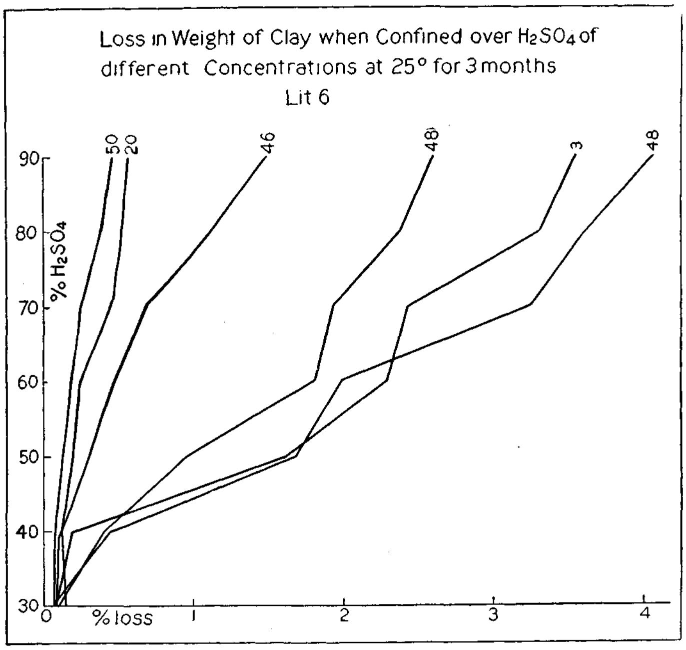


FIG. 10.

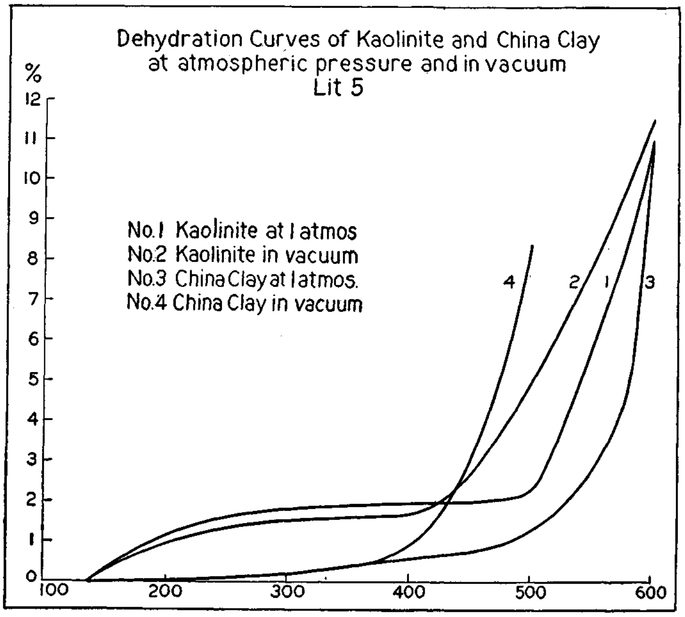


FIG. 11.

HEAT ABSORBED AND EVOLVED BY CLAY DURING FIRING AND COOLING, G-CAL/G (7)

For the first two clays the values given are the average results of two independent experiments and the deviations from this average are indicated

Clay type	Loss on ignition, %	Heat absorbed per g per deg. on heating the air-dried (110°) clay over the temperature ranges given				Heat evolved per deg. on cooling the resulting quantity of fired clay			Specific heat of the fired clay cal/g	Dehydration period		
		25–420°	420–900°	900–1200°	25–1200°	1200–900°	900–700°	1200–700°	1200–700°	Pressure rises, deg.	Period of max. pressure, 20 mm, deg.	Pressure falls to 3 mm, deg.
N. C. kaolin	14.0	0.49 ±0.07	0.69 ±0.05	0.23 ±0.01	0.50 ±0.035	0.23 ±0.01	0.28 ±0.06	0.24 ±0.05	0.28 ±0.05	25–460	460–570	570–780
A-1 English china	12.5	0.42 ±0.01	0.95 ±0.07	0.075 ±0.004	0.55 ±0.07	0.17	0.31	0.20	0.23	25–480	480–540	540–760
Tenn. ball No. 5	13.8	0.47	0.53	0.51	0.51	0.20	0.33	0.25	0.29	25–470	470–550	550–830
Laclede-Christy raw flint	13.0	0.47	0.68	0.24	0.50	0.17	0.37	0.25	0.29	25–470	470–630	630–850
Average		0.46			0.51	0.19	0.32	0.24	0.27			

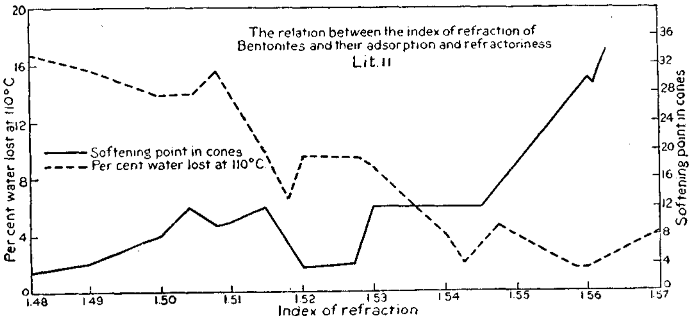


FIG. 12.

BENTONITE (12), *cf.* (9)

1. Source of samples tested: 1. Quilchena, British Columbia; 2. Camrose, Alberta; 3. Rosedale, Alberta; 4. Newcastle, Wyo.; 5. Medicine Bow, Wyo.

Sample No.	1	2	3	4	5
Sp. gr. (pycnometer)	2.44	2.73	2.72	2.77	2.78
Softening point, cone	15		14	11	10
Refractive index	1.547		1.558	1.557	
Water absorption, g per g	1.53	4.15	4.71	4.93	4.95
Loss on ignition, %					
Air drying	4.64	3.70	4.28	3.67	
At 450°C	4.04*				
At 500°C	3.94	3.60*		3.49	
At 550°C			4.17*		
At 600°C	2.53	2.09		3.43*	
At 700°C	1.50	1.14		0.77	
% remaining on 200 mesh sieve	2.18	1.58	3.16	0.95	1.21
% passing 200 mesh which settles out of water in 24 hr	76.72	10.10	13.14	29.75	11.59
% in suspension in water after 24 hr	21.10	88.32	83.70	69.30	87.20

* Capability of swelling completely destroyed.

COAGULATING EFFECTS OF REAGENTS UPON BENTONITE

Water suspensions

Sample No. / Reagent	1		3		4	
	10 g in 500 cc H_2O		2 g in 500 cc H_2O			
	Reagent, cc	Precipitate, cc	Reagent, cc	Precipitate, cc	Reagent, cc	Precipitate, cc
N HCl	4	200	10	225	4	175
$\frac{1}{2}N$ NaCl	17	200	19	275	18	215
$\frac{1}{2}N$ NH_4Cl	14	225	19	250	19	475
$\frac{1}{2}N$ $BaCl_2$	4	165	9	200	14	185
$\frac{1}{2}N$ $CaCl_2$	7	175	5	200	10	180
$\frac{1}{2}N$ $AlCl_3$	2	200	3	215	4	225
N HNO_3	4	195	3	275	4	225
$\frac{1}{2}N$ KNO_3	11	200	15	225	10	375
$\frac{1}{2}N$ NH_4NO_3	12	200	19	220	19	485
$\frac{1}{2}N$ Ba $(NO_3)_2$	5	200	3	200	4	200
$\frac{1}{2}N$ $Al(NO_3)_3$	3	220	2	215	4	225
N H_2SO_4	3	175	3	175	5	125
$\frac{1}{2}N$ Na_2SO_4	13	200	19	435	18	180
$\frac{1}{2}N$ $(NH_4)_2SO_4$	11	230	19	260	30	275
N $Al_2(SO_4)_3$	5	175	4	200	12	175
Satd. $CaSO_4$	No coagulation up to 50 cc				35	230
Satd. $Ca(OH)_2$	No coagulation up to 50 cc				36	185
$\frac{1}{2}N$ NaOH	No coagulation up to 50 cc		14	285	28	380
NH_4OH (0.9 sp. gr.)	No coagulation up to 100 cc				No coagulation up to 50 cc	
$\frac{1}{2}N$ $(NH_4)_2CO_3$	20	225	40	210	20	215
$\frac{1}{2}N$ Na_2CO_3	No coagulation up to 100 cc		14	300	25	230
CO_2	No coagulation		No coagulation		No coagulation	
$\frac{1}{2}N$ $Na_2C_2O_4$	No coagulation up to 40 cc		No coagulation up to 50 cc		30	300
CaO	g 0.3	150	g 0.5	225	g 0.3	200

EFFECT OF DILUTION, COAGULATION AND PRECIPITATION

Ten g of sample No. 3 agitated in 350 cc of water and diluted to volume given

Volume in liters / Days	% in suspension after, days				
	1	4	6	10	120
0.5	88.5	87.3	87.3	60.7	
1.0	86.5	74.1	63.4	56.7	33.6
1.5	85.4	71.3	58.3	48.5	
2.0	83.3	60.1	55.0	42.6	34.4
3.0					29.6
4.0					27.6
5.0					25 1

Properties of Some Clay-Like Minerals of the Bentonite Type(11)

Source	Index of refraction n_D	% water lost at 110°C after air drying	Softening point, cone	% water of plasticity in terms dry wt.	% vol. shrinkage in terms dry vol.	Drying behavior*	Color after firing†
Sanders, Ariz	1.48	16.6	3	71.83	69.08	B	Bf
Daggett, Cal	1.495–1.505	14.87	8	69.52	94.21	B	Bf
Creede, Colo., No. 1	1.505	14.93	12	48.07	59.00	A	Bf
Lovelock, Nev	1.505–1.525	10.82	12	78.10	77.26	C	Bf
Newcastle, Wyo	1.5175	7.26	9	114.61	161.39	B, E	Bf
Wyoming	1.5175–1.5375	9.25	4	99.21	162.73	B, D	Br
Belle Fourche, S. D	1.525–1.535	8.79	12	108.07	195.81	B, E	Bf
Creede, Colo., No. 2	1.545	1.83	12	37.30	30.16	C	Bf
Enid, Miss	1.5475	4.64	14	46.16	73.25	C	Bf
Camden, Ark	1.5575	2.19	27	37.30	41.94	C	W
Grossalmerode clay, Germany	1.56	1.34	27	22.07	24.21	C	W
Las Vegas, Nev	1.56	1.68	30				W
Glass pot clay	1.5615	3.02	29	36.08	41.94	C	W
Houston, Tex	1.563	0.27	34				W
Enid, Miss	1.563	3.25	30	29.75	32.13	C	W
New York	1.57	4.55	1	40.97	47.38	C	Bf

* A = cracks, B = cracks badly, C = does not crack, D = warps, E = becomes very hard on drying. † Bf = buff; Br = brown; W = white.

LITERATURE

(For key to the periodicals see end of volume)

(1) Brown and Montgomery, *32*, No. **21**; 13. (2) Houldsworth and Cobb, *82*, **22**: 111; 23. (3) Howe and Ferguson, *38*, **6**: 496; 23. (4) Mellor, *82*, **16**: 73; 17. (5) Mellor and Holdcroft, *82*, **11**: 169; 12. (6) Mellor, Sinclair and Devereux, *82*, **21**: 104; 22. (7) Navias, *38*, **6**: 1268; 23. (8) Rieke, *100*, **44**: 638; 11. (9) Ross and Shannon, *38*, **9**: 77; 26. (10) Schurecht, *30*, No. **233**; 20. (11) Schurecht and Donda, *38*, **6**: 940; 23. (12) Spence, *Canada*, *Mines Branch*, *Rep.* No. **626**; 24.

HEAVY CLAY PRODUCTS

H. G. Schurecht

1. CLAY BRICK: SPECIFICATIONS AND PROPERTIES

True specific gravity, 2.4–2.6 (7).
Specific heat, 20–100°C, 0.20–0.25 cal g^{-1} $deg.^{-1}C$ (1)

	Bulk density, g/cm³	Water absorption, %	Compressive strength, kg/cm²	Crossbreaking strength, modulus of rupture, kg/cm²
Vitrified brick	2.0–2.2	<5	281 to 351	56 to 84
Hard brick	1.9–2.1	5–12	175 to 281	28 to 56
Medium brick*	1.8–2.0	12–20	105 to 176	21 to 28
Soft brick	1.7–1.9	>20	56 to 105	14 to 21
Paving brick†	1.7–2.2	0.9–8.0	227 to 592	84 to 178

* Thermal conductivity = 1.6 kg-cal m^{-2} hr^{-1} $(°C, m^{-1})^{-1}$ (7), *see also* p. 314).

† Rattler loss, 22–26 % (1).

2. SAND-LIME BRICK

Compressive Strength of Sand-lime Brick Walls (9)

Walls 1.83 m long and 2.74 m high

Wall No.	Thickness, cm	Mortar	Compressive strength, kg/cm²	
			First crack	Failure
1	21.3	Lime	15.3	22.2
2	33.5	Lime	14.1	20.4
3	21.1	Cement-lime	34.0	47.8
4	33.2	Cement-lime	38.7	39.7
5	21.3	Cement	50.4	67.5
6	32.7	Cement	48.1	59.8

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3	21.1	Cement-lime	34.0	47.8
4	33.2	Cement-lime	38.7	39.7
5	21.3	Cement	50.4	67.5
6	32.7	Cement	48.1	59.8

SAND-LIME BRICK (2)

Dry brick			Effect of wetting. % change in		Effect of freezing. % change in			Effect of fire. % change in		
Compressive strength, kg/cm²		Cross-breaking strength, modulus of rupture, kg/cm²	Compressive strength	Crossbreaking strength	Compressive strength	Crossbreaking strength	Absorption	Compressive strength		Crossbreaking strength
American method	German method							Dry	Wet	
122–706	66–185	14–83	+17 to −55	+25 to −75	+38 to −55	−22 to −46	+3.8	+53 to −100	−42	−72 to −95

PER CENT WATER ABSORPTION OF SAND-LIME BRICK (10)

Plant		1 hr	24 hr	Total (boiling 5 hr)
A	Maximum	10.6	12.0	17.7
	Minimum	4.2	8.2	10.6
	Average of 1000	6.8	9.7	13.3
B	Maximum	7.9	15.3	18.0
	Minimum	4.8	11.3	12.8
	Average of 54	6.1	13.2	15.6
C	Maximum	6.9	11.9	18.3
	Minimum	5.1	10.8	15.9
	Average of 6	6.0	11.3	16.9
D	Maximum	10.5	14.2	20.6
	Minimum	5.4	11.1	15.6
	Average of 56	7.1	12.2	17.3
E	Maximum	14.4	15.4	22.0
	Minimum	5.8	13.2	18.2
	Average of 50	8.1	14.1	20.0
F	Maximum	16.3	16.7	23.5
	Minimum	8.0	13.6	18.8
	Average of 51	12.2	14.9	20.7
G	Maximum	18.0	18.4	23.8
	Minimum	13.1	15.9	21.9
	Average of 8	16.1	16.9	22.8
H	Maximum	22.4	23.0	31.2
	Minimum	8.2	16.8	18.3
	Average of 100	16.8	19.5	25.2

3. HOLLOW BUILDING TILE (2)

Water absorption, %	Compressive strength, kg/cm²						Softening temperature, °C
	Gross area including voids			Net area excluding voids			
	End	Edge	Side	End	Edge	Side	
7.5 to 26	69–373	22–185	49–97	162–798	84–315	162–414	1100–1390

5. SANITARY BODIES (4)

	Water absorption, %	Crossbreaking strength, modulus of rupture
Fire clay ware	16 to 18	70 to 92 kg/cm²
Vitreous ware	2 to 3	184 to 230 kg/cm²

6. FLOOR AND WALL TILE (6)

Water Absorption.—Vitreous, 0 to 2%. Semi-vitreous, 2 to 10%. Plain unglazed, 10%.

7. DRAIN TILE

A. S. T. M. Specifications (1).

Types.—A, Extra quality, H_2O absorption, 11%; B, Standard, H_2O absorption, 13%; C, Farm, H_2O absorption, 14%. For compressive strength, *see* Fig. 1.

8. SEWER PIPE

A. S. T. M. specifications for vitrified salt-glazed sewer pipe (1). H_2O absorption, 8%. For crushing strength, *see* Fig. 1.

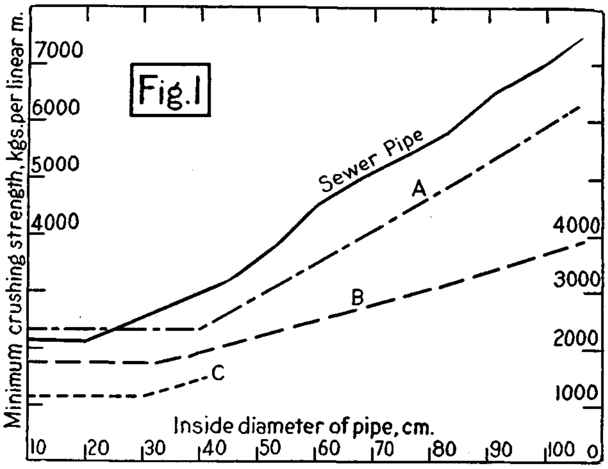
Fig. I

4. STONEWARE (7)

Type	True specific gravity	Bulk density, g/cm³	Water absorption, %	Compressive strength, kg/cm²	Tensile strength, kg/cm²	Crossbreaking strength, modulus of rupture, kg/cm²	Young's modulus of elasticity	Ball compression strength, kg	Resistance to shock, pendulum impact test, cm kg/cm²	Resistance to abrasion, sand blast tests, g/cm²	Hardness, scleroscope	Linear coef. of expansion, per °C	Specific heat, 20°–100°C, g-cal g⁻¹ per °C	Softening cone	Heat conductivity, kg-cal m⁻² hr⁻¹ (°C, m⁻¹)⁻¹	Dielectric constant
Common	2.44–2.65	2.06–2.37	0.03–5.1	3248–5833	63–116	234–416	4189– 6850	476–1044	1.26–1.90	3.0–9.9	39–62	4.1×10^{-6} to 4.9×10^{-6}	0.185–0.191	17–29	0.95–1.35	
Chemical	2.45–2.53	2.28–2.32	0.13–1.80	5816	163–178	416–980	5087–15130	792–980	1.70–2.40	2.4–3.9	55–64	4.9×10^{-6} to 5.7×10^{-6}		17–30	1.00–1.25	5.17

9. TERRA COTTA BODIES (5)

Water absorption, 10 to 19 %. Crossbreaking strength, modulus of rupture, 105 to 180 kg/cm². Linear coefficient of expansion, 17° to 100°C, (3.7 to 6.0) × 10^{-6} per °C.

10. CRUSHING STRENGTH OF MASONRY WITH DIFFERENT MORTARS (8)

Brick employed: 23 × 11 × 5.5 cm (nine different types). *a*, Cement mortar, 1:3. *b*, Lime mortar. *c*, Mortar mixtures. a + b (1:1).

Strength of one meter cubes of masonry in kilograms

a	*b*	*c*
1929	1959	1977
1908	1940	1955
1852	1885	1903
1772	1812	1851
1722	1780	1829
1713	1771	1823
1715	1770	1824
1709	1767	1821
1709	1765	1819

According to Kreuger (11) the compressive strength of a brick pier is *ca.* 0.22 × the compressive strength of the brick used in its construction. The corresponding relation to the compressive strength of the mortar used is shown in Fig. 2.

LITERATURE

(For a key to the periodicals see end of volume)

(1) American Society for Testing Materials, Specifications. (2) Emley, *32*, No. **85**: 35; 17. (3) Foster, *38*, **7**: 189; 24. (4) Fuller, Bureau of Standards, *O*. (5) Fuller and Merrit, Bureau of Standards, *O*. (6) Pence, *81*, **17**: 484; 15. (7) Singer, *Keramik* (Braunschweig, Vieweg und Sohn). 470; 23. (8) Svenson, *314*, **36**: 341; 12. (9) Whittemore and Stang, *32*, No. **276**: 65; 25.

(10) Johnson, Bureau of Standards, *O*. (11) Kreuger, *314*, **40**: 597; 16.

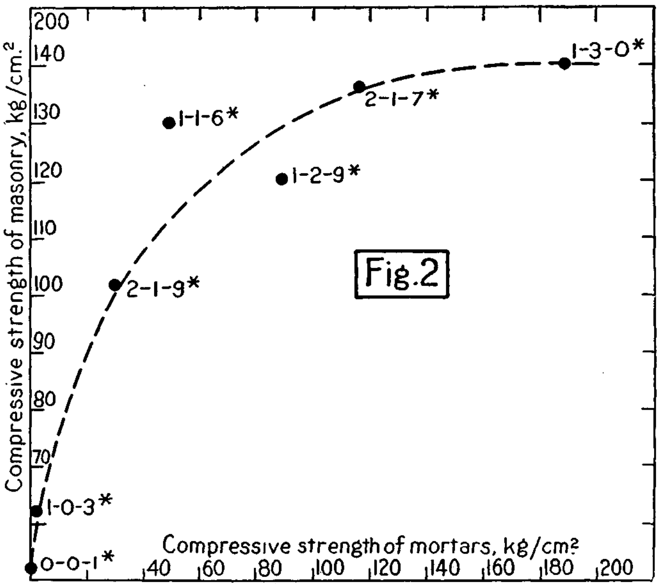

Fig.2

* Compositions of mortars: lime-cement-sand.

PORCELAIN AND WHITEWARE

I. Electrical porcelain. II. Laboratory porcelain and white ware. Owing to the overlapping of these two classes a certain amount of duplication occurs in the tables but for the complete data both sections should be consulted.

I. Porcelaines électriques. II. Porcelaines et faïences de laboratoire. Etant donné le chevauchement de ces deux classes, il y a un certain nombre de répétitions dans les tables; pour avoir des données complètes, les deux sections doivent être consultées.

I. Elektro-Porzellan. II. Laboratoriums Porzellane und Steingut. Da beide Gattungen in engerer Beziehung stehen, ist eine gewisse Wiederholung in den Tafeln vorhanden. Doch sollen für vollständige Daten beide Abschnitte herangezogen werden.

I. Porcellane elettriche. II. Porcellane di laboratorio e grès ceramico. Per la stretta relazione tra le due categorie, vi è qualche ripetizione nelle tabelle. Per avere dati completi bisogna però consultare entrambi i capitoli.

9. TERRA COTTA BODIES (⁵)

Water absorption, 10 to 19 %. Crossbreaking strength, modulus of rupture, 105 to 180 kg/cm². Linear coefficient of expansion, 17° to 100°C, (3.7 to 6.0) × 10^{-6} per °C.

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(For a key to the periodicals see end of volume)

(¹) American Society for Testing Materials, Specifications. (²) Emley, *32*, No. **85**: 35; 17. (³) Foster, *38*, **7**: 189; 24. (⁴) Fuller, Bureau of Standards, *O*. (⁵) Fuller and Merrit, Bureau of Standards, *O*. (⁶) Pence, *81*, **17**: 484; 15. (⁷) Singer, *Keramik* (Braunschweig, Vieweg und Sohn). 470; 23. (⁸) Svenson, *314*, **36**: 341; 12. (⁹) Whittemore and Stang, *32*, No. **276**: 65; 25.
(¹⁰) Johnson, Bureau of Standards, *O*. (¹¹) Kreuger, *314*, **40**: 597; 16.

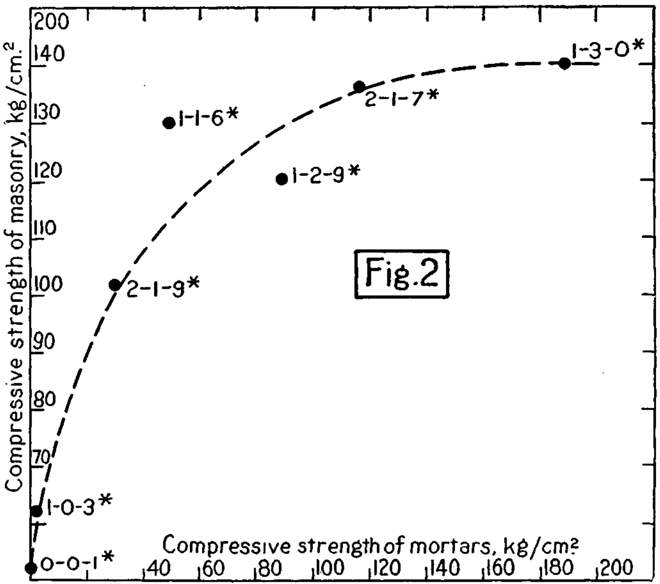


Fig.2

*Compositions of mortars: lime-cement-sand.

PORCELAIN AND WHITEWARE

I. Electrical porcelain. II. Laboratory porcelain and white ware. Owing to the overlapping of these two classes a certain amount of duplication occurs in the tables but for the complete data both sections should be consulted.

I. Porcelaines électriques. II. Porcelaines et faïences de laboratoire. Etant donné le chevauchement de ces deux classes, il y a un certain nombre de répétitions dans les tables; pour avoir des données complètes, les deux sections doivent être consultées.

I. Elektro-Porzellan. II. Laboratoriums Porzellane und Steingut. Da beide Gattungen in engerer Beziehung stehen, ist eine gewisse Wiederholung in den Tafeln vorhanden. Doch sollen für vollständige Daten beide Abschnitte herangezogen werden.

I. Porcellane elettriche. II. Porcellane di laboratorio e grès ceramico. Per la stretta relazione tra le due categorie, vi è qualche ripetizione nelle tabelle. Per avere dati completi bisogna però consultare entrambi i capitoli.

I. ELECTRICAL PORCELAIN

FRANK H. RIDDLE[1]

Classification of Porcelains Based on Their Use

I. Normal porcelains.
  (*A*) Low tension porcelain, porosity, 1%.
    Dry or wet process used under 5000 volts. Flint, clay, feldspar porcelain.
  (*B*) High tension porcelain, porosity, 0%.
    Wet process used above 5000 volts. Flint, clay, feldspar porcelains.
II. Special porcelains.
  (*C*) Spark plug core porcelains, porosity, 0%.
    Usually free from free quartz which has objectionable expansion and alkalis which have an injurious effect upon the insulation at increased temperatures.
  (*D*) Heating element porcelains, porosity, 1%.
    Usually containing over 50% magnesia compounds.
  (*E*) Thermocouple porcelains for protection.
    High in alumina and free from free quartz.

Practically nothing is available in the literature regarding low tension porcelain or heating element porcelain.

Fig. 1 Application of local heating (22)

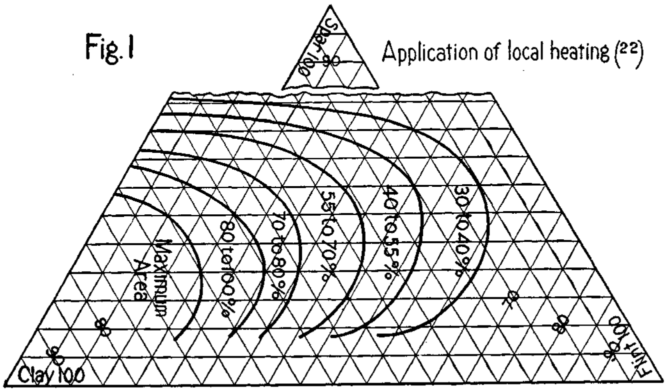
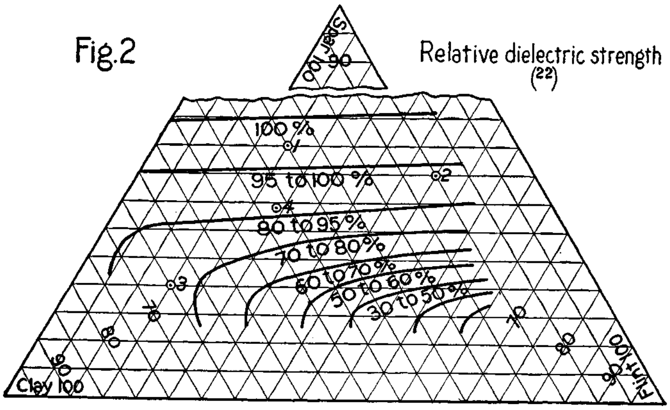


Fig. 2 Relative dielectric strength (22)



Chemical Composition of Fired Body and Batch Composition of Raw Body

Typical compositions of the possible range of raw bodies are shown in Figs. 1, 2, 3 and 4. These figures can be used only as a general guide, since they do not portray the effects of the different varieties of clay, feldspar and flint, or the methods of grinding, etc.

The actual compositions of some of the bodies whose properties are listed in the following pages are shown below, together with the reference numbers by which they are identified in the tables.

BODY COMPOSITIONS

Calcines, wt. % (Chamotte, Aufbereitungsstoffe, Materiali digrassanti)

	Cone	$MgCO_3$	Kaolin	Flint	Al_2O_3	Boric acid
(*A*)	12	14.40	44.30	41.30		
(*B*)	13	18.20	56.00	25.80		
(*C*)	18		70.20		27.80	2.0
(*D*)	18		55.80		44.20	
(*E*)		23.85	76.15			

Fig. 3 Compositions Areas of commercial wares (22)

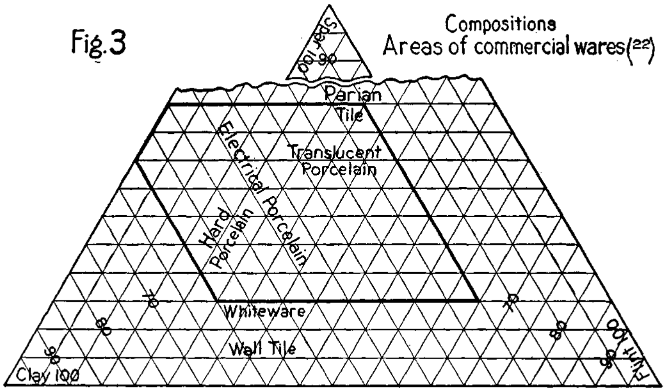
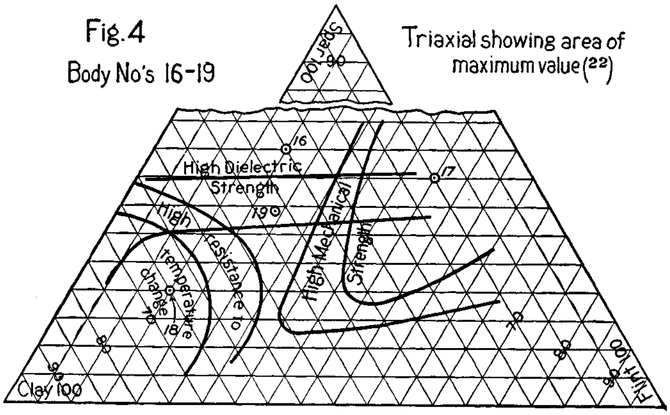


Fig. 4 Body No's 16-19 Triaxial showing area of maximum value (22)



Bodies, wt. % (Matières céramiques, Keramische Massen, Paste ceramiche)

Ref. No.	1	2	3	4	5	6	7	8	9	10	11
Clay	35	35	45	45	50	50	55	55	55	55	65
Flint	40	30	30	20	25	15	10	22.5	15	5	10
Feldspar	25	35	25	35	25	35	35	22.5	30	40	25

Ref. No.	15	16	17	18	19	20	21	22	23	24	25
Clay	40	35	15	65	42	*	22	30.2	40	50.0	50.0
Sillimanite											30.0
Flint	15	20	45	15	24					32.5	2.5
Feldspar	45	45	40	20	34					16.0	16.0
Al_2O_3							18	12.6			
Whiting										1.5	1.5
Calcine							60D	57C	20B 40C		
Cone	10 to 14					18	32	30	17	11	11

* Natural sillimanite (andalusite) with clay bond.

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[1] Grateful acknowledgments are due to Dr. Joseph A. Jeffery for the privilege of carrying out considerable research work in the research laboratories of the Champion Porcelain Company; to Messrs. H. F. Royal, E. K. Bibb, Walter Schmidt, and to Miss Chenoweth and other members of the staff for valuable aid in the assembling and classification of data; and to Messrs. L. E. Barringer and F. W. Peek, Jr., of the General Electric Company, for much valuable information.

Ref. No.	26	27	28	29	30	31	32	33	34	35
Clay	50.0	50.0	50.0	50.0	45	50	55.0	60	50	45
Calcined clay	20.0	8.5	35.0	5.0						35
Flint	18.5				27	26	15.0	10	30	
Sillimanite		30.0		30.0						
Feldspar	10.0	10.0	13.5	13.5	28	24	28.5	30	8	
Whiting	1.5	1.5	1.5	1.5			1.5			
Calcine									12E	20A

Ref. No.	36	37	38	39	40	41	42	Range %*	Standard %†
Clay	50	50	46	46	50	50	50	40–55	50
Feldspar	25	16	26	21	20	20	20	25–30	30
Flint	25	34	28	33	30	30	30	15–25	20

* For satisfactory bodies (20).

† A standard composition (20).

CHEMICAL COMPOSITION

Ref. No.	1	2	3	4	5	6	7	24*	25*	26*	27*	28*	29*
SiO_2	74.08	70.81	69.23	65.96	66.78	63.51	61.08	72.51	52.10	64.59	49.81	55.93	50.38
Al_2O_3	15.63	17.47	18.50	20.34	19.95	21.79	23.22	22.60	42.24	30.86	45.05	38.40	44.10
TiO_2	0.40	0.40	0.56	0.56	0.64	0.64	0.72	0.16	0.12	0.15	0.24	0.19	0.23
Fe_2O_3	0.48	0.50	0.59	0.61	0.64	0.66	0.71	0.14	0.59	0.53	0.64	0.66	0.63
CaO	0.25	0.32	0.27	0.34	0.28	0.35	0.36	1.05	1.10	1.07	1.11	1.13	1.13
MgO	0.22	0.25	0.26	0.29	0.28	0.31	0.33	0.18	0.26	0.22	0.28	0.28	0.27
K_2O	2.72	3.67	2.79	3.74	2.83	3.78	3.82	1.98	2.18	1.58	1.67	2.07	1.98
Na_2O	1.39	1.75	1.57	1.93	1.66	2.02	2.11	1.08	1.31	1.05	1.20	1.34	1.28
Ignition loss	4.83	4.83	6.24	6.24	6.94	6.94	7.65						

* Fired body.

Petrographic Character of Insulator Porcelains

A comparative petrographic study of a number of insulator porcelains of American, French and German manufacture leads to the following conclusion.

A good porcelain insulator made from clay, feldspar and flint should consist largely of a glassy matrix with embedded crystals of quartz and mullite ($3Al_2O_3.2SiO_2$) evenly distributed throughout. The quartz should not exceed 20 to 25%, preferably less, and the fragments should have rounded edges and corners, as indicating partial solution by the feldspar glassy matrix. The average grain size of the quartz should not exceed 0.03 to 0.04 mm diameter, and the particles should be evenly distributed. No clay or partially decomposed clay particles should be present. The crystals of mullite should be abundant, well-formed, evenly distributed, and should not exceed *ca.* 0.01 mm length by 0.002 mm thickness.

Owing to the very close resemblance between mullite and sillimanite crystals, the following crystallographic characterization is given (9, 70).

	Mullite $3Al_2O_3.2SiO_2$	Sillimanite $Al_2O_3.SiO_2$
Crystal system	Orthorhombic	Orthorhombic
Prism angle, $110 \wedge 1\bar{1}0$	89° 13′	88° 15′
Cleavage	∥ 010	∥ 010
Optic orientation	$\acute{c} = \gamma$ and $a = \alpha$	$\acute{c} = \gamma$ and $a = \alpha$
Refractive indices γ	1.654	1.677
Refractive indices α	1.642	1.657
Axial angle, $2V$	+45°, −50°	+25°, −30°

BULK DENSITY, SPECIFIC GRAVITY AND POROSITY

1. Typical electrical porcelains for high-tension work

Specific gravity	Bulk density, g/cm³	Open-pore porosity, %	Total porosity, %	Type	Lit.
2.3–2.5				Hermsdorf	(53)
2.46	2.317		5.8	Berlin hard	
2.45	2.233	1.80	8.9	DTS sill. Z54	(53)
2.45	2.276	0.19	7.3	DTS sill. Z55	(53)
	2.24–2.35			In general	(4)
		0.01		Elec. average of 8	(63)
2.46	2.25		7.7	Elec. Ref. No. 15	(48)

2. Special spark plug and vitrified pyrometer porcelains (48)

2.77	2.54	0.00	8.4	"Sill." spark plug 6012, Ref. No. 20
3.03	2.83	0.00	6.8	Artificial mullite, Ref. No. 21
2.89	2.72	0.00	5.7	Artificial mullite, Ref. No. 22

Coefficient of Cubical Compressibility

$\frac{10^6 dV}{VdP}$ = 1.4 to 1.8 per atm. The lower figure is for highly siliceous, and the latter for highly feldspathic, porcelains (56).

TENSILE STRENGTH (DEF. 4)

kg/cm²	Type	Cross section*	Lit.
843.6	Sill. (mullite)	0.864 cm²	(38)
684	Sill. (mullite)	0.864 cm²	(39)
519	Insulator	3.226 cm²	(20)
514	Sill. (mullite)	6.45 cm²	(39)
421.8	Insulator average of 7†	0.864 cm²	(12)
360	Hermsdorf 103	3.14 cm²	(53)
320	Berlin hard	3.14 cm²	(53)
261	Rosenthal H	7½ × 2 cm	(56)
240	Various	7½ × 2 cm	(15)
178	DTS sill. Z54	0.314 cm²	(53)
163	DTS sill. Z55	7½ × 2 cm	(53)
140–260	Various	7½ × 2 cm	
130–200	Hermsdorf		(42)
122	Marquardt	7½ × 2 cm	(53)
98	Insulator	7½ × 2 cm	(45)

* The area of the cross section of the test piece is important, *see* Fig. 5.

† Batch weights and chemical compositions of these bodies are shown under Ref. Nos. 1–7.

ILLUSTRATING THE INFLUENCE OF THE GLAZE

All pieces made of the same body and all burned together (40); *see also* especially (21.1)

kg/cm²	623	720	642	305
Type	No glaze	Best glaze	Good glaze	Crazed glaze

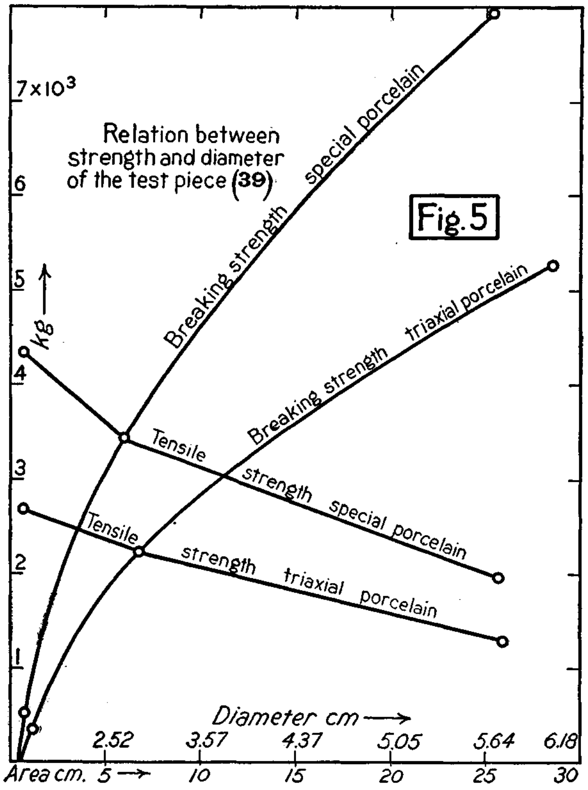
Compare the tensile and crushing strengths of American and German bodies. The German bodies have a greater crushing strength, the American bodies a greater tensile strength.

Modulus of Rupture*

kg/cm²	Type	Lit.	kg/cm²	Type	Lit.
590	Insulator......	(45)	500		(49)
580	DTS sill. Z55..	(53)	490	Hermsdorf.....	(46)
595–469	Average of 7 elec.†........	(38)	416	DTS sill. Z54..	(53)
560–420		(19)	246	Marquardt....	(53)
540	Insulator H...	(46)			

* Extruded cyl. pieces 120 mm long, and 16 mm diam., burned hanging in vertical position and sawed to length. Supported on steel knife edges 10 cm apart and loaded centrally, 1 kg per sec.

† For compositions *see* Ref. Nos. 1–7, inclusive. For effect of glaze *see* (21.1).



Crushing Strength

Unit is 1000 kg/cm²

Strength	Type	Remarks	Lit.
5.8*	DTS sill....................		(53)
≯5.6*	Hermsdorf....................		(53)
≯5.0*	Rosenthal H................	2.11 cm²	(46)
4.8–4.2	Hermsdorf....................	16 × 16 mm	(56)
4.5	Insulator.....................		(45)
4.2	Berlin hard...................	2.5 cm cubes	(42)
4.0	Sill. average of 7.............	4.90 cm²	(39)
4.0†	Insulator.....................		(56)
2.5†	Insulator average of 3.........	2.54 cm diam.	(38)
1.6–1.8‡	....	6 × 3 cm	(8)
1.0	Marquardt....................		(53)
4.2–3.1§	Elec. various..................	Cyl. 3.14 cm²	(44)

* The higher values are probably due to the use of cylindrical test pieces instead of square ones. In 1920 the German committee appointed to arrange standard tests decided on a test piece 16 × 16 mm diameter. According to Demuth (15) test pieces smaller than 50 × 50 mm are too small and the high results obtained are misleading.

† For compositions *see* Ref. Nos. 4, 5 and 7.

‡ The higher value is for glazed, the lower for unglazed.

§ For compositions *see* Ref. Nos. 8–11.

Crushing Strength between Spheres* (53)

kg	982	792	748
Type..........	DTS sill. Z55	DTS sill. Z54	Marquardt

* The Gary press (43) used for this test holds a piece 1 cm thick and 10 cm wide between steel balls 31.7 mm in diameter, through which the pressure is applied. Results calculated to correspond to a disc 1 mm thick.

Modulus of Elasticity (Def. 10)

The unit is 1000 kg/mm²

Modulus	Type	Remarks	Lit.
10.6	"G. E."..................	Bending	(10)
10.2	"G. E."..................	Tensile (*v.* Fig. 1)	(10)
8.9	Marquardt................	Bending	(53)
8.7	O. S. Univ................	Tensile	(10)
8.4*	Rosenthal................	Bending	(56)
8.3	Berlin hard...............	Bending average of 72	(59)
8.0–7.0	Hermsdorf................		(53)
7.8	Rosenthal................		(53)
7.8	Insulator..................		(53)
7.1–5.4	Hermsdorf 104............	End support	(19)
7.0	Average...................		(4)
7.0–5.0	Hermsdorf 1915...........		(42)
6.5	DTS sill. Z55............		(53)
5.1	DTS sill. Z54............		(53)
8.9	Westinghouse.............	Bending 12.7 mm rod	(20)
6.3	Hermsdorf 1921...........	End support	(56)
5.2	Westinghouse.............	Bending 19 mm rod	(20)

* With varying loads this value varied from 8.4 to 17.9 with the same test pieces and under uniform conditions. Tests made by Steger's method (59).

The modulus is dependent more upon the conditions of manufacture than upon chemical composition. It is substantially the same for tension and compression. For G. E. porcelain Boyd (10) found the following relations: $D = 0.133L$ for compression; $D = 0.133L$ for bending; $D = 0.143L$ for tension; where D = deformation in 0.00001ths. and L = load in kg-cm⁻².

Modulus of Elasticity in Shear (Def. 11)

kg/cm²	Type	Lit.	kg/cm²	Type	Lit.
600–480	Hermsdorf 103	(53)	481	Insulator 101 G	(46)
500	Rosenthal H	(46)	430	Seger 6833*	(46)
500	Rosenthal laboratory porcelain	(46)	323	DTS sill. Z54	(53)

* Square test piece.

Fixed Impact and Bending Shock (Def. 16)*

cm-kg-wt./cm²	Rosenthal porcelains	Lit.	cm-kg-wt./cm²	Type			Lit.
2.4	Spec. 6412..........	(56)	1.9	Hermsdorf			(53)
1.61	Spec. 6048..........	(45)	1.8	DTS sill. Z54			(53)
1.38	Spec. 6048..........	(56)	1.7	DTS sill. Z55			(53)
1.23	Laboratory..........	(56)	Cone 15	Spar	Kaolin	Quartz	Lit.
1.00	Seger 6833..........	(56)					
0.95	Insulator H.........	(56)	1.43	34	48	18	(61)
0.90	Insulator G.........	(56)	1.29	26	46	28	(61)
0.08	Hard 6292...........	(56)	1.23	25	50	25	(61)

* Pendulum-hammer method. 16 × 16 × 120 mm bar, 100 mm span, 10 cm-kg-wt. blow (53).

SUCCESSIVE INCREASING IMPACT SHOCKS*

cm-kg-wt./cm³	Rosenthal porcelain	Lit.
146	Stoneware 6412	(56)
117	Laboratory	(56)
105	Insulator H	(56)
98	Insulator G	(56)
69	Seger 6833	(56)
10	Marquardt	(53)

* Marten's method consists in letting a weight drop from successively increasing heights upon a disc-shaped test piece until rupture occurs. The effect is measured in cm-kg-wt. per unit volume of the test piece. Result independent of size of test piece.

RESISTANCE TO ABRASION

Gary sand blast test, 2 min at 3 atm

Type	Loss in cm³	Lit.
Insulator G	2.4	(46)
Rosenthal (Selb.) H	3.3	(46)
Marquardt 1	10.3	(14)
DTS sill. Z54	2.5	(53)
DTS sill. Z55	3.9	(53)
Seger hard 6412	1.7	(46)

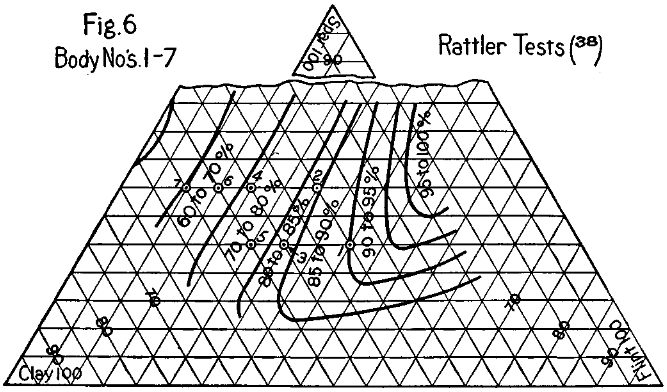


Fig. 6
Body No's. 1-7
Rattler Tests (38)

TOUGHNESS AND HARDNESS BY THE "RATTLER" TEST*

Per cent loss of weight by rattler test (38).

15 min	30 min	3 hr	Type
2.2	3.5	10.6	1, Fig. 6
3.2	5.2	14.4	2, Fig. 6
4.4	8.8	21.6	3, Fig. 6
8.0	14.5	27.4	4, Fig. 6
5.1	9.6	23.6	5, Fig. 6
7.8	12.2	29.6	6, Fig. 6
10.2	14.2	33.6	7, Fig. 6

* The 15 min test is an indication of the toughness or resistance to chipping. The 3 hr test is an indication of hardness after edges and corners are gone.
Ratio: Marquardt to DTS sill. Z54, is 2.6, time not stated (53).

With a constant clay content the higher spar and lower flint body is invariably weaker. Increase in clay and decrease in flint decreases strength. The compositions of the bodies are plotted on the triaxial diagram, Fig. 6. Note the relation between loss in wt. and body composition.

Tests were carried out under the following conditions: 13 test pieces 2.25 × 2.25 × 5.0 cm with square edges. Tested in porcelain jar mills 24.75 cm diam. × 33 cm long inside rotating at 40 r.p.m. Besides the test pieces there were 61 pebbles weighing 10 kg. The test pieces were removed and weighed at the time specified.

SOFTENING POINT

Cone	Type	Lit.
20	Ref. No. 15	(48)
18	Ref. No. 16	(48)
15 down	Raw Ref. No. 17	(48)
31	Ref. No. 18	(48)
20 down	Ref. No. 19	(48)
26	American Typical insulator	(48)
27	French	
31 tipped	German	
32 down	"Sill." spark plug	(48)

Softening point varies with size and shape of test piece, time of heating, etc.

COEFFICIENT OF THERMAL EXPANSION

$\frac{10^6 \Delta l}{l \Delta t}$	Type	Range, °C	Lit.
4.25	Hermsdorf		(53)
4.00	G. E.		(2)
5.42	Lock insulator ('09)	20–101	(65)
5.35		19–243	(65)
3.79	High tension	16	(55)
3.79	Rosenthal	20–100	(56)
3.80	Seger 6833	20–100	(53)
6.66	Elec. 1 EL	20–500	(11)
4.36	Elec. 1 EL	20–400	
4.85	Elec. 2 EL	400–600	(11)
5.2	Marquardt		(53)
2.7	Fired to Cone 26 ($Al_2O_3.SiO_2$)	25–200	(37)
3.9		200–400	(37)
3.3		25–400	(37)
3.36	"Sill." spark plug; Ref. No. 23	30–200	(6)
4.19		200–400	(6)
4.78		400–500	(6)
3.81		30–400	(6)
5.3	Ref. No. 24	25–400	(37)
3.5	Ref. No. 25	25–400	(37)
5.5	Ref. No. 26	25–400	(37)
3.5	Ref. No. 27	25–400	(37)
3.3	Ref. No. 28	25–400	(37)
3.7	Ref. No. 29	25–400	(37)
6.17	High tension	?	(20)
5.27	High tension	?	(20)
3.43	$Al_2O_3.SiO_2$ vitrified at cone 32	119.0	(67)
3.78		230.5	
4.01		317.7	
4.16		392.7	
4.40		512.7	
3.63	$3Al_2O_3.2SiO_2$ vitrified at cone 32	117.0	
3.95		216.5	
4.18		304.3	
4.36		383.3	
4.62		492.5	
2.37	Average of five refractory porcelains	114.2	(68)
3.07		234.7	
3.69		357.2	
4.00		482.6	
4.21		601.7	
4.51		724.1	
4.84		844.2	

Resistance to Thermal Shock

The recorded data are not comparable owing to lack of standard methods *v.* (8, 54, 66, 29). The *relative* heat shock strengths of a series of electrical porcelains covering the whole range of compositions is shown in Fig. 4 (22). Substitution of ZrO_2 for SiO_2 improves the resistance to thermal shock (60, 69). "Sillimanite" (mullite) porcelains have a greater resistance than ordinary kinds.

VOLUME RESISTIVITY

Temp., °C	Sp. resist. Megohm-cm	Type	Lit.
613–900	0.068–1.098		(33)
727	0.007	Berlin	(17)
727–1292	0.100–0.0034		(33)
20	129 × 10⁶		(16)
189	0.385 × 10⁶		(16)
300	19	Stand. G. E. plastic	(2)
350	9		(2)
400	3.5		(2)
500	1.5		(2)
600	0.8		(2)

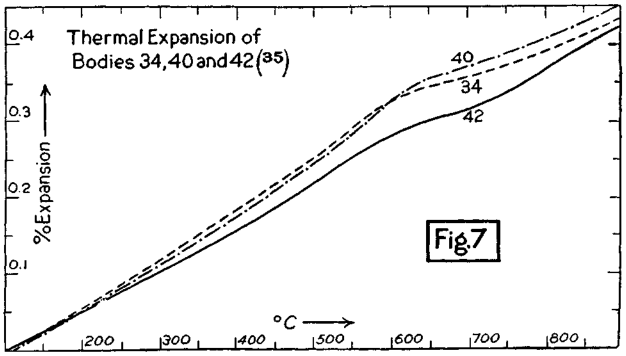


Fig. 7

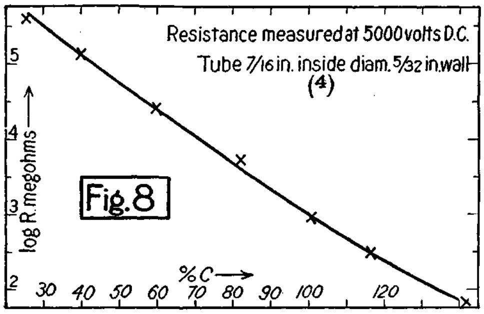


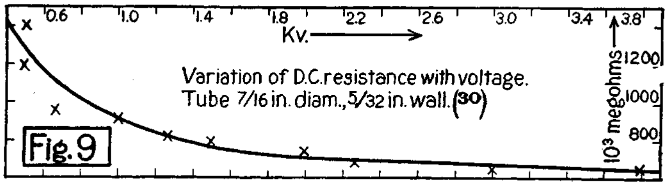
Fig. 8

Some experimenters compare porcelains by finding the temperature at which the resistance is equal to one megohm-cm. They have termed this temperature the "effective temperature," T_E; *see also* Figs. 8, 9 and 10.

T_E, °C	Composition	Cone	Lit.
370	Ref. No. 30	14	(52)
358	Ref. No. 31	14	(52)
390	Ref. No. 32	12	(52)
400	Ref. No. 33	10	(6)
590	Ref. No. 34	15	(6)
610	Ref. No. 35	16	(6)
690	Ref. No. 23	16	(6)

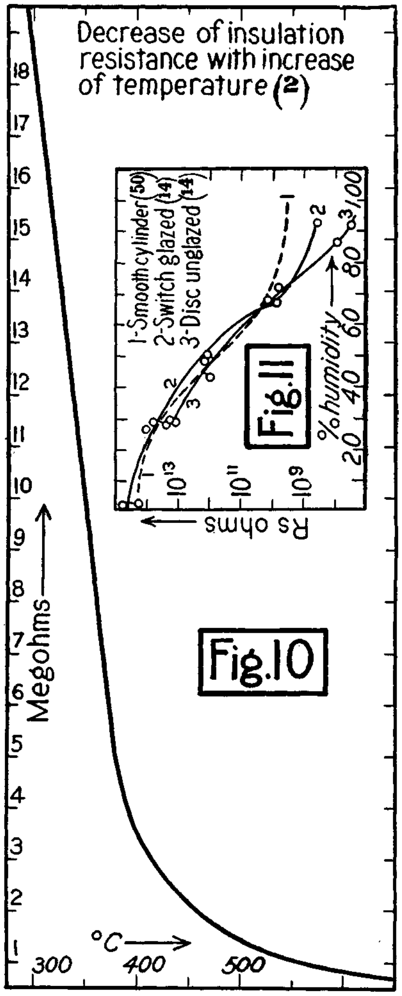
SURFACE RESISTIVITY

Varies enormously with humidity of the atmosphere and with the nature of the surface film. For variation of the resistivity of a *clean* surface with atmospheric humidity, *see* Fig. 11.



Variation of D.C. resistance with voltage. Tube 7/16 in. diam., 5/32 in. wall. (30)

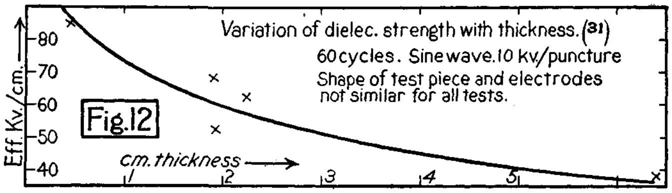
Fig. 9



Decrease of insulation resistance with increase of temperature (2)

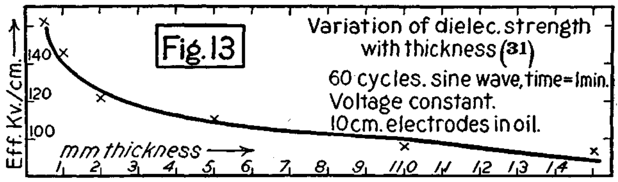
Fig. 11

Fig. 10



Variation of dielec. strength with thickness. (31)
60 cycles. Sine wave. 10 kv./puncture
Shape of test piece and electrodes not similar for all tests.

Fig. 12



Variation of dielec. strength with thickness (31)
60 cycles. sine wave, time = 1 min.
Voltage constant.
10 cm. electrodes in oil.

Fig. 13

DIELECTRIC CONSTANT

6.15 for a G. E. wet process porcelain at 10^5 cycles, 25°C and 60% relative humidity (2); *see further* p. 80.

DIELECTRIC STRENGTH

1. Shape of the electrodes not given. Voltage increased 1 kv/2 sec, starting at 20 kv under oil

Volts per mm	Type	Remarks	Lit.
10 000	Hermsdorf.........	5 mm thick test porcelain	(19)
9 000	Hermsdorf.........	10 mm thick test porcelain	(19)
$\frac{1}{30}$ of above	....	At 275°C	(19)
16 000	Royal Berlin.......	$2\frac{1}{2}$ mm thick	(42)
17 200	Ref. No. 36......	5 mm discs. Cone 15	(61)
12 500	Ref. No. 37......		(61)
18 100	Ref. No. 38......		(61)
20 300	Ref. No. 39......		(61)
27 400	Ref. No. 40......		(61)
18 300	Ref. No. 41......		(61)
28 700	Ref. No. 42......		(61)

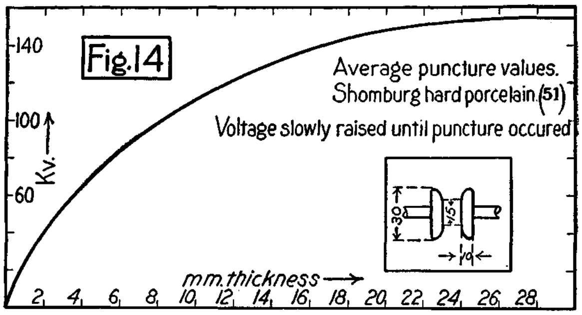


Fig.14

Average puncture values. Shomburg hard porcelain (51)

Voltage slowly raised until puncture occured

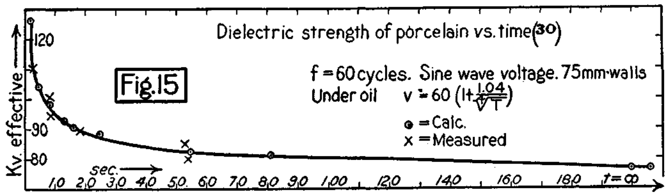


Fig.15

Dielectric strength of porcelain vs. time (30)

f = 60 cycles. Sine wave voltage. 75 mm walls Under oil $v \doteq 60\left(1+\frac{1.04}{\sqrt{T}}\right)$

2. 25°C under oil, 12.7 mm electrodes with rounded edges, voltage increased 1 kv per sec

9 100	Ref. No. 16......	Test piece 6.35 mm to 9.14 mm. 60 cycle sine-wave voltage	(3)
9 400	Ref. No. 17......		(3)
10 600	Ref. No. 18......		(3)
8 400	Ref. No. 19......		(3)

According to Peek (31) the puncture tests on solid insulators vary greatly between different samples of the same material, shape and area of the electrodes, time of application of voltage, etc.; *see* Figs. 12–16.

DIELECTRIC LOSSES

For variation of dielectric losses and power factor with frequency, *see* (25).

FLASH-OVER VOLTAGE

Effect of humidity, Fig. 18.
Effect of length of test piece, Fig. 17.

ELECTROLYSIS OF HOT PORCELAIN

Above 300° porcelain behaves as an electrolytic conductor, the alkali metals migrating toward the cathode. For experimental details, results and conclusions, *v.* Haber (23).

VELOCITY OF SOUND

Velocity km/sec	Type	Lit.	Velocity km/sec	Type	Lit.
5.63	Insulator H	(46)	5.05	Hermsdorf hard	(46)
5.34	Seger 6833	(46)	4.9–5.2	In general	(56)

Velocity of transmission, or vibration of sound, varies with the modulus of elasticity. Porcelains having the highest velocity are the best. Velocity increases with increasing clay content.

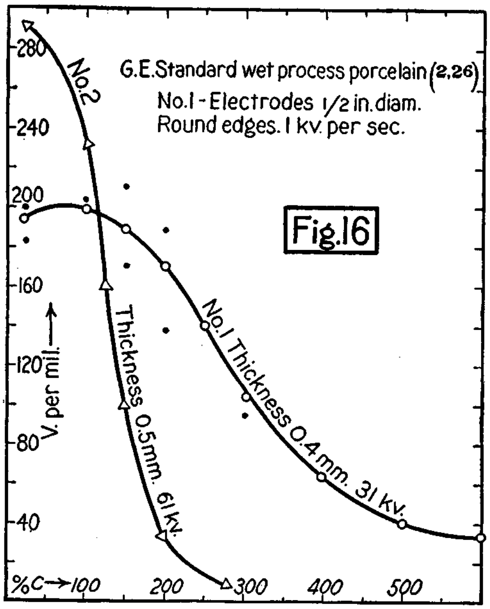


Fig.16

G.E. Standard wet process porcelain (2,26)

No.1 - Electrodes 1/2 in. diam. Round edges. 1 kv. per sec.

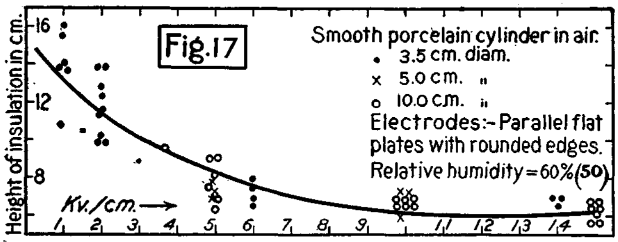


Fig.17

Smooth porcelain cylinder in air.

Electrodes:– Parallel flat plates with rounded edges. Relative humidity = 60% (50)

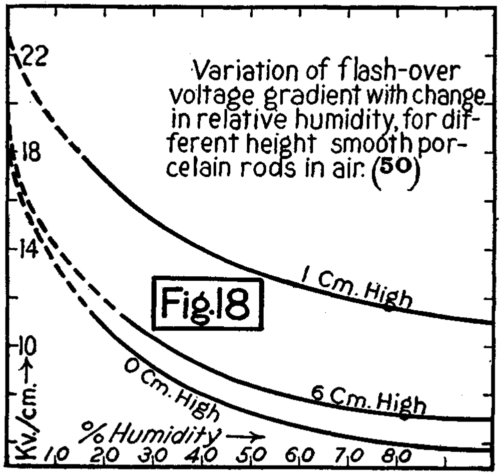


Fig.18

Variation of flash-over voltage gradient with change in relative humidity, for different height smooth porcelain rods in air. (50)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Austin, *129*, **30**: 2303; 11. (2) Barringer, General Electric Co., Schenectady, *0*. (3) Bibb, Jeffery DeWitt Insulator Co., Kenover, West Virginia, *0*. (4) Bleininger, *33*, **16**: 589; 17. (5) Bleininger, *109*, **1919**: 101. (6) Bleininger and Riddle, *38*, **2**: 564; 19. (7) Boudouard, *106*, **1920**: 681. (8) Boudouard, *102*, **24**: 79; 21. *103*, **29**: 496; 21. (9) Bowen, Grieg and Zies, *128*, **14**: 183; 24.

(10) Boyd, *122*, **38**: 222; 16. (11) U. S. Bureau of Standards, *0*. (12) Champion Porcelain Co., Detroit, *0*. (13) Curie, *6*, **17**: 385; 89. (14) Curtis, *31*, No. 234; 14. (15) Demuth, *101*, **41**: 892; 20. (16) Dietrich, *63*, **11**: 187; 10. (17) Doelter, *B10*. (18) Foussereau, *6*, **5**: 241; 85. (19) Friese, *B12*.

(20) E. H. Fritz, Westinghouse Electric and Manufacturing Co., East Pittsburgh, *0*. (21) Gary, *100*, **56**: 429; 23. (21.1) Gerold, *103*, **33**: 188; 25. (22) Gilchrist and Klinefelter, *B6*. (23) Haber, *93*, **57**: 154; 08. (24) Harker, *3*, **10**: 430; 05. (25) Haworth, *5*, **81**: 221; 08. (26) Henderson and Weimer, *81*, **13**: 469; 11. (27) Henning, *8*, **22**: 631; 07. (28) Honaman and Fonseca, *109*, **1919**: 91. (29) Meyer, *101*, **40**: 278; 19.

(30) F. W. Peek, Jr., General Electric Co., Pittsfield, Mass., *0*. (31) Peek, *B7*. (32) Peek, *107*, **76**: 1061; 20. (33) Pirani and Siemens, *9*, **15**: 969; 09. (34) Purdy, *81*, **13**: 550; 11. (35) Purdy, *81*, **15**: 499; 13. (36) Purdy and Potts, *81*, **13**: 431; 11. (37) Riddle, *38*, **2**: 804; 19. (38) Riddle, Champion Porcelain Co., Detroit, *0*. (39) Riddle and Laird, *38*, **5**: 385; 22.

(40) Riddle and Laird, *38*, **5**: 500; 22. (41) Rieke, *103*, **22**: 143; 14. (42) Rieke, *92*, **28**: 374; 15. (43) Rieke and Gary, *B5*. (44) Rosenthal, *100*, **48**: 445; 15. (45) Rosenthal and Singer, *101*, **41**: 705; 20. (46) Rosenthal and Singer, *103*, **29**: 81, 93; 21. (47) Roth, *100*, **55**: 533; 23. (48) Royal, Champion Porcelain Co., Detroit, *0*. (49) Rziha and Seidener, *B8*.

(50) Schwaiger, *101*, **43**: 875; 22. (51) J. F. Scheid, H. Schomberg and Sons, Margarethenhütte, Saxony, Germany, *0*. (52) Silsbee and Honaman, *109*, **1919**: 79. (53) Singer, *0* and *B4*. (54) Singer, *92*, **31**: 221, 227, 229; 18. (55) Singer, *112*, **9**: 96; 20. (56) Singer and Rosenthal, *104*, **1**: 3; 20. *105*, **5**: 175; 21. *100*, **54**: 250; 21. (57) Starke, *8*, **60**: 629; 97. (58) Steger, *124*, **2**: 51; 14. (59) Steger, *103*, **27**: 113; 19.

(60) Twells and Lin, *38*, **4**: 195; 21. (61) Urban, *103*, **32**: 217; 24. (62) Wagner, *125*, **3**: 67; 14. (63) Washburn and Bunting, *38*, **5**: 527; 22. (64) Waters, *32*, No. **105**; 17. (65) Watts, *81*, **11**: 84; 09. (66) Watts, *81*, **11**: 179; 09. (67) Spencer, National Lamp Works, Nela Park, Cleveland, *0*. (68) MacGee, U. S. Bureau of Mines, *0*. (69) Geller and Woods, *38*, **4**: 842; 21. (70) Grieg, *12*, **11**: 1; 26.

II. LABORATORY PORCELAINS AND WHITEWARES

JAMES A. AUDLEY[1]

A Classification of Porcelains and Whitewares Based on Their Composition and Properties

I. Body vitrified Little or no porosity.
  (*A*) Porcelain. More or less translucent.
    1. Hard porcelain.
      Body and glaze fired up together to a comparatively high temperature, with or without a previous low fire biscuiting. Glaze composition approximating that of the body, but with lime and often zinc oxide added.
    2. Soft porcelain.
      (*a*) Seger porcelain.
      (*b*) Frit porcelain.
      (*c*) Bone porcelain.
      (*d*) Belleek.
      (*e*) Parian (biscuit or figure porcelain).
  (*B*) Stoneware. Not translucent.
II. Body not completely vitrified, porous.
  (*C*) General whiteware (earthenware).
    This includes a variety of wares which pass under different trade names (semi-porcelain, white granite, etc.), but almost imperceptibly grade into one another, and into porcelain at one extreme.

Examples illustrating composition are given further on.

Wall tiles and floor tiles may be of porcelain, stoneware, or earthenware. They are made chiefly by the dry press process.

Electrical porcelain possesses properties which give it a distinct value for certain technical purposes, so that it is impracticable to draw any hard and fast lines between it and some other porcelains. For electrical porcelains proper, *v.* p. 67.

Chemical Composition of Fired Body and Batch Composition of Raw Body

For composition limits assigned to the various types of porcelain and whiteware, *v.* the standard works such as those of Seger, Kerl, Bourry, Granger, etc., and special works such as (**82, 99, 119**).

The actual compositions of some of the bodies whose properties are listed in the following pages are appended hereto, together with the reference numbers by which they are identified in the subsequent pages.

BODY COMPOSITION, WT. %

Ref. No.	6	7	8	9	10	11	12	13	14	15	16	17	18
Kaolin	55	60	60	60	55	55	55	55	50	50	50	50	50
Quartz	22.5	25	20	15	30	25	20	15	35	30	25	20	15
Feldspar	22.5	15	20	25	15	20	25	30	15	20	25	30	35

Ref. No.	19	20	21	22	23	24	25	26	27	28	29	30	31
Kaolin	45	45	45	45	40	40	40	55	55	55	55	55	65
Quartz	35	30	25	20	35	30	25	40	30	22.5	15	5	25
Feldspar	20	25	30	35	25	30	35	5	15	22.5	30	40	10

Ref. No.	32	33	34*	35†	36†	37	38	39
Kaolin	65	65	25	30	35	43.4	40.5	52.0‡
Quartz	17.5	10	45	12	11	29.5	25.1	
Feldspar	17.5	25	30	60	54	25.6	29.2	42.0
$CaCO_3$						1.5	5.2	6.0

* Seger porcelain. † Figure porcelain. ‡ Sornzig kaolin.

Ref. No.	40	41	42	43	44	45	46	47	48	49
China clay	30	30	30	30	30	30	15		30	30
Ball clay	25	25	25	25	15	35	40	20	25	25
Flint	30	20	10		30	10		15		20
Feldspar	15	25	35	45	25	25	45	30	35	10
Red clay								35		
Zirconia									10	
Steatite										15

Ref. No.	50	51	52	53	54	55	56	57	58
Clay	60	65	70	65	70	75	70	75	80
Quartz	20	15	10	20	15	10	20	15	10
Feldspar	20	20	20	15	15	15	10	10	10

Ref. No.	59	60	61	62	63	64	65	66	67	68
Clay	60	55	50	45	40	60	55	50	45	40
Flint	20	22.5	25	27.5	30	25	30	35	40	45
Feldspar	20	22.5	25	27.5	30	15	15	15	15	15

Ref. No.	69	70	71	72	73	74	75	76	77	78
Clay	60	55	50	45	40	60	55	50	45	40
Flint	20	25	30	35	40	15	20	25	30	35
Feldspar	20	20	20	20	20	25	25	25	25	25

Ref. No.	79	80	81	82	83	84	85	86	87	88	89
Clay	60	55	50	45	40	35	65	40	45	50	55
Flint	10	15	20	25	30	35	10	25	20	15	10
Feldspar	30	30	30	30	30	30	25	35	35	35	35

Ref. No.	90	91	92	93	94	95	96	97	98	99	100
Clay	40	50	40	40	40	40	40	40	50	50	50
Flint	20	10	31.20	22.85	13.50	42.90	38.60	34.25	14	28.70	23.30
Feldspar	40	40	28.80	37.15	46.50	15.20	19.20	23.00	36	19.10	24.00
Whiting						1.80	2.26	2.75		2.28	2.70

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[1] Acknowledgments are due to Dr. J. W. Mellor for the free use of his library, which is rich in scientific and technical literature, and for occasional assistance kindly rendered in tracing important references.

BODY COMPOSITION, WT. %.—(*Continued*)

Ref. No.	101	102	103	104	105	106	107	108	109
Clay, raw	50	50	50	50	50	50	50	50	50
Clay, calcined	20	20	20	20	20	25	25	25	25
Flint	18.5	13.5	9.5	5.0		13.5	10	5	
Feldspar	10	15	19	23.5	28.5	10	13.5	18.5	23.5
Whiting	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Ref. No.	110	111	112	113	114	115
Clay, raw	50	50	50	50	50	50
Clay, calcined	30	30	30	35		
Flint	8.5	5			32.5	34
Feldspar	10	13.5	18.5	13.5	16	16
Whiting	1.5	1.5	1.5	1.5	1.5	

Ref. No.	116	117	118	119	120	121	122	123	124
Clay	71.5	77.0	80.1	85	80	80	75	75	75
Feldspar	15.6	12.5	9.5	13.5	18.5	13.5	23.5	18.5	10
Flint	2.4					5		5	13.5
Whiting	1.4	1.45	1.43	1.5	1.5	1.5	1.5	1.5	1.5
Alumina	9.1	9.05	8.97						

Ref. No.	125	126	127	128	129	130	131	132
Clay	70	70	70	80	75	70	50	50
Feldspar	23.5	19	15	10	13.5	10	16	16
Flint	5	9.5	13.5	8.5	10	18.5	32.5	34
Whiting	1.5	1.5	1.5	1.5	1.5	1.5	1.5	

Ref. No.	136	137	138	139	140	141	142
Kaolin	39	39	39	39	39	39	39
Ball clay	6	6	6	6	6	6	6
Flint	37	37	37	37	37	37	37
Feldspar	18	18	18	18	18	18	18
Whiting	3	2.5	2	1.5	1	0.5	0
Dolomite	0	0.5	1	1.5	2	2.5	3

Ref. No.	143	144	145
Kaolin	48	46	46
Quartz	18	28	33
Feldspar	34	26	21

Ref. No.	158	159	160	161	162	163	164	165
Clay substance	50	41	40	62	48	51.5	50	55
Quartz sand	22.5	54	52	33	42	43.5	42	40
Feldspar	22.5	5	5	5		5	5	5
Chalk			3		10		3	

Ref. No.	166	167	168	169	170	171	172	173	174
Clay	24*	23*	25†	22‡	24‡	23‡			
Kaolin	33	32	50	45	48	46	35	35	25
Quartz	38	37	20	22	23	23	60	60§	45
Feldspar	5	5	5		5	5	5	5	30
Chalk		3		10		3			

* Lean clay. † Fat clay. ‡ Meissen clay. § Quartz sand calcined twice at cone 15.

BODIES, CHEMICAL COMPOSITION

Ref. No.	1*	2*	3*	4*	5†	6‡
SiO_2	60.75	69.37	74.52	79.32	70.7	67.5
Al_2O_3	32	23.61	2.70	18.42	23.4	26.6
TiO_2						0.4
Fe_2O_3						0.8
CaO	4.15	1.22	16.10	0.36	1.0	0.4
MgO	0.08	0.08	0.61			0.3
K_2O	3.02	2.58	3.45	1.82	4.8	3.3
Na_2O		2.42	2.63	0.32		0.7

BODIES, CHEMICAL COMPOSITION.—(*Continued*)

Ref. No.	101	102	103	104	105	106	107	108	109
SiO_2	64.59	62.90	61.61	60.10	58.52	62.07	60.90	59.27	57.64
Al_2O_3	30.86	31.76	32.53	33.36	34.25	33.15	33.80	34.70	35.63
TiO_2	0.15	0.15	0.15	0.15	0.15	0.17	0.17	0.17	0.17
Fe_2O_3	0.53	0.55	0.57	0.61	0.63	0.56	0.58	0.60	0.64
CaO	1.07	1.08	1.09	1.10	1.12	1.09	1.11	1.15	1.14
MgO	0.22	0.23	0.23	0.24	0.25	0.23	0.24	0.25	0.25
K_2O	1.58	2.08	2.47	2.92	3.40	1.61	1.97	2.45	2.96
Na_2O	1.05	1.25	1.35	1.52	1.68	1.12	1.23	1.41	1.57

Ref. No.	110	111	112	113	115	133	134	135
SiO_2	59.56	58.36	56.80	55.93	72.51	72.49	71.40	75.64
Al_2O_3	35.43	36.08	37.00	38.40	22.60	22.03	27.58	22.63
TiO_2	0.18	0.18	0.18	0.19	0.16			
Fe_2O_3	0.63	0.65	0.62	0.66	0.44	3.66	0.75	0.68
CaO	1.10	1.12	1.13	1.13	1.05	Trace	0.35	0.68
MgO	0.26	0.27	0.28	0.28	0.18	0.24	0.06	0.06
K_2O	1.67	2.05	2.53	2.07	1.98		2.22	2.61
Na_2O	1.17	1.29	1.46	1.34	1.08			
Ig. loss							0.10	0.22

Ref. No.	151	152	153	154	155	156	157
SiO_2	68.4	70.00	69.52	67.65	76.45	71.27	75.02
Al_2O_3	27.7	26.21	26.56	27.74	18.90	25.24	23.40
Fe_2O_3	0.82	0.75	0.76	0.73	1.01	0.71	0.15
CaO	0.3	0.54	0.51	0.63	0.93	0.72	0.61
K_2O	1.37	1.45	1.34	1.38	0.97	1.74	
Na_2O	1.03	0.88	0.87	0.97	1.35	0.81	0.89

Ref. No.	159	160	161	162	163	164
SiO_2	74.6	72.4	60.5	62.7	68.9	67.0
Al_2O_3	17.1	16.6	25.2	19.1	20.8	20.2
Fe_2O_3	0.8	0.7	1.5	0.8	0.9	0.8
CaO	0.4	1.9	1.5	6.0	0.9	2.5
MgO			0.6	0.5	0.5	0.5
K_2O	1.7	1.7	2.2	0.5	1.2	1.2
Ig. loss	5.6	6.7	9.3	10.9	6.8	7.8

* Sèvres hard porcelain, new body, soft porcelain and stoneware, respectively, according to Coupeau (20, 21). † Limoges porcelain according to Vogt (20, 21). ‡ Berlin porcelain, general chemical composition according to Rieke (103).

DISTRIBUTION OF REFERENCE NUMBERS (COMPOSITIONS) AMONG LITERATURE REFERENCES

Ref. No.	Lit.	Ref. No.	Lit.	Ref. No.	Lit.
1– 5	(20, 21)	36	(158, 159)	101–115	(93)
6	(18, 19,	37–39	(33)	116–132	(127)
	103, 105,	40–49	(144)	133	(134)
	129, 158,	50–58	(72)	134, 135	(90)
	159)	59–84	(74, 77,	136–142	(94)
7–25	(106)		85)	143–145	(138)
15	(56, 57)	85–91	(80, 84)	151–157	(25, 26)
16	(106, 114)	52, 69		158	(18, 19)
26–33	(112)	73–79		159–164	(42)
34	(105, 129,	81		165	(58)
	158, 159)	92–100	(76)	166–171	(88, 89)
35	(105, 129)			172, 173	(101, 102)

Petrographic Character of Laboratory Porcelains and Whiteware

The petrographic character of a ceramic body made from clay, feldspar, and flint varies according to the proportions of the component materials and also with the method of preparation (involving physical conditions) and conditions of firing. In porcelains wide variations occur in the relative amounts of glassy matrix, undissolved quartz (or cristobalite), undecomposed or undissolved clay, and mullite ($3Al_2O_3.2SiO_2$). The mullite was for a long time regarded as sillimanite ($Al_2O_3.SiO_2$), discrimination being difficult owing to the close resemblance, *v.* p. 68.

A good porcelain of the kind indicated should consist largely of a feldspathic glassy matrix with embedded crystals of quartz and mullite distributed evenly, but no visible particles of clay. The quartz should not exceed 20, or at most 25 % and the average size of its particles should not exceed 0.03 to 0.04 mm diameter, all edges and corners being rounded off through partial solution in the matrix. The crystals of mullite should be numerous and well formed, and should not exceed *ca.* 0.01 mm in length and 0.002 mm in thickness. Porcelains answering to this description can be produced only at a comparatively high firing temperature. With lower temperatures smaller proportions of glassy matrix and mullite crystals are produced, the proportions diminishing gradually until the crystals cease to be formed and the amount of glassy matrix becomes relatively insignificant, and the product is no longer porcelain but simply white earthenware.

For the microscopic characters of thin sections of porcelains and whitewares, *see* (56, 57, 67, 68, 69, 79, 90, 91, 92, 108, 150, 158, 159).

BULK DENSITY, SPECIFIC GRAVITY, AND POROSITY

Specific gravity	Bulk density	% open pore porosity*	% total porosity	Type	Lit.
	2.15–2.02			Bayeux hard porcelain at red to white heat	(115)
2.3 –2.5†				Hard porcelain	(29)
2.60–2.64†				*Idem.*, baked at *ca.* 950°C	(29, 103)
2.46				Berlin technical porcelain	(103)
2.46	2.32		4.4	Berlin hard porcelain	(119, 121)
2.30–2.40				Hermsdorf porcelain	(32)
	1.45–1.55			Hermsdorf porcelain, baked	(32)
2.42–2.49	2.27–2.38		4.1 - 7.9	8 commercial porcelains	(108, 118, 119)
2.49				Meissen porcelain	(123)
2.24				Sèvres porcelain	(123)
2.38				Chinese porcelain	(123)
2.44				Laboratory porcelain (Rosenthal)	(123)
2.26				Seger porcelain (Rosenthal)	(123)
2.28				Rosenthal porcelain	(123)
2.36				Jàpanese porcelain	(134)
2.47–2.53	2.27–2.41		3 –10	19 trial porcelains, fired at cone 12	(80)
			0.00– 1.76	6 American commercial porcelains, cone 12	(157)
		0.010– 0.034		10 trial porcelains, cone 10	(144)
		0.05 - 9.7		26 trial porcelains, cone 10	(77)
	2.35–2.39	0.02 - 0.86		3 American hotel chinas	(128)
	1.96–2.12	6.4 –11.6		4 American hotel semi-porcelains	(128)
	2.03–2.40	0.0 - 9.8		14 American hotel wares	(125)
	1.98–2.10	7.4 –10.2		8 American household wares (semi-vitreous)	(125)
	2.13–2.33	2.7 - 6.0		4 English hotel wares	(125)
	2.18–2.35	0.0		3 French and German hotel wares	(125)
2.53	2.32	0.13	8.5	Fine stoneware 538	(119)
2.45	2.23	1.80	8.9	Fine stoneware DTS sill. 54	(119)
2.45	2.28	0.19	7.7	Fine stoneware, DTS sill. 55	(119)
1.33–1.65		17.1 –21.6		6 earthenware bodies, cone 4a	(42)
2.48–2.54	2.15–2.20		11.8 –15.2	4 stonewares	(121)

* For direct determination of pore volume, *v.* (142). Different absorption methods (140).

† For effects of firing temperatures and fineness of grinding, *v.* (42, 62, 63, 80, 84, 94, 105).

SPECIFIC GRAVITY AND BULK DENSITY (13)

Specific gravity	Bulk density	Type
2.628	2.363	Palissy faience
2.884	2.354	Nevers faience
2.789	2.363	Rouen faience
2.564	2.433	Creil fine faience
2.482*		Creil fine faience
2.482	2.226	English fine faience
2.567	2.455	Flemish stoneware
2.610	2.556	Japanese stoneware
2.505	2.436	English stoneware
2.569	2.508	Hard porcelain from Saxony
2.531	2.314	Bayeux hard porcelain
2.556	2.133†	Sèvres hard porcelain (1798)
2.527	2.259†	Sèvres hard porcelain (1788)
2.470	2.334	Limoges hard porcelain
2.500	2.290	Chinese hard porcelain
2.525	2.384	English soft porcelain
2.525	1.873	Sèvres soft porcelain
2.477	2.143	Tournay soft porcelain

* After firing with Sèvres hard porcelain. Specific gravities of other bodies are given in the same table. † Pores very visible.

COEFFICIENT OF CUBICAL COMPRESSIBILITY

See p. 68. *Cf.* (29, 32, 123).

MODULUS OF RUPTURE (DEF. 5)

kg/cm^2	Type	Lit.
774–943	Berlin technical porcelain	(107, 108, 119)
588–777	7 commercial porcelains, other than Berlin	(107, 108, 119)
420–560	Hermsdorf porcelain	(32, 113, 123)
≯690	Hermsdorf porcelain	(119)
550–670	Hermsdorf porcelain	(35)
930	A special Hermsdorf porcelain	(35)
590	Rosenthal insulator G porcelain	(113, 119, 123)
540	Rosenthal insulator H porcelain	(113, 119, 123)
640	Rosenthal table porcelain	(113, 119, 123)
410	Rosenthal laboratory porcelain	(113, 119, 123)
520	Trial porcelain 6292 (copied from American insulator porcelain)	(113, 119, 123)
106–185	6 trial earthenwares, cone 8–9, Ref. No. 159–164*	(42)
233	Faience body 135	(119)
416	Fine stoneware, DTS sill. 54	(119)
580	Fine stoneware, DTS sill. 55	(119)
980	Special trial stoneware 6412	(113, 119, 123)

Extruded cylindrical rods 16 mm diameter are fired hanging vertically, and sawn to 120 mm lengths. Loaded centrally, between steel knife edge supports, 1 kg/sec.

* Values for firings at cones 01a and 4a are also given in this paper.

TENSILE STRENGTH (DEF. 4)

kg/cm^2	Type	Cross section,* cm^2	Lit.
1000–2000	Hard porcelain		(29)
280–363	Berlin technical porcelain	2.5 –2.9	(107, 108, 121)
161–265	7 commercial hard porcelains (other than Berlin)	2.8 –3.9	(107, 108, 119)
≯360	Hermsdorf porcelain		(119)
360–420	Hermsdorf porcelain	3.14	(35)
ca. 261	Rosenthal insulator porcelain H		(113, 123)
500	Chinese porcelain		(119)
106–887	American porcelain		(119)
258–396	19 trial porcelains, cone 15, Ref. No. 7–25		(106)
180–240	Soft porcelain, cone 8–9	3.50–3.63	(33)
184–283	Soft porcelain, cone 8–9	2.76–3.40	(33)
84–191†	10 trial porcelains fired to vitrification, cone 7–10, Ref. No. 40–49	*ca.* 3.2	(144)
108–185	6 trial earthenwares fired at cone 8, Ref. No. 166–171‡		(88, 89)
44–80	6 trial earthenwares fired at cone 8–9, Ref. No. 159–164‡		(42)
118	Special hard earthenware 237		(119)
67	Faience body 135		(119)
178	Fine stoneware DTS sill. 54		(119)
163	Fine stoneware DTS sill. 55		(119)

* The area of the cross section of the test piece is important. On comparing the tensile and crushing strengths of German and American porcelains, it may be noted that, in general, the former have greater crushing strength and the latter greater tensile strength.

† The respective values in order of the composition Ref. No. 40–49 are 125.8, 126.5, 126.5, 109.7, 123, 83.7, 92.1, 126.5, 191.2, and 141.3.

‡ Values for firings at cones 01a and 4a are also given in this paper. For other measurements of tensile strengths of trial bodies, *v.* (145). For influence of glaze, *v.* p. 68.

CRUSHING STRENGTH
Unit = 1000 $kg./cm^2$

Strength	Type	Remarks	Lit.
4–5	Hard porcelain		(14, 15, 113, 119)
4.2	Hard porcelain		(112, 123)
ca. 4.2	Berlin technical porcelain	2.5 cm cubes, determined by Rosenthal	(103)
≯5.6	Hermsdorf porcelain		(32, 119, 123)
4.8	Hermsdorf porcelain		(32, 113)
4.5 –5.5	Hermsdorf porcelain	16 mm diam., 16 mm long	(35)
2.8 –4.6	American porcelain		(119)
7.43	Porcelain 152		(119)
2.7 –4.2	8 trial porcelains, cone 16, Ref. No. 26–33*	2 cm diam. cylinders (with 3.14 cm^2 cross section)	(112)
2.7 –4.0	7 trial porcelains, cone 11		(94)
2.8 –4.5	6 American commercial porcelains, cone 11	Cylinders *ca.* 3.1 cm when just formed	(157)
0.04–0.08	6 trial earthenwares, cone 8†, Ref. No. 166–171		(88, 89)
5.8	Fine stoneware, DTS sill. 55		(119)

The higher values (5 and over) are probably due to the use of cylindrical instead of square test pieces. In 1920 the German Committee specified test pieces 16 mm diameter and 16 mm long.

* Highest value given by body with 55 % Zettlitz kaolin and 22.5 % each of quartz sand and feldspar. Only a little inferior were the values for bodies having 15 % feldspar and 30 % quartz, and 30 % feldspar and 15 % quartz, respectively.

† Value for firings at cones 01a and 4a are also given in this paper.

CRUSHING STRENGTH BETWEEN SPHERES*

kg	Type	Lit.
118–152	Berlin technical porcelain	(107, 108, 119)
76–137	7 commercial hard porcelains (other than Berlin)	(107, 108, 119)
50–94	19 trial porcelains fired at cone 15, Ref. No. 7 to 25	(106)
96 (90 – 99)	Trial soft porcelain	(33)
526	Faience body 135	(119)
792	Fine stoneware, DTS sill. 54	(119)
982	Fine stoneware, DTS sill. 55	(119)

* Gary press, *v.* p. 69 (34, 107, 108). The last three values are those of the breaking load—as are some of the others given in (119) and elsewhere—and are about 10 times as large as they should be. Unfortunately, the details are not available.

MODULUS OF ELASTICITY (DEF. 10)
The unit is 1000 kg/mm^2

Modulus	Type	Remarks	Lit.
5.4–7.1	Hermsdorf porcelain		(29, 32, 123)
7–8	Hermsdorf porcelain		(119)
8.7–7.4	Hermsdorf porcelain		(35)
8.2–8.4	Berlin technical porcelain	Bending. Av. of 72 tests	(107, 121, 123, 131)
7.1	Sèvres hard porcelain	Fired at 1370°	(62, 63)
6.7	Sèvres new porcelain	Fired at 1270°	(62, 63)
5.0	Sèvres soft porcelain	Fired at 1100°	(62, 63)
2.5	Sèvres stoneware	Fired at 1270°	(62, 63)
3.7	Fine faience	Fired at 1270°	(62, 63)

MODULUS OF ELASTICITY (DEF. 10).—(*Continued*)

Modulus	Type	Remarks	Lit.
8.4	Rosenthal insulator porcelain G and H	Bending	(123)
7.8	Rosenthal insulator porcelain G and H	Bending	(119)
9.1	Rosenthal table porcelain	Bending	(123)
8.1	Rosenthal table porcelain	Bending	(119)
8.6	Rosenthal trial porcelain 6292	Bending	(123)
14.9	Rosenthal trial stoneware 6412	Bending	(123)
8.9	Rosenthal laboratory porcelain		(119)
6.8	Rosenthal Seger porcelain 6833		(119)
6.5	Chinese porcelain		(119)
2.4	Faience body 135		(119)
5.1	Fine stoneware DTS sill. 54		(119)
6.5	Fine stoneware DTS sill. 55		(119)
151	Trial stoneware 6412		(119)

The value of the modulus changes (usually inversely) with the load. It depends less upon chemical composition than upon conditions of manufacture. It is substantially the same for tension and compression.

MODULUS OF ELASTICITY IN SHEAR (DEF. 11)

kg/cm²	Type	Lit.
430	Trial Seger porcelain Body 6833 (Rosenthal)*	(113)
481	Rosenthal insulator Body G	(113, 119)
500	Rosenthal insulator Body H	(113, 119)
500	Rosenthal laboratory porcelain	(113, 119)
480–600	Hermsdorf porcelain	(119)
226	Fine stoneware 238	(119)
323	Fine stoneware DTS sill. 54	(119)
169	Faience Body 135	(119)
232	Special hard earthenware 237	(119)
246	Special body 240	(119)

* Square cross section.

FIXED IMPACT AND BENDING SHOCK (DEF. 16)

Pendulum-hammer method (34, 108, 119)

cm-kg/cm²	Type	Lit.
2.0	Berlin technical porcelain	(107, 108, 119, 121)
1.75–1.95	7 commercial porcelains (other than Berlin)	(107, 108, 119)
1.9	Hermsdorf porcelain	(119)
1.9–2.3	Hermsdorf porcelain	(35)
0.90	Rosenthal insulator porcelain G	(113, 119, 123)
0.95	Rosenthal insulator porcelain H	(113, 119, 123)
1.36	Rosenthal table porcelain	(113, 119, 123)
1.23	Rosenthal laboratory porcelain	(113, 119, 123)
0.08	Rosenthal trial hard porcelain 6292 (copied from American insulator porcelain body)	(113, 119, 123)
1.0	Rosenthal Seger porcelain 6833	(113, 119, 123)
2.4	Rosenthal trial porcelain 6412	(113, 119, 123)
1.61*	Rosenthal trial porcelain 6048	(113, 123)
1.76–1.95	19 trial porcelains fired at cone 15, Ref. Nos. 7–25	(106)
1.23–1.8	8 trial porcelains, Ref. No. 15 considered the best	(138)
1.68–1.92	Soft porcelain, cone 8–9	(33)
1.6	Faience body 135	(119)
2.0	Hard earthenware 236	(119)
1.5	Hard earthenware 237	(119)
1.7	Earthenware 240	(119)
1.7	Fine stoneware 238	(119)
1.8	Fine stoneware DTS sill. 54	(119)
1.7	Fine stoneware DTS sill. 55	(119)
1.3–1.9	Stonewares Z58, Z59, Z60, Z61	(121)

* In (123) this value is given as 1.38, but the 1.61 occurs twice in (113).

See also (125) for a different impact test.

SUCCESSIVE INCREASING IMPACT SHOCKS

Marten's method

112 cm × kg/cm³ for a table porcelain (113); *see also* p. 70

RESISTANCE TO ABRASION*

Gary sand blast test, 2 min at 3 atm

Type	Loss in cm³	Lit.
Stoneware 6412 (Rosenthal)	1.7	(113, 123)
Faience body 135	7.2	(119)
Special hard earthenware 236	5.8	(119)
Special hard earthenware 237	5.9	(119)
Fine stoneware 238	2.4	(119)

* In (123, p. 57) Singer quotes from (32) results for hardness obtained by Linck with the use of the sclerometer, and the corresponding values according to the hardness scale of Mohs, as follows:

	Sclerometer number	Number in Mohs scale
Easy baked porcelain	10–12	2
Hard baked porcelain	22–25	2.5
Porcelain fired to maturity, unglazed	550–650	7
Surface layer of glaze	950–1000	8
Glaze below the surface	350–400	6.3

TOUGHNESS AND HARDNESS BY THE RATTLER TEST

% loss of weight by rattler test		Type	Lit.	% loss of weight by rattler test		Type	Lit.
15 min	60 min	Ref. No.		15 min	60 min	Ref. No.	
1.93	4.62	92	(76)	4.42	8.21	70	(77)
0.68	1.95	93	(76)	2.33	5.09	71	(77)
1.57	4.33	94	(76)	2.30	4.39	72	(77)
0.30	0.88	95	(76)	1.96	4.12	73	(77)
0.58	1.97	96	(76)	5.66	10.23	74	(77)
1.17	3.31	97	(76)	5.19	8.22	75	(77)
1.73	3.46	98	(76)	2.51	5.45	76	(77)
1.95	3.70	99	(76)	2.82	5.65	77	(77)
1.96	4.95	100	(76)	5.02	8.51	79	(77)
5.36	13.94	59	(77)	4.33	8.02	80	(77)
6.10	15.36	60	(77)	3.38	6.34	81	(77)
5.18	14.73	61	(77)	2.71	4.80	82	(77)
4.77	9.32	64	(77)	2.19	4.78	83	(77)
1.06	5.54	65	(77)	1.98	4.17	84	(77)
4.03	7.43	69	(77)				

% loss of weight by rattler test			Type (94)	% loss of weight by rattler test			Type (94)
15 min	30 min	180 min	Ref. No.	15 min	30 min	180 min	Ref. No.
4.67	6.38	11.25	136	3.66	5.20	10.70	140
4.09	5.60	11.40	137	3.60	5.15	9.80	141
4.47	5.98	12.80	138	3.05	4.12	10.30	142
2.95	4.60	9.42	139				

The 15 min test serves to indicate the toughness or resistance to chipping.

The 180 min test indicates hardness after edges and corners have been removed.

These rattler tests were made in a ball mill 9¾ in. diameter and 13 in. long inside, making 40 revolutions per minute. The charge consisted of 61 nearly equal pebbles, weighing 22¾ lb. For each test 13 specimens of porcelain were used, which were weighed at the proper time intervals. For a standard test it is suggested that 10 kg of pebbles might be used along with 12 specimens. The above results of tests are comparable, as the same conditions were maintained throughout.

Further data relating to the rattler test with trial bodies will be found in (53, 65, 128, 145).

Softening Point and Cone Melting Point

°C	Type and remarks	Lit.
1500	Normal	(122)
1700	Special	(122)
1710	Rosenthal porcelain melts	(119, 120, 123)
1390	Japanese table porcelain, Ref. No. 133	(134)
1690	Porcelain, Ref. No. 134 melts	(90)
1670	Porcelain, Ref. No. 135 melts	(90)
	Berlin porcelain	
900–1000	Appreciable softening begins	(103, 123)
ca. 1680	Melting takes place	(103, 119, 123)
ca. 950	Berlin glaze softens	(103, 123)
Cone		
25	Berlin porcelain begins to deform	(72)
25	Ref. No. 58 begins to deform	(72)

Softening point varies with size and shape of test piece and also with time of heating, etc.

In spite of the softening of Berlin porcelain, perceptible far below 1000°C according to Rieke (103, 123), porcelain tubes, crucibles, etc., if suitably protected and not too severely loaded, can be safely used at temperatures up to 1400° or even higher. For Rosenthal porcelain it is claimed that when very strongly heated it can be worked like glass to make laboratory apparatus, *see* (120).

Rosenthal (112) heated one side of thick rods of different hard porcelains in an electric arc-light. He found that bodies rich in feldspar immediately split off in numerous small pieces, bodies rich in quartz and clay substance cracked off more slowly and in larger pieces, whilst specially resistant bodies merely melted at the heated places.

Coefficient of Thermal Expansion

$\frac{10^6\Delta l}{l\Delta t}$	Type	Range °C	Lit.
3.43	Berlin technical porcelain, unglazed.	23–200	(29, 101, 102, 103, 119)
3.53		23–400	(101, 102, 103, 119)
3.55		23–600	(101, 102, 103)
3.56		23–700	(29, 101, 102, 103)
1.77	Berlin porcelain	−191 to 16	(49, 101, 102, 103, 123)
3.36		16–250	(49, 101, 102, 103, 123)
3.64		16–500	(49, 101, 102, 103, 123)
3.77		16–750	(49)
4.34		16–1000	(49, 101, 102, 103, 119, 123)
3.16		0–250	(50)
3.50		0–500	(50)
3.60		0–750	(50)
4.09		0–1000	(50)
ca. 4.4		>1000	(52)
3.76		0–625	(51)
ca. 1.79	Berlin porcelain	−191 to 16	(117, 118)
2.94		14–56	(117, 118)
3.08		14–100	(117, 118)
2.99		0–100	(14, 15, 16, 17)
3.12			(100)
3.8			(119, 121)
3.03–4.31		Various up to 1000*	(119)
4.25	Hermsdorf porcelain		(119)
3.80	Seger porcelain 6833	20–100	(123)
3.52	Rosenthal laboratory porcelain	20–100	(123)
3.60–4.79	Rosenthal elec. porcelain	0–100	(119)
2.69	Meissen porcelain	0–99	(101, 102, 123, 153)
5.4	Bayeux porcelain	0–1106	(115)*
5.3		0–1298	(20, 21, 115)
5.3		0–1457	(20, 21, 115)
6.8		0–1524	(20, 21, 115)
2.82–3.81		0–83	(14, 15, 20, 21)
2.522		0	(101, 102, 123, 135, 136)
2.819		20	(135, 136)
3.166		40	(135, 136)
3.265		50	(101, 102, 123, 135, 136)
3.414		60	(135, 136)
3.711		80	(135, 136)
4.008		100	(101, 102, 123, 135, 136)
4.305		120	(101, 102, 123, 135, 136)
3.53–4.07		100–600	(1, 2, 3, 119)
	Ref. No. 16, fired at:		
7.76	1000°C		(110)
5.71	1100°C		(110)
5.21	1250°C		(110)
3.97	Cone 15		(110)
3.74	Cone 16		(110)
3.72–3.60	Fired more than once		(110)
	Sèvres new porcelain fired at:		
5.23	1270°		(20, 21, 25, 26)
5.01	1370°		(20, 21, 25, 26)
2.99	1500°		(20, 21, 25, 26)
	Sèvres hard porcelain:		
5.1	Fired at 1000°	0–200	(20, 21)
6.0		0–400	(20, 21)
6.1		0–600	(20, 21)
5.5		0–800	(20, 21)
3.9	Fired at 1370°	0–200	(20, 21)
4.3		0–400	(20, 21)
4.5		0–600	(20, 21)
4.7		0–800	(20, 21)
13.5	Soft, fired at 1100°	0–200	(20, 21)
14.3		0–400	(20, 21)
5.5	New, fired at 1000°	0–200	(20, 21)
6.5		0–400	(20, 21)
8.5		0–600	(20, 21)
6.4	New, fired at 1270° (normal).	0–200	(20, 21)
7.0		0–400	(20, 21)
7.5		0–600	(20, 21)
6.9		0–800	(20, 21)
4.5	New, fired at 1370°	0–200	(20, 21)
4.7		0–400	(20, 21)
4.8		0–600	(20, 21)
4.9		0–800	(20, 21)
	Sèvres stoneware:		
4.5	Fired at 1000°	0–200	(20, 21)
5.0		0–400	(20, 21)
6.6		0–600	(20, 21)
4.8		0–800	(20, 21)
6.0	Fired at 1270° (normal)	0–200	(20, 21)
7.1		0–400	(20, 21)
8.6		0–600	(20, 21)
6.8		0–800	(20, 21)
9.0	Fired at 1370°	0–200	(20, 21)
8.3		0–400	(20, 21)
7.7		0–600	(20, 21)

* Deville and Troost made more than 200 experiments in all.

COEFFICIENT OF THERMAL EXPANSION.—(*Continued*)

$\frac{10^6\Delta l}{l\Delta t}$	Type	Range °C	Lit.
7.2	Fired at 1370°	0–800	(20, 21)
3.8	Limoges porcelain fired at 1370°	0–200	(20, 21)
4.2		0–400	(20, 21)
4.5		0–600	(20, 21)
4.5		0–800	(20, 21)
5.0	Fine faience (Choisy) fired at 1200°	0–200	(20, 21)
6.0		0–400	(20, 21)
7.8		0–600	(20, 21)
6.3		0–800	(20, 21)
8.1	Body of composition, Al_2O_3.-$2SiO_2$,[†] fired at 1250°.	0–300	(22)
7.2		0–500	(22)
6.8		0–700	(22)
6.4		0–900	(22)
7.0	Body of composition, Al_2O_3.-$10SiO_2$,[†] fired at 1250°.	0–300	(22)
8.2		0–500	(22)
9.8		0–700	(22)
9.3		0–900	(22)
2.9	Ref. No. 116	Room temperature to 200°	(127)
3.4	Ref. No. 117		(127)
3.1	Ref. No. 118		(127)
3.2	Ref. No. 119		(127)
2.9	Ref. No. 120		(127)
3.3	Ref. No. 121		(127)
3.5	Ref. No. 122		(127)
3.2	Ref. No. 123		(127)
4.1	Ref. No. 124		(127)
3.7	Ref. No. 125		(127)

COEFFICIENT OF THERMAL EXPANSION.—(*Continued*)

$\frac{10^6\Delta l}{l\Delta t}$	Type	Range °C	Lit.
3.3	Ref. No. 126	Room temperature to 200°	(127)
3.4	Ref. No. 127		(127)
4.7	Ref. No. 128		(127)
3.7	Ref. No. 129		(127)
6.1	Ref. No. 130		(127)
6.2	Ref. No. 131		(127)
4.7	Ref. No. 132		(127)
5.4	Special hard earthenware 236		(119)
7.1	Special hard earthenware 237		(119)
5.7	Fine stoneware 238		(119)
4.9	Fine stoneware DTS sill. 55		(119, 121)
4.3–4.9	4 stonewares (58–61)		(119)
	Earthenwares fired at cone 9		
ca. 10.3	Ref. No. 172, 173	22–150	(101, 102)
12.2	Ref. No. 172	220–340	(101, 102)
10.8	Ref. No. 173	220–340	(101, 102)

For other values for Berlin porcelain, *v.* (119, p. 428). For expansion coefficients of bodies with calcined clay replaced by sillimanite (mullite) or other special component, *v.* p. 70, and also (93, 127).

[†] Chantepie records results obtained with these two bodies fired at 1370°, and also at 1000° in the case of the former; also with bodies obtained by admixture of considerable percentages of iron oxide, feldspar, or chalk respectively with the former, and of lime or magnesia respectively with the latter. Coefficients for the range 200°–400° are also given in (127). Other thermal expansion coefficients, mainly of trial bodies, will be found in (84, 85, 146, 149). For coefficients of thermal expansion of glazes, *v.* (20, 21, 25, 26, 109).

HEAT CAPACITY (SPECIFIC HEAT)

g-cal/g°C	Range	Type	Cone	Lit.	g-cal/g°C	Range	Type	Cone	Lit.
0.258	15–912	Porcelain		(40)	0.212	20–200	Marquardt body	15	(130)
0.256	15–958	Porcelain		(40)	0.229	20–400	Marquardt body	15	(130)
0.254	15–1075	Porcelain		(40)	0.190		Porcelain, Japanese table		(134)[*]
0.202	20–210	Porcelain, Berlin technical	15	(103, 130)	0.17		Porcelain, hard		(32)
0.221	20–400	Porcelain, Berlin technical	15	(103, 130)	0.25		Porcelain, Rosenthal		(123, 130)[†]
0.212	20–200	Marquardt body	09	(130)	0.2		Porcelain, Hermsdorf		(119)
0.229	20–400	Marquardt body	09	(130)	0.185–0.187	17–100	Stonewares		(121)

[*] A "brown porcelain" (Japanese) used for making bottles with specific heat reported as 0.171, is evidently a stoneware.

[†] According to Dolazalek, the heat capacity per cm^3 is 0.575, the specific gravity being 2.3.

AVERAGE SPECIFIC HEAT IN MEAN CALORIES BETWEEN 20°C AND

°C	100	200	300	400	500	600	700	800	900	1000	1100	Lit.
Berlin porcelain, green[*]	0.185	0.187	0.197	0.213	0.228							(18, 19)
Berlin porcelain, fired	0.189	0.195	0.203	0.212	0.222	0.232	0.245	0.264	0.287	0.304	0.337	(18, 19)
Berlin porcelain, glaze, green	0.170	0.174	0.183	0.193	0.208							(18, 19)
Berlin porcelain, glaze, fired	0.179	0.181	0.189	0.197	0.199	0.202	0.204	0.211	0.218	0.230	0.245	(18, 19)
Earthenware, green[†]	0.181	0.183	0.192	0.201	0.215							(18, 19)
Earthenware, fired	0.186	0.192	0.203	0.212	0.223	0.234	0.275	0.286	0.296	0.307	0.324	(18, 19)

[*] For composition, see Ref. No. 6, fired at cone 16 (1460°C).

[†] For composition, see Ref. No. 158, fired at cone 9.

THERMAL CONDUCTIVITY

Joule cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$	cal cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$	BTU_{60} $ft.^{-2}$ sec^{-1} (°F, $in.^{-1})^{-1}$	Type and remarks	Lit.
0.0104	0.00248 (95°)	0.00200	Porcelain	(64, 119)
0.0185	0.00442	0.00356	Japanese table porcelain	(119, 134)
0.0080	0.0019 (15°–20°)	0.00153	Rosenthal porcelain	(123)
ca. 0.00837	*ca.* 0.002	*ca.* 0.00161	Hermsdorf porcelain	(32)
0.00837–0.0167	0.002 –0.004	0.00161–0.00322	Porcelain	(29, 103)
0.0163 –0.0197	0.0039–0.0047 (165°–1055°)	0.00314–0.00379	Sèvres porcelain	(155, 156)
0.0121 –0.0222	0.0029–0.0053 (70°–1000°)	0.00234–0.00427	Stoneware	(155, 156)
0.0113	0.0027	0.00218	Fine stoneware (DTS sill.)	(121)
0.0121	0.0029	0.00234	Stoneware 58	(121)
0.0105	0.0025	0.00202	Stoneware 59, 60, 61	(121)

RESISTANCE TO THERMAL SHOCK

No standard methods of testing have been adopted, and the recorded data therefore are not comparable; *see* (**10, 11, 72, 74, 103, 120, 137, 143, 147, 148, 154**).

SPECIFIC RESISTIVITY (144)

Unit: 10^{12} ohm-cm

Temp., °C	Ref. No.									
	40	41	42	43	44	45	46	47	48	49
20	165	129	109	66	85	109	53	109	109	355
30	80	62	52	31	40	52	25	52	52	173
40	39	30	25	15	20	25	13	25	25	86
50	19	15	13	8	10	13	6	13	11	42
60	9.5	6.3	4.8	3.8	4.2	5.4	2.1	6.3	4.2	21
70	4.8	2.7	1.9	1.7	1.9	2.4	0.9	3.2	1.8	10
80	2.0	1.2	0.8	0.8	0.8	1.0	0.4	1.3	0.8	3.8
90	1.0	0.5	0.3	0.3	0.3	0.5	0.2	0.6	0.3	1.9
100	0.44	0.21	0.17	0.15	0.14	0.18	0.07	0.25	0.13	0.84
120	0.11	0.05	0.04	0.04	0.03	0.04	0.02	0.06	0.03	0.18
140	0.029	0.013	0.011	0.01	0.008	0.011	0.005	0.017	0.008	0.044
160	0.0083	0.0039	0.0032	0.0031	0.0033	0.0036	0.0014	0.0056	0.0024	0.0136
180	0.0028	0.0014	0.0011	0.0011	0.001	0.0012	0.0005	0.002	0.0008	0.0043
200	0.0010	0.0006	0.0004	0.0004	0.0004	0.0005	0.0002	0.0008	0.0003	0.0016

Unit: 10^9 ohm-cm

Temp., °C	40	41	42	43	44	45	46	47	48	49
220	0.43	0.21	0.18	0.18	0.18	0.21	0.09	0.31	0.13	0.66
240	0.20	0.10	0.08	0.08	0.07	0.07	0.04	0.14	0.06	0.29
260	0.08	0.051	0.037	0.035	0.035	0.041	0.021	0.073	0.033	0.14
280	0.046	0.029	0.021	0.018	0.021	0.023	0.012	0.041	0.02	0.078
300	0.026	0.016	0.013	0.010	0.012	0.015	0.007	0.033	0.013	0.050

VOLUME RESISTIVITY

Specific resist. = $A \times 10^{12}$ ohm-cm

Temp., °C	(*A*)	Type	Lit.
50	2150	Porcelain	(31)
100	16.1	Porcelain	(31)
150	0.416	Porcelain	(31)
200	0.134	Porcelain	(31)
210	0.00651	Porcelain	(31)
ca. 1000	0.033	Porcelain	(75)
727	0.017	Berlin porcelain	(78, 103)
20	129	Coburg porcelain	(27, 28)*
51	281	Coburg porcelain	(27, 28)
97.5	40	Coburg porcelain	(27, 28)
160.5	1.72	Coburg porcelain	(27, 28)
189	0.385	Coburg porcelain	(27, 28)
400	20	Berlin porcelain, glazed	(36)
600	3.125		(36)
800	1.818		(36)
1000	1.000		(36)
1100	0.769		(36)
400	20	Meissen porcelain, glazed	(36)
600	5.556		(36)
800	2.500		(36)
1000	1.064		(36)
1100	0.787		(36)
22	300	Chemical porcelain, unglazed	(24)
30	220		(24)
2.1	141	Hermsdorf porcelain	(43, 44)
20.5	35.5	Hermsdorf porcelain	(43, 44)
50.4	2.64	Hermsdorf porcelain	(43, 44)
59.1	1.08	Hermsdorf porcelain	(43, 44)
81.9	0.15	Hermsdorf porcelain	(43, 44)

For results of resistivity tests on a typical porcelain body (fired up to 1400°C) at temperatures ranging from 860°–1315°, *v.* (**55**).

TEMPERATURE COEFFICIENTS OF ELECTRICAL RESISTANCE

Berlin porcelain (124)

Temp., °C	$\frac{1}{R_t}\frac{dR}{dt}$	Temp., °C	$\frac{1}{R_t}\frac{dR}{dt}$	Temp., °C	$\frac{1}{R_t}\frac{dR}{dt}$
575	−16.00	725	−2.00	875	−0.35
600	− 9.80	750	−1.60	900	−0.30
625	− 6.20	775	−1.00	925	−0.25
650	− 4.60	800	−0.70	950	−0.20
675	− 3.70	825	−0.50	975	−0.16
700	− 2.80	850	−0.40	1000	−0.12

EFFECT OF MOISTURE ON ELECTRICAL RESISTANCE OF POWDERED PORCELAIN (47)

Glazed porcelain		Unglazed porcelain	
Moisture, %	Resistance of a cube of 1 cm edge, kilo-ohm	Moisture, %	Resistance of a cube of 1 cm edge, kilo-ohm
0.43	121 700	1.14	4 521
1.58	12 160	1.54	3 292
1.90	5 953	6.12	1 241
3.34	2 382	9.39	673.8
5.48	563.2	14.1	278.3
8.08	320.7	19.2	40.30
10.9	150.0	23.8	13.78
15.3	39.40	27.3	3.822
19.0	19.32		

SURFACE RESISTIVITY

This varies enormously with humidity of the atmosphere and with the nature of the surface of the film, *see* (**29, 119**).

DIELECTRIC CONSTANT

Dielectric constant	Type	Remarks	Lit.
5.73	Berlin hard porcelain	Ref. No. 6 for composition, sp. gr., 2.38	(129, 103, 119)
6.61	Berlin Seger porcelain	Ref. No. 34, fired at cone 9, sp. gr., 2.40	(103, 129)
6.84	Berlin figure porcelain	Ref. No. 35, sp. gr., 2.41	(103, 129)
4.5–5.3	Hermsdorf porcelain		(29, 32)
5–6	Hermsdorf porcelain		(119)
5.8	Hard porcelain	Ref. No. 16, same value whether potash feldspar or soda feldspar used	(37, 114)
4.38	Baked porcelain*	"Doit être un peu fort"	(23)
8.95	Hermsdorf porcelain at 20°C		(43, 44)
5.17	Fine stoneware, DTS sill. 55		(119)

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* Dietrich found no essential difference between glazed and unglazed porcelain.

* The value is low probably because the test piece was "une plaque de porcelaine dégourdie" or product of the low biscuit firing, and therefore would be very porous.

DIELECTRIC STRENGTH

1. Shape of the electrodes not specified (except in (112)). Voltage increased 0.5 kv per sec, starting at 20 kv under oil (138)

Volts per mm	Type	Remarks	Lit.
13 200	Ref. No. 26	Test pieces, 10 cm in diam. and about 2.5 mm thick, with rounded edges, under oil. Fired at cone 16	(112)
13 800	Ref. No. 27		
14 000	Ref. No. 28		
13 200	Ref. No. 29		
12 400	Ref. No. 30		
12 800	Ref. No. 31		
13 200	Ref. No. 32		
12 400	Ref. No. 33		

2. Electrodes cup-shaped. Voltage increased 250 volts per sec, starting at 50% of the estimated puncture voltage (144)

11 150?	Ref. No. 40	Test cups 65 and 69 mm diam. at bottom and top respectively and 65 mm in height. Minimum thickness 3 mm (middle of bottom). Firing temp. resp. cones 10+, 10, 9, 8, 9+, 9, 8, 7, 9, 7. The figures in each case represent the peak value of the puncture pressure, which was found to be 1.46 × *RMS* value of puncture pressure
13 300	Ref. No. 41	
22 650	Ref. No. 42	
32 300	Ref. No. 43	
14 300	Ref. No. 44	
27 750	Ref. No. 45	
23 000	Ref. No. 46	
16 300	Ref. No. 47	
18 400	Ref. No. 48	
15 600	Ref. No. 49	

EFFECT OF TEMPERATURE AND OF DIFFERENT FIRING TEMPERATURES

Volts per mm	Temp.	Type	Remarks	Lit.
11 380	24	Composition 49% mixed clays, 16% flint, 35% feldspar. Fired at cone 9 (all American materials)	Tested in elec. furnace	(48)
375	274			
17 700	25	Ref. No. 88 Fired at cone 11 or 12	Test pieces were small cups (jiggered) 5¼ in. high, 3 in. diam., 0.15 in. thick. At 325° all four bodies became conductors, though still offering high resistance	(152)
16 600	100			
7 200	200			
790	300			
17 450	25	Ref. No. 86		
16 550	100			
6 560	200			
920	300			
16 800	25	Ref. No. 74		
16 250	100			
7 750	200			
1 840	300			
17 600	25	Ref. No. 76		
16 400	100			
6 950	200			
1 310	300			
13 550		Composition 59% mixed clays, 18% flint, 23% feldspar	Fired quickly to cone 10; cooled slowly	(86)
13 470			Fired quickly to cone 13; cooled to cone 02 in. one hour; then slowly	
14 660			Fired quickly to cone 10; then slowly to cone 12; quickly to cone 17; cooled slowly	
12 850			Fired quickly to cone 10; then slowly to cone 13 and fired 20 hr; cooled quickly to cone 2 and then slowly	
13 560		Composition as above but with soda-feldspar instead of potash-feldspar	Fired like the foregoing Other bodies of different compositions gave similar results	(86)
14 820				
14 100				
13 860				

EFFECT OF TEMPERATURE AND OF DIFFERENT FIRING TEMPERATURES.—(*Continued*)

Volts per mm	Temp.	Type	Remarks	Lit.
25 400	14	Ref. No. 42	Test pieces were the cups described above	(144)
18 000	104			
5 030	150			
1 620	213			
1 020	248			
1 040	310*			
520	325*			

* After prolonged application of pressure. Two curves are given (30) showing the current-time effects of the application of a potential of 584 volts (from a storage battery) to porcelain test-pieces heated to 530°. For other tests of dielectric strength of various trial bodies refer to (6, 71, 145).

VELOCITY OF SOUND

Velocity km/sec	Type	Lit.	Velocity km/sec	Type	Lit.
5.93	Rosenthal laboratory porcelain	(113, 123)	4.9–5.2	Porcelain in general	(32, 113, 123)
6.68	Rosenthal special trial porcelain 6048	(113, 123)	3.6	Bad porcelain	(32, 113, 123)
5.05	Hermsdorf hard porcelain	(29, 113)			

The velocity of transmission of sound vibrations depends on the modulus of elasticity of the material. Hence the tone given by porcelain when struck is a function of the velocity of sound, and from such tones may be obtained indications of the quality of the porcelain.

TRANSLUCENCY OF PORCELAIN

For methods and results, *v.* (**65, 74, 77, 81, 133, 151**).

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(For a key to the periodicals see end of volume)

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(110) Rieke and Steger, *100*, **48**: 297; 15. (111) Rieke and Steger, *103*, **27**: 193, 203; 19. (112) Rosenthal, *100*, **48**: 445; 15. (113) Rosenthal and Singer, *103*, **29**: 81, 93; 21. (114) Roth, *100*, **55**: 533; 23. (115) Sainte Claire-Deville and Troost, *34*, **59**: 162; 64. (116) Scheel, *89*, **4**: 35; 04. (117) Scheel, *243*, **28**: 106; 08. (118) Scheel, *96*, **5**: 167; 21. (119) Singer, *B4*.

(120) Singer, *92*, **31**: 221, 227, 229; 18. (121) Singer, *104*, **4**: 49; 23. **4**: 164; 24. (122) Singer, *112*, **335**: 96; 20. (123) Singer and Rosenthal, *104*, **1**, No. **3**: 47; 20. (124) Somerville, *2*, **31**: 261; 10. (125) Sortwell, *38*, **5**: 276; 22. (126) Sortwell, *32*, No. **196**: 21. (127) Souder and Hidnert, *31*, No. **352**: 19. (128) Staley and Hromatko, *38*, **2**: 227; 19. (129) Starke, *8*, **60**: 629; 97.

(130) Steger, *124*, **2**: 51; 14. (131) Steger, *103*, **27**: 113; 19. (132) Steger, *103*, **27**: 313; 19. (133) Steger, *104*, **2**: 9; 21. **3**: 50; 22. (134) Tadokoro, *159*, **10**: 339; 21. (135) Tutton, *3*, **3**: 631; 02. (136) Tutton, *67*, **18**: 182; 02. (137) Twells and Lin, *38*, **4**: 195; 21. (138) Urban, *103*, **32**: 217; 24. (139) Urban, *103*, **32**: 229; 24.

(140) Walker, *81*, **18**: 444; 16. (141) Ward, *81*, **17**: 431; 15. (142) Washburn and Bunting, *38*, **5**: 527; 22. (143) Waters, *32*, No. **105**: 17. (144) Watkin, *82*, **23**: 185; 24. (145) Watts, *81*, **4**: 86; 02. **9**: 600; 07. (146) Watts, *81*, **11**: 84; 09. (147) Watts, *81*, **10**: 265; 08. (148) Watts, *81*, **11**: 179; 09. (149) Watts, *81*, **13**: 406; 11.

(150) Watts, *81*, **11**: 185; 09. (151) Weelans and Ashley, *81*, **13**: 102; 11. (152) Weimer and Dun, *81*, **14**: 280; 12. (153) Weinhold, *8*, **149**: 186; 73. (154) White, *82*, **21**: 320; 22. (155) Wologdine, *420*, **1909**: 879. (156) Wologdine and Queneau, *33*, **7**: 383, 433; 09. (157) Wright and Sewell, *38*, **2**: 282; 19. (158) Zoellner, *100*, **41**: 471, 533; 08. (159) Zoellner, *Diss.*, Berlin, 1908.

REFRACTORY MATERIALS

GORDON B. WILKES

TYPICAL COMPOSITIONS, % BY WEIGHT

Materials	Al_2O_3	CaO	Fe_2O_3	MgO	SiO_2	Others	Lit.
Alundum	92–99						(72)
Bauxite brick	65–95		3–8		5–13	TiO_2, 1–7	(34)
Carborundum brick	0–5		0–1		0–5	SiC, 90–100	(28, 34)
Chrome brick	14–20	Trace	14–19	11–17	3–10	Cr_2O_3, 36–46	(34)
Fire clay brick	15–45	0–0.7	0–6	0–0.7	40–75	Alkalies, 0–2	(13, 34, 36, 84)
Magnesite brick	0–4	0–6	0–10	80–94	0–11	TiO_2, 0–2.8	(34, 47, 54)
Silica brick	0–2	0–6	0–2	0–0.8	90–98	Alkalies, 0–0.6	(24, 35, 40, 49, 53, 70, 86)
Zirconia brick						ZrO_2, 75–95	(74, 34, 28, 8)

BULK DENSITY AND SPECIFIC GRAVITY

	Bulk density g/cm³	True sp. gr.	Lit.
Alumina, Al_2O_3		α3.93–4.01 β3.03± 0.01	(62, 68)
Alundum	2.6	3.02–4.00	(48, 34)
Bauxite brick		3.15–3.25	(34, 11)
Carborundum, SiC		3.12–3.20	(80)
SiC brick	2.05–2.60		(25, 80)
Chrome brick	2.8–3.2	3.90–4.00	(80, 34)
Fire clay brick	1.7–2.1	2.1–2.8	(34, 84, 18, 25)
Magnesium oxide (MgO).		α3.2 β3.67–3.69	(81, 55)
Magnesite brick	2.0–2.8	3.1–3.6	(80, 55, 34, 18, 54)
Silica, fused	2.22 (transparent) 2.07 (translucent)		(41)
Quartz, SiO_2		2.646–2.656	(48, 14)
Tridymite, SiO_2		2.31–2.32	(48)
Cristobalite, SiO_2		2.32–2.41	(48, 14)
Silica, amorphous		2.04–2.21	(48)
Silica brick	1.50–1.88	2.05–2.75	(70, 34, 18, 42, 29, 53, 86, 84)
Zirconia, ZrO_2		5.48–5.90	(48, 66, 74, 8)
Zirconia brick		4.55–5.00	(58, 74)
Carbon		1.7–2.0	(48)
Graphite		2.17–2.32	(48, 18)

POROSITY

Material	Porosity, %	Lit.
Bauxite brick	46–50	(38)
Carborundum brick	17–34	(25)
Fire clay brick	20–30	(37, 84)
Magnesite brick	24–40	(42)
Silica brick	18–43	(70, 38, 42)
Zirconia brick	19	(58, 74)

and Siemens, *9*, **15**: 969; 09. (79) Plenske, *100*, **41**: 256, 271, 287, 301, 326; 08.

(80) Potts and Knollman, *81*, **15**: 285; 13. (81) Priest, *81*, **17**: 150; 15. (82) Purdy, *81*, **13**: 86; 11. (83) Purdy, *81*, **13**: 550; 11. (84) Purdy, *81*, **15**: 499; 13. (85) Purdy and Potts, *81*, **13**: 431; 11. (86) Radcliffe, *81*, **14**: 575; 12. (87) Rebuffat, *420*, **1906**: 222. (88) Regout, *Klei*, No. 17; 21. (89) Regout, *103*, **30**: 131; 22.

(90) Reichau, *82*, **23**: 145; 24. (91) Reichau, *82*, **24**: 279; 24. (92) Reichau, *103*, **32**: 531; 24. (93) Riddle, *38*, **2**: 804; 19. (94) Riddle, *38*, **2**: 812; 19. (95) Riddle and Laird, *38*, **5**: 385; 22. (96) Riddle and Laird, *38*, **5**: 500; 22. (97) Riddle and Laird, *66*, **21**: 1050; 21. (98) Riddle and McDanel, *38*, **1**: 606; 18. (99) Rieke, *B74*.

(100) Rieke, *100*, **45**: 225; 12. (101) Rieke, *103*, **22**: 143, 155; 14. (102) Rieke, *124*, **2**: 125; 14. (103) Rieke, *92*, **28**: 374; 15. (104) Rieke, *103*, **25**: 259, 263, 267; 17. (105) Rieke, *100*, **51**: 95, 135; 18. (106) Rieke, *104*, **3**: 187; 22. (107) Rieke, *92*, **37**: 190; 24. (108) Rieke and Gary, *104*, **3**: 5; 22. (109) Rieke and Steger, *100*, **47**: 457, 577; 14.

(110) Rieke and Steger, *100*, **48**: 297; 15. (111) Rieke and Steger, *103*, **27**: 193, 203; 19. (112) Rosenthal, *100*, **48**: 445; 15. (113) Rosenthal and Singer, *103*, **29**: 81, 93; 21. (114) Roth, *100*, **55**: 533; 23. (115) Sainte Claire-Deville and Troost, *34*, **59**: 162; 64. (116) Scheel, *89*, **4**: 35; 04. (117) Scheel, *243*, **28**: 106; 08. (118) Scheel, *96*, **5**: 167; 21. (119) Singer, *B4*.

(120) Singer, *92*, **31**: 221, 227, 229; 18. (121) Singer, *104*, **4**: 49; 23. **4**: 164; 24. (122) Singer, *112*, **335**: 96; 20. (123) Singer and Rosenthal, *104*, **1**, No. **3**: 47; 20. (124) Somerville, *2*, **31**: 261; 10. (125) Sortwell, *38*, **5**: 276; 22. (126) Sortwell, *32*, No. **196**: 21. (127) Souder and Hidnert, *31*, No. **352**: 19. (128) Staley and Hromatko, *38*, **2**: 227; 19. (129) Starke, *8*, **60**: 629; 97.

(130) Steger, *124*, **2**: 51; 14. (131) Steger, *103*, **27**: 113; 19. (132) Steger, *103*, **27**: 313; 19. (133) Steger, *104*, **2**: 9; 21. **3**: 50; 22. (134) Tadokoro, *159*, **10**: 339; 21. (135) Tutton, *3*, **3**: 631; 02. (136) Tutton, *67*, **18**: 182; 02. (137) Twells and Lin, *38*, **4**: 195; 21. (138) Urban, *103*, **32**: 217; 24. (139) Urban, *103*, **32**: 229; 24.

(140) Walker, *81*, **18**: 444; 16. (141) Ward, *81*, **17**: 431; 15. (142) Washburn and Bunting, *38*, **5**: 527; 22. (143) Waters, *32*, No. **105**: 17. (144) Watkin, *82*, **23**: 185; 24. (145) Watts, *81*, **4**: 86; 02. **9**: 600; 07. (146) Watts, *81*, **11**: 84; 09. (147) Watts, *81*, **10**: 265; 08. (148) Watts, *81*, **11**: 179; 09. (149) Watts, *81*, **13**: 406; 11.

(150) Watts, *81*, **11**: 185; 09. (151) Weelans and Ashley, *81*, **13**: 102; 11. (152) Weimer and Dun, *81*, **14**: 280; 12. (153) Weinhold, *8*, **149**: 186; 73. (154) White, *82*, **21**: *320; 22.* (155) Wologdine, *420*, **1909**: 879. (156) Wologdine and Queneau, *33*, **7**: 383, 433; 09. (157) Wright and Sewell, *38*, **2**: 282; 19. (158) Zoellner, *100*, **41**: 471, 533; 08. (159) Zoellner, *Diss.*, Berlin, 1908.

REFRACTORY MATERIALS

Gordon B. Wilkes

Typical Compositions, % by Weight

Materials	Al_2O_3	CaO	Fe_2O_3	MgO	SiO_2	Others	Lit.
Alundum	92–99						(72)
Bauxite brick	65–95		3–8		5–13	TiO_2, 1–7	(34)
Carborundum brick	0–5		0–1		0–5	SiC, 90–100	(28, 34)
Chrome brick	14–20	Trace	14–19	11–17	3–10	Cr_2O_3, 36–46	(34)
Fire clay brick	15–45	0–0.7	0–6	0–0.7	40–75	Alkalies, 0–2	(13, 34, 36, 84)
Magnesite brick	0–4	0–6	0–10	80–94	0–11	TiO_2, 0–2.8	(34, 47, 54)
Silica brick	0–2	0–6	0–2	0–0.8	90–98	Alkalies, 0–0.6	(24, 35, 40, 49, 53, 70, 86)
Zirconia brick						ZrO_2, 75–95	(74, 34, 28, 8)

Bulk Density and Specific Gravity

	Bulk density g/cm³	True sp. gr.	Lit.
Alumina, Al_2O_3		α3.93–4.01 β3.03± 0.01	(62, 68)
Alundum	2.6	3.02–4.00	(48, 34)
Bauxite brick		3.15–3.25	(34, 11)
Carborundum, SiC		3.12–3.20	(80)
SiC brick	2.05–2.60		(25, 80)
Chrome brick	2.8–3.2	3.90–4.00	(80, 34)
Fire clay brick	1.7–2.1	2.1–2.8	(34, 84, 18, 25)
Magnesium oxide (MgO).		α3.2 β3.67–3.69	(81, 55)
Magnesite brick	2.0–2.8	3.1–3.6	(80, 55, 34, 18, 54)
Silica, fused	2.22 (transparent) 2.07 (translucent)		(41)
Quartz, SiO_2		2.646–2.656	(48, 14)
Tridymite, SiO_2		2.31–2.32	(48)
Cristobalite, SiO_2		2.32–2.41	(48, 14)
Silica, amorphous		2.04–2.21	(48)
Silica brick	1.50–1.88	2.05–2.75	(70, 34, 18, 42, 29, 53, 86, 84)
Zirconia, ZrO_2		5.48–5.90	(48, 66, 74, 8)
Zirconia brick		4.55–5.00	(58, 74)
Carbon		1.7–2.0	(48)
Graphite		2.17–2.32	(48, 18)

Porosity

Material	Porosity, %	Lit.
Bauxite brick	46–50	(38)
Carborundum brick	17–34	(25)
Fire clay brick	20–30	(37, 84)
Magnesite brick	24–40	(42)
Silica brick	18–43	(70, 38, 42)
Zirconia brick	19	(58, 74)

CRUSHING STRENGTH, MEGADYNE CM^{-2}

1 megadyne cm^{-2} = 14.5 lb. in.^{-2} = 1020 g cm^{-2}

	20°C	800°C	1000°C	1300°C	1500°C	Lit.
Bauxite brick*	390–650	260–350	670–700	54–93	15	(4)
Carborundum*	407	417	574	147	69	(4)
Chrome brick*	442	442	417	211	74	(4)
	252		116	5.8	1.9	(51)
Fire clay brick*	191–1090	123–544	103–740	113–726	20–64	(4, 51, 84, 87)
	70–300	60–300	70–250	20–120	0–20	
Magnesite brick*	441	201	186	152	29	(4, 51, 54)
	140–600		82	64	3.5	
Silica (fused)*	2500	1020	765	164	98	(4)
Silica brick	150–200	90–170	70–160	60–110	20–80	(4, 51, 54, 57, 29, 70)
Zirconia*	388	270	338	88	9.8	(4)

* Values given by Bodin, probably high for standard brick. Test specimens were 2 cm cube.

FUSION TEMPERATURE

	°C	Lit.
Alumina, Al_2O_3	2010–2050	(8, 48)
Alundum	1750–2000	(79, 72)
Bauxite clay	1750–2000	(84, 35)
Bauxite brick	1565–1785	(44, 45)
Carborundum	2200–2240 *d*	(82, 8, 21, 72)
Chromium oxide, Cr_2O_3	1990	(44)
Chrome brick	1850–2050	(44, 54, 45, 48)
Fire clay brick	1500–1750	(44, 34, 40, 39, 45, 84)
Magnesium oxide, MgO	2800	(8)
Sintered magnesia	2200–2600	(84, 10)
Magnesite brick	2150–2165	(54, 12, 44)
Silica, SiO_2	1700–1710	(8, 44, 48)
Silica brick	1685–1800	(29, 19, 38, 48, 12, 40, 44, 45)
Mullite ("sillimanite"), $(Al_2O_3)_3(SiO_2)_2$	1816	(15)
Spinel, $MgO.Al_2O_3$	2135	(68)
Zirconia, ZrO_2	2500–2950	(8, 71, 1, 83)
Zirconia brick	2000–2600	(8, 71, 1, 74)

TEMPERATURE OF FAILURE UNDER LOAD

Load = 34.5 × 10^5 dyne cm^{-2} = 50 lb. in.^{-2} = 3520 g cm^{-2}

Material	Alundum brick	Bauxite brick	Carborundum	Chrome	Fire clay	Magnesite brick	Silica	Zirconia brick
Temp. °C	1550+	1350	1650+	1400–1450	1250–1500*	1410–1555	1600–1650	1510
Remarks	No failure	Softens	No failure	Shears	Softens	Shears	Shears	Softens
Lit.	(7)	(69, 7)	(52, 25)	(7, 35)	(84, 3, 19, 35)	(7)	(7, 25, 19)	(7)

* Load = 25 lb. in.^{-2}.

MEAN LINEAR COEFFICIENT OF THERMAL EXPANSION BETWEEN t°C AND 25°C

$$k = \frac{1}{l_{25}}\frac{l_t - l_{25}}{t - 25} = A \times 10^{-6}$$

	Variation	A				Lit.
		100°C	500°C	1000°C	1500°C	
Alumina, Al_2O_3	7.2–8.0 between 900°C and 25°C					(79)
Alundum		7.1–8.5				(79, 72)
Bauxite brick		4.4	5.2	5.3	5.3	(84)
Carborundum, SiC	4.38(800–700°C) 2.98(900–800°C)	6.58		4.35		(43)
SiC brick	6.0(1300–25°C)		5.2	5.8		(84)
Chrome brick				9.0	1.1	(48, 78)
Fire clay brick		8.1 ± 3.0	7.5 ± 3.0	6.7 ± 3.0	5.9 ± 3.0	(84, 78, 63, 55)
Mag. oxide, MgO	11.5–13.1 (300–25°C)	9.7–11.4				(23, 84)
Magnesite brick		11.5 ± 1.0	11.7 ± 2.0	12.4 ± 1.5	13.5 ± 1.0	(78, 54, 64, 50, 65, 48)
Silica brick	36 ± 3(200–25°C)	28 ± 3	22 ± 5	13 ± 2	8.6 ± 1	(78, 29, 77, 55, 53, 70, 84, 48)
Zirconia (fused), ZrO_2		8.4				(8)
Carbon			1.5–5.5			(84, 48)
Graphite	7.8(40–25°C)					(48)

For mean coefficient between any two temperatures, $\alpha_m = \frac{\alpha_{t_1}(t_1 - 25) - \alpha_{t_2}(t_2 - 25)}{t_1 - t_2}$, where α_{t_1} and α_{t_2} may be taken from a graph.

EXPANSION AND CONTRACTION DURING HEATING

The data given in Figs. 1–4 and in the table below record the % changes in length undergone by 1 × 1 × 9 in. test bars when heated in a gas fired muffle furnace with neutral atmosphere at the rate of 100°C per hour. Specimens marked "brick" are commercial products. For compositions of these and methods of preparing all specimens, *v.* the original (⁸⁸).

No.	Type	M. P.,* °C	Fired to, °C	$\frac{10^7\Delta l}{l\Delta t}$ 0° to t_s	t_s† °C
1	Silica brick	1700		83	1550
2	Kaolin	1740	1300	47	1050
3	Kaolin	1740	1430	68	1380
4	Kaolin	1740	1500	53	1580
5	Kaolin	1740	1620	43	1610
6	Fire clay brick (Mo.)	1720		54	1300
7	Fire clay brick (Pa.)	1680		51	1250
8	Fire clay brick (Colo.)	1700		54	1220
9	Fire clay brick (Md.)	1610		45	1100
10	SiC brick	>2000		43	>1700
11	Zircon white	>2000	1650	64	1510
12	Zircon brown	1935	1590	42	1550
13	ZrO_2	>2000	1675	59	1600
14	Mullite	1850	1785	53	>1700
15	Magnesite	>2000	1680	142	>1700
16	Magnesite brick			147	1440
17	Chrome brick			104	1540
18	Mg-spinel	>2000	1690	76	1600
19	Lime	>2000	1740	138	>1700
20	Fused Al_2O_3	>2000	1650	77	1580
21	Infusorial-earth brick	1630		74	1050

* Reducing atm.

† Beginning of shrinkage or expansion.

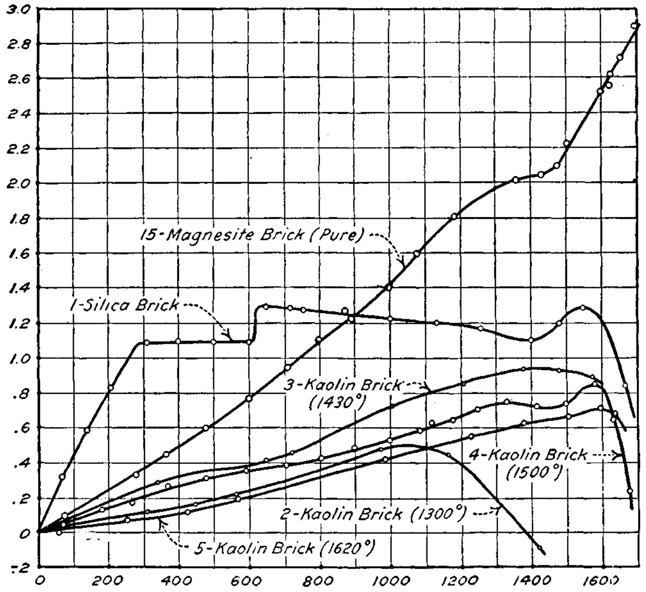

FIG. 1.

Figure 5 shows a comparison of the expansion of German and American silica brick. Curves 1, 2 and 3 are for American silica brick (measurements reported by the National Bureau of Standards); Curves I, II and III, for German silica brick (measurements by Endell and Steger, *Glastech. Ber.*, **4**; May, 1926).

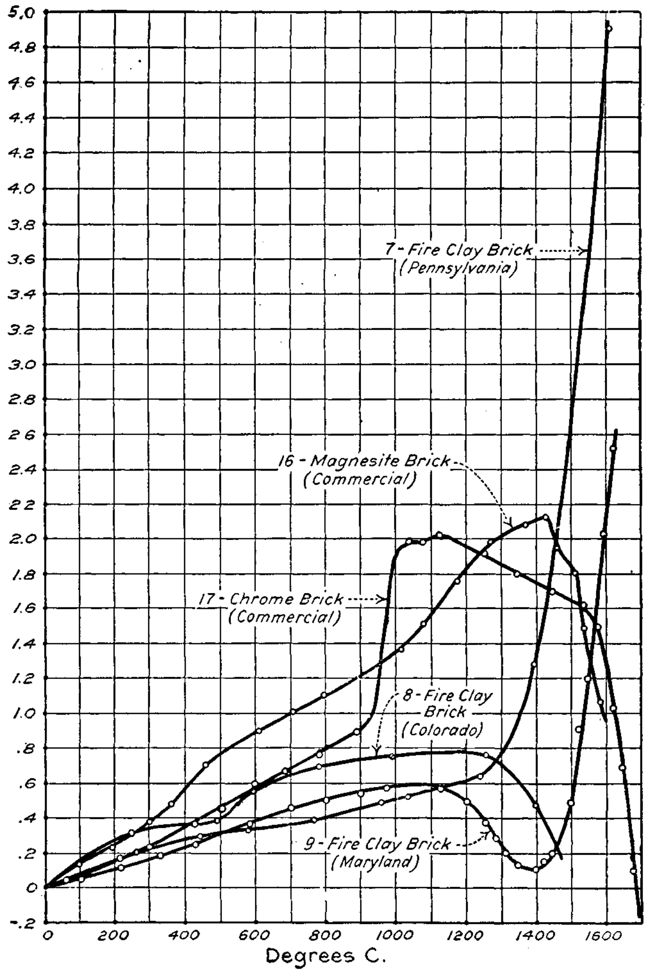

FIG. 2.

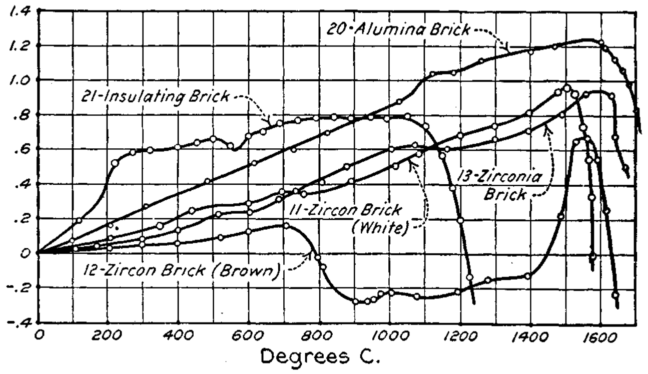

FIG. 3.

MEAN SPECIFIC HEAT BETWEEN $t°$ AND 25°C

Joule per gram per °C

1 joule g^{-1} per °C = 0.239 g-cal g^{-1} per °C = 0.239 BTU $lb.^{-1}$ per °F

	100°C	500°C	1000°C	1500°C	Lit.
Alumina, Al_2O_3	0.837	1.00	1.09	1.15	(84)
Alundum	0.778				(79)
SiC brick	0.838 ± 0.13		0.78 ± 0.17		(79, 33, 18)
Chrome brick	0.71	0.84	0.92		(78)
Fire clay brick	0.83 ± 0.04	0.93 ± 0.04	1.08 ± 0.04	1.25 ± 0.04	(78, 5, 85, 18, 31)
Mag. oxide, MgO	0.98 ± 0.02	1.09 ± 0.02	1.17 ± 0.02	1.21 ± 0.02	(84, 48, 54)
Magnesite brick	0.93 ± 0.04	1.05 ± 0.04	1.16 ± 0.04	1.24 ± 0.04	(32, 76, 84, 78, 18)
Silica brick	0.84 ± 0.06	0.95 ± 0.06	1.10 ± 0.06	1.24 ± 0.06	(5, 32, 76, 84, 61, 78, 18)
Zirconium oxide	0.46 ± 0.02	0.55	0.66	0.75	(5, 8)
Carbon	0.516	2.0 at 2000°C	1.3		(16)
Graphite		2.2 at 2000°C	1.23	1.71	(16, 46)

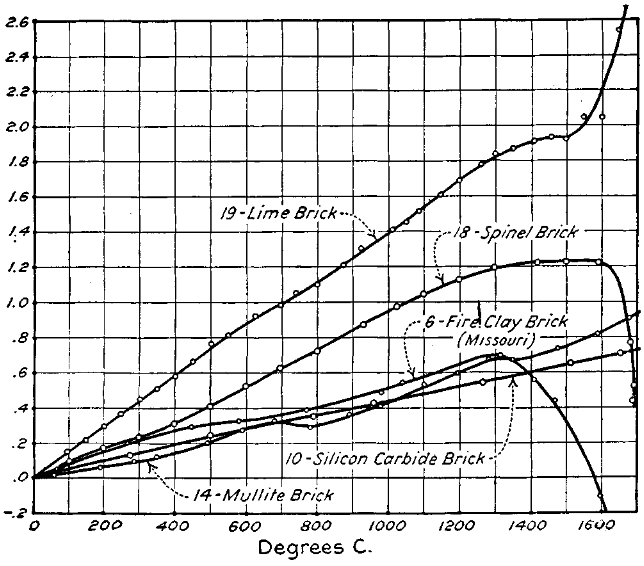

FIG. 4.

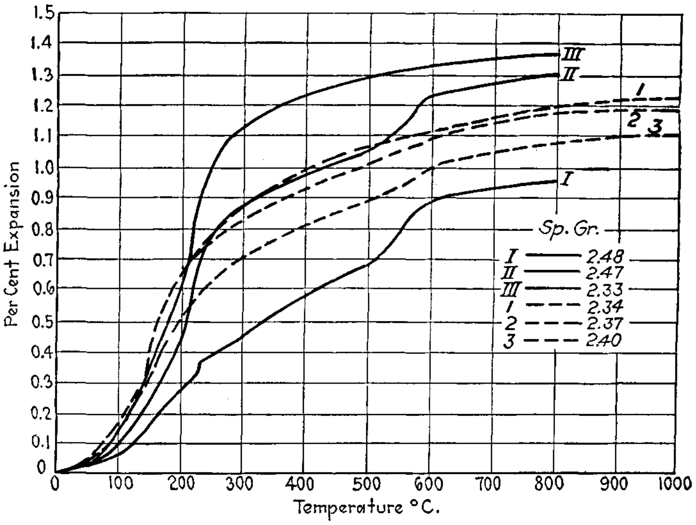

FIG. 5.

MEAN COEFFICIENT OF THERMAL CONDUCTIVITY BETWEEN $t°$ AND 25°C

Joule cm^{-2}, sec^{-1} (°C, $cm^{-1})^{-1}$

1 joule cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$ = 0.239 g-cal cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$ = 0.193 BTU $ft.^{-2}$ sec^{-1} (°F, $in.^{-1})^{-1}$

	100°C	500°C	1000°C	1500°C	Lit.
Alundum	0.035 between 1250°C and 650°C				(62, 67)
Bauxite brick	0.0046		0.0064		(6)
SiC bonded brick			0.08–0.10		(18, 86, 79)
Chrome brick			0.024		(86)
Fire clay	0.0065 ± 0.0015	0.0089 ± 0.0015	0.0117 ± 0.0015	0.0143 ± 0.0020	(18, 22, 17, 84, 25, 31, 86)
		0.048			(84)
Magnesite bonded brick, elec. sintered	0.041 ± 0.009	0.044 ± 0.015	0.047 ± 0 020		(18, 22, 17, 84, 86)
Silica brick	0.0080 ± 0.0010	0.0096 ± 0.0010	0.0121 ± 0.0010		(18, 22, 17, 84, 16)
Carbon	0.38 at 360°C	0.45	0.55	0.58	(30)
Graphite	1.41 at 390°C	1.38	1.19	1.15	(30)

For mean coefficient between any two temperatures, $k_m = \frac{k_{t_1}(t_1 - 25) - k_{t_2}(t_2 - 25)}{t_1 - t_2}$ where k_{t_1} and k_{t_2} may be taken from a graph.

Electrical Resistivity

	Megohm-cm³	Ohm-cm³				Lit.
	25°C	1000°C	1200°C	1400°C	1500°C	
Alundum		1.8×10^6				(79)
Diaspore	137		193 000		2 500	(28)
Bauxite brick	133	17 200	6 100	2 200	1 100	(27)
Carborundum		3.7	1.3	0.65		(80)
Carborundum refrax brick	107×10^{-6}	4.1	2.5	1.74	1.62	(27)
Carborundum 95% SiC bonded	107×10^{-3}	4 720	4 160	1 435	745	(27)
Carborundum 90% SiC bonded	127	197 000	29 500	10 100	8 590	(27)
Chrome brick	48.1	171	63	85	41	(27)
		420	450	320		(75)
Fire clay brick	137	10 800	4 160	1 420	890	(27)
		6 600	480 000	180 000	80 000	(84)
			2 300	690	280	(75)
Magnesite brick	137	708 000	193 000	22 400	2 500	(27)
			100 000	40 000	3 000	(84)
			12 000	400		(60)
Silica (fused)	5×10^{12}	4×10^4 at 727°C				
Silica brick	125	300 000	62 000	16 500	8 420	(27)
			360 000	125 000	63 000	(84)
				2 400	710	(75)
Zirconia brick	134	131 300	1 230			(56)
			1 250	300		(1)
			7 710	968	412	(27)
Zirconia			12×10^7			(8)
Carbon	46×10^{-10}	3.7×10^{-3}	3.7×10^{-3}	3.7×10^{-3}	3.6×10^{-3} at 2000°C	(30)
Graphite	85×10^{-11}	7.95×10^{-4}	7.9×10^{-4}	7.9×10^{-4}	7.9×10^{-4} at 2000°C	(30)

For review of recent literature *v.* (89).

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(For a key to the periodicals see end of volume)

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(10) Anon., *276*, **8**: 419; 23. (11) Crawford, J. L., *O.* (12) Dana and Foote, *33*, **23**: 23, 63; 20. (13) Davidson, *135*, **116**: 75; 17. (14) Day, Sosman and Hostetter, *12*, **37**: 1; 14. (15) Demasure, *Bull. fed. Ind. Chim. Belg.* **3**: 182; 24. (16) Dewar, *25*, **5**: 814; 72. (17) Dougill, Hodsman and Conn, *54*, **36**: 465; 15. (18) Dudley, *78*, **27**: 285; 15. (19) Endell, *77*, **41**: 6; 20.

(20) Fitzgerald, *33*, **10**: 129; 12. (21) Gillett, *50*, **15**: 213; 11. (22) Goerens and Gillis, *139*, **12**: 17; 15. (23) Goodwin and Mailey, *78*, **9**: 89; 06. (24) Graham, *307*, **102**: 639; 18. (25) Hartmann and Westmont, *78*, **46**: 485; 24. (26) Hartmann and Kobler, *78*, **37**: 707; 20. (27) Hartmann, Sullivan and Allen, *78*, **37**: 292; 20. (28) Hartmann and Sullivan, *78*, **38**: 279; 20. (29) Havard, *Refractories and Furnaces* (McGraw-Hill Book Company, Inc., 1912).

(30) Hering, *119*, **29**: 485; 10. (31) Hersey and Butzler, *313*, No. **2564**; 24. (32) Heyn, *312*, **32**: 185; 14. (33) Howe, *33*, **23**: 1215; 20. (34) *Ibid.*, **23**: 232; 20. (35) Howe, *Refractories for Electric Furnaces* (Elec. Fur. Assoc., Niagara Falls, 1920). (36) Howe, *38*, **6**: 471; 23. (37) Howe, *45*, **11**: 1145; 19. (38) Howe and Ferguson, *38*, **4**: 37; 21. (39) Howe and Shepherd, *38*, **4**: 207; 21.

(40) Howe, Phelps and Ferguson, *38*, **6**: 590; 23. (41) Hougen, *33*, **30**: 737; 24. (42) Houldsworth and Cobb, *38*, **6**: 658; 23. (43) Quoted by Hougen, *33*, **30**: 740; 24. (44) Kanolt, *32*, No. **10**; 12. (45) Kanolt, *78*, **22**: 93; 12. (46) Kopp, *12*, Suppl. **III, 1**: 289; 64. (47) Kowalke and Hougen, *307*, **102**: 639; 18. (48) Quoted from *B3.* (49) Lange, *77*, **32**: 1731; 12.

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(60) Northrup, *78*, **27**: 233; 13. (61) Norton, C. L., *O.* (62) Boeck, *81*, **14**: 470; 12. (63) Norton F. H., *38*, **8**: 29; 25. (64) Phelps, Mellon Inst., *O.* (65) Pierce, Harbison-Walker Refractories Co., *O.* (66) Podszus, *92*, **30**: 17; 17. (67) Randolph, *120*, **16**: 120; 13. (68) Rankin and Merwin, *1*, **38**: 568; 16. (69) Rochow, *45*, **11**: 1148; 19.

(70) Ross, *32*, No. **116**; 19. (71) Ruff and Lauschke, *100*, **36**: 70; 16. (72) Saunders, *78*, **19**: 333; 11. (73) Seaver, *80*, **53**: 125; 16. (74) Sheppard, *38*, **6**: 294; 23. (75) Stansfield, MacLeod and McMahon, *78*, **22**: 89; 12. (76) Steger, *124*, **2**: 203; 14. (77) Stockman, *Thesis*, Mass. Inst. Tech., 1902. (78) Tadokoro, *159*, **10**: 339; 21. (79) Norton Co., Trade Cat. and *O.*

(80) Carborundum Co., Trade Cat. (81) Vitrefrax Co., Trade Cat. (82) Tucker and Sampen, *1*, **28**: 953; 06. (83) Washburn and Libman, *38*, **3**: 634; 20. (84) Wilkes, G. B., *O.* (85) Wilson, Holdcroft and Mellor, *82*, **12**: 279; 12. (86) Wologdine and Queneau, *33*, **7**: 383; 09. (87) Dupuy, *102*, **25**: 308; 22. (88) Norton, *38*, **8**: 799; 25. (89) Ferguson, *324*, **10**: 131; 26.

ABRASIVE MATERIALS

M. L. Hartmann

COMMON AND TRADE NAMES

Ind. No.

1. Aluminium oxide (fused, impure) ("aloxite," "alundum," "lionite," "borolon," "alumo"). Al_2O_3
2. Corundum. Al_2O_3
3. Diatomaceous earth (infusorial earth, kieselguhr, fossil flour, fossil meal, tripolite, diatomite, polerschiefer, desmid earth, molera, white peat, tellurine, randanite, ceyssatite, bergmehl, radiolarian earth). SiO_2
4. Emery.
5. Flint. SiO_2
6. Garnet (almandite, rhodolite).
7. Glass (alkali lime).
8. Pumice (pumicite, santorini, santorine earth).
9. Silicon carbide ("carborundum," "crystolon," "carbolon.") SiC

For diamond, iron oxides, iron alloys and quartz, *see* other sections of I. C. T.

ELECTRICAL RESISTIVITY

	Megohm-cm^3	Ohm-cm^3				Lit.
	25°C	1000°C	1200°C	1400°C	1500°C	
Alundum		1.8×10^6				(79)
Diaspore	137		193 000		2 500	(28)
Bauxite brick	133	17 200	6 100	2 200	1 100	(27)
Carborundum		3.7	1.3	0.65		(80)
Carborundum refrax brick	107×10^{-6}	4.1	2.5	1.74	1.62	(27)
Carborundum 95% SiC bonded	107×10^{-3}	4 720	4 160	1 435	745	(27)
Carborundum 90% SiC bonded	127	197 000	29 500	10 100	8 590	(27)
Chrome brick	48.1	171	63	85	41	(27)
		420	450	320		(75)
Fire clay brick	137	10 800	4 160	1 420	890	(27)
		6 600	480 000	180 000	80 000	(84)
			2 300	690	280	(75)
Magnesite brick	137	708 000	193 000	22 400	2 500	(27)
			100 000	40 000	3 000	(84)
			12 000	400		(60)
Silica (fused)	5×10^{12}	4×10^4 at 727°C				
Silica brick	125	300 000	62 000	16 500	8 420	(27)
			360 000	125 000	63 000	(84)
				2 400	710	(75)
Zirconia brick	134	131 300	1 230			(56)
			1 250	300		(1)
			7 710	968	412	(27)
Zirconia			12×10^7			(8)
Carbon	46×10^{-10}	3.7×10^{-3}	3.7×10^{-3}	3.7×10^{-3}	3.6×10^{-3} at 2000°C	(30)
Graphite	85×10^{-11}	7.95×10^{-4}	7.9×10^{-4}	7.9×10^{-4}	7.9×10^{-4} at 2000°C	(30)

For review of recent literature *v.* (89).

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ABRASIVE MATERIALS

M. L. HARTMANN

COMMON AND TRADE NAMES

IND. NO.

1. Aluminium oxide (fused, impure) ("aloxite," "alundum," "lionite," "borolon," "alumo"). Al_2O_3
2. Corundum. Al_2O_3
3. Diatomaceous earth (infusorial earth, kieselguhr, fossil flour, fossil meal, tripolite, diatomite, polerschiefer, desmid earth, molera, white peat, tellurine, randanite, ceyssatite, bergmehl, radiolarian earth). SiO_2
4. Emery.
5. Flint. SiO_2
6. Garnet (almandite, rhodolite).
7. Glass (alkali lime).
8. Pumice (pumicite, santorini, santorine earth).
9. Silicon carbide ("carborundum," "crystolon," "carbolon.") SiC

For diamond, iron oxides, iron alloys and quartz, *see* other sections of I. C. T.

Ind. No.	Hardness Mohs' scale	Density g/cm³	Thermal expansion $\frac{10^6}{l}\frac{dl}{dt}$ per °C	Thermal conductivity $k = 10^{-6} \times$ A g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$ A
1	9+ (25)	3.93–4.00 (3, 25)	8.7 (25–900°C) (2) 7.7 (0–1580°C) (17)	
2	9 (1, 4, 10, 11, 21)	3.95–4.10 (1, 4, 10, 21)	6.76 (19)	
3	1–1.5 (10)	2.1–2.2 (10)		227 (200°C) (10) 315 (800°C)
4	7–9 (10)	3.75–4.35 (4)		
5	7 (4,10)	2.61–2.63 (26)	17.4 (15–1000°C) (7)	
6	6.5–7 (10), *cf.* (1, 16)	3.4–4.3 (10), *cf.* (1, 16)		
7		2.4–2.6 (14)	8.01–11.88 (15)	1080–2270 (18)
8	6 (10)	2.5 (10)		
9	9–10 (9, 22)	3.17–3.21 (3, 5)	4.74 (100–900°C) (2) . 4.3 (0–1700°C) (9)	43000 (1350°C) (6) (34 % porosity)

Compressibility $\frac{dV}{VdP}$ (P in atm.) = 3.8×10^{-7} for No. 2 (12); 2.2×10^{-7} for No. 9 (100–500 atm.) (24).

Specific heat in g-cal/g = 0.1976 (8–98°C) for No. 2 (23); 0.212–0.236 (133–405°C) for No. 7 (8); 0.186 (31–98°C) for No. 9 (20), *cf.* (13, 27).

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(1) Barlow, *386*, No. **50**; 15. (2) Boeck, *81*, **14**: 470; 12. (3) Carborundum Company, Niagara Falls, New York, *O.* (4) Dana, *System of Mineralogy*, 6th ed., New York, Wiley, 1892. (5) Fitzgerald, *143*, **143**: 81; 97. (6) Hartmann and Westmont, *38*, **8**: 259; 25. (7) Houldsworth and Cobb, *in* Searle, *The Chemistry and Physics of Clays and Other Ceramic Materials*, p. 579. London, Benn, 1924. (8) Iitaka, *159*, **8**: 99; 19. (9) Kunz, *78*, **12**: 40; 07.

(10) Ladoo, *Non-Metallic Minerals*, New York, McGraw-Hill Book Company, Inc., 1925. (11) Larsen, *156*, No. **679**; 21. (12) Madelung and Fuchs, *8*, **65**: 293; 21. (13) Magnus, *8*, **70**: 303; 23. (14) Mellor, *B71*, **VI**: 524; 25. (15) Mellor, *B71*, **VI**: 529; 25. (16) Mellor, *B71*, **VI**: 911; 25. (17) Norton, *38*, **8**: 799; 25. (18) Paalhorn, *in B71*, **VI**: 531; 25. (19) Pfaff, *8*, **107**: 148; 59.

(20) Potter, *78*, **12**: 191; 07. (21) Pratt, *156*, No. **269**; 06. (22) Pratt, *387*, **15**: 98; 06. (23) Regnault, *6*, **1**: 129; 41. (24) Richards, Stull, Brink and Bonnet, *152*, No. **76**; 07. (25) Saunders, *78*, **19**: 333; 11. (26) Washburn and Navias, *38*, **5**: 565; 22. (27) Weigel, *188*, **1915**; 264, 320.

PROPERTIES OF GLASS

GEORGE W. MOREY

Ind. No.	Hardness Mohs' scale	Density g/cm³	Thermal expansion $\frac{10^6}{l}\frac{dl}{dt}$ per °C	Thermal conductivity $k = 10^{-6} \times$ A g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$ A
1	9+ (25)	3.93–4.00 (3, 25)	8.7 (25–900°C) (2) 7.7 (0–1580°C) (17)	
2	9 (1, 4, 10, 11, 21)	3.95–4.10 (1, 4, 10, 21)	6.76 (19)	
3	1–1.5 (10)	2.1–2.2 (10)		227 (200°C) (10) 315 (800°C)
4	7–9 (10)	3.75–4.35 (4)		
5	7 (4,10)	2.61–2.63 (26)	17.4 (15–1000°C) (7)	
6	6.5–7 (10), *cf.* (1, 16)	3.4–4.3 (10), *cf.* (1, 16)		
7		2.4–2.6 (14)	8.01–11.88 (15)	1080–2270 (18)
8	6 (10)	2.5 (10)		
9	9–10 (9, 22)	3.17–3.21 (3, 5)	4.74 (100–900°C) (2) 4.3 (0–1700°C) (9)	43000 (1350°C) (6) (34 % porosity)

Compressibility $\frac{dV}{VdP}$ (P in atm.) $= 3.8 \times 10^{-7}$ for No. 2 (12); 2.2×10^{-7} for No. 9 (100–500 atm.) (24).

Specific heat in g-cal/g = 0.1976 (8–98°C) for No. 2 (23); 0.212–0.236 (133–405°C) for No. 7 (8); 0.186 (31–98°C) for No. 9 (20), *cf.* (13, 27).

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PROPERTIES OF GLASS

GEORGE W. MOREY

CONTENTS.—(*Continued*)

The "Index Nos." of Table 1 are identification numbers by means of which the glasses are identified in the property tables which follow.

TABLE 1.—GLASS COMPOSITIONS

With the exception of those glasses whose index numbers are in italics, all the compositions listed below are calculated from the ingredients melted to produce the glass type (so-called "batch" compositions). The glasses actually measured will therefore differ from the compositions given by unknown amounts; a difference in optical properties between the types of Table 1 and like numbered glasses in subsequent tables indicates such uncontrolled variations. The analyses of similar types shown in Table 1 give an idea of the magnitude of the difference to be expected. In the tables which follow, this uncertainty as to the actual glass composition is usually greater than that introduced by errors in measurement.

The numbers under "Glass Types" in Table 1 represent $(n_D - 1)10^3/10v$; in which $v = \frac{n_D - 1}{n_F - n_C}$. Glasses 1–114 are arranged in the order of increasing n_D; glasses 115–133, in order of decreasing SiO_2 content; glasses 134–146 in order of decreasing n_D.

MATIÈRES.—(*Suite*)

Les nombres index de la Table 1 sont des nombres d'identification au moyen desquels les verres sont identifiés dans les tables des propriétés qui font suite.

TABLE 1.—COMPOSITIONS DES VERRES

A l'exception des verres dont les nombres index sont en italique, toutes les compositions indiquées ci-dessous sont calculées à partir des substances de départ entrant dans la fabrication du verre type. La composition réelle des verres dont on donne les mesures peut donc différer des compositions indiquées par un montant inconnu; une différence dans les propriétés optiques entre les types de la Table 1 et les verres de même numéro dans les tables subséquentes met en évidence ces variations incontrôlées. Les analyses de types similaires indiquées dans la Table 1 donnent une idée de l'ordre de grandeur de la différence à laquelle on peut s'attendre. Dans les tables qui suivent, cette incertitude en ce qui concerne la composition réelle du verre est ordinairement plus grande que celle introduite par des erreurs dans les mesures.

Les nombres dans "Verres types" dans la Table 1 représentent $(n_D - 1)10^3/10v$; dans laquelle $v = \frac{n_D - 1}{n_F - n_C}$. Les verres 1 à 114 sont disposés dans l'ordre de n_D accroissant; les verres 115 à 133 dans l'ordre de la teneur décroissante en SiO_2; les verres 134 à 146 dans l'ordre de n_D décroissant.

INHALTSVERZEICHNIS.—(*Fortsetzung*)

Die Indexnummern der Tafel 1 sind Erkennungszahlen mit Hilfe deren die Gläser in den folgenden Eigenschaftstafeln identifiziert sind.

TAFEL 1.—GLAS-ZUSAMMENSETZUNGEN

Mit Ausnahme bei jenen Gläsern deren Indexnummern kursiv geschrieben sind, ist ihre folgende Zusammensetzung aus den Bestandteilen berechnet, die zur Erschmelzung des Glases verwendet worden sind (Glassatz). Die wirkliche Zusammensetzung des Glases wird deshalb von der angegebenen in unbekanntem Ausmasse abweichen. Ein Unterschied in den optischen Eigenschaften der Glastypen in der Tafel 1 und denen in den folgenden Tabellen, welche ähnlich bezeichnet sind, zeigt solche unkontrollierbare Veränderungen. Die Analyse ähnlicher Glassorten, welche in der Tabelle 1 verzeichnet sind, geben eine Vorstellung von der Grösse der Abweichungen die zu erwarten sind. In den folgenden Tabellen ist die Unsicherheit bezüglich der wirklichen Glaszusammensetzung gewöhnlich grösser, als sie durch Messfehler verursacht werden kann.

Die Zahlen unter "Glass Types" in der Tafel 1 bedeuten $(n_D - 1)10^3/10v$ wobei $v = \frac{n_D - 1}{n_F - n_C}$ ist. Die Gläser 1–114 reihen sich nach aufsteigenden n_D-Werten, Gläser 115–133 nach absteigendem SiO_2-Gehalt und Gläser 134–146 nach absteigenden n_D-Werten.

INDICE.—(*Azione*)

I numeri indici della Tabella 1 sono numeri di identificazione a mezzo dei quali si possono individuare i diversi vetri nelle tabelle delle proprietà.

TABELLA 1.—COMPOSIZIONE DEI VETRI

Fatta eccezione per i vetri con numero indice scritto in corsivo, per tutti gli altri le composizioni riportate sono quelle che si calcolano dalle quantità dei componenti messe a fondere assieme.

Le composizioni effettive differiscono perciò da quelle indicate di una quantità sconosciuta; ed eventuali differenze nelle proprietà ottiche dei vetri della Tabella 1 e di quelli delle tabelle successive contradistinti da uno stesso numero stanno a dimostrare appunto queste incontrollatibili variazioni. Le analisi di tipi simili di vetri riportate nella Tabella 1, danno una idea della grandezza delle differenze che possono aversi. La incertezza intorno alla composizione effettiva del vetro è, in genere, maggiore di quella che può essere dovuta ad errori di misura.

I numeri sotto la dicitura "Glass Types" nella Tabella 1 rappresentano $(n_D - 1)10^3/10v$; dove $v = \frac{n_D - 1}{n_F - n_C}$. I vetri da 1 a 114 sono disposti in ordine accrescente di n_D; i vetri da 115 a 133 in ordine decrescente del contenuto di SiO_2; i vetri da 134 a 146 in ordine decrescente di n_D.

Ind. No.	Type	Name		Lit.	SiO_2	B_2O_3	Na_2O	K_2O	CaO	BaO	ZnO	PbO	MgO	Al_2O_3	Fe_2O_3	Mn_2O_3	Sb_2O_3	As_2O_5	As_2O_3	Cl	SO_3	H_2O	Table No.
1	475/636	Pyrex laboratory		(12)	80.75	12.00	4.10	0.10	0.30					2.20				0.40					2, 5, 11*a*, 11*b* 11*c*, 12*a*, 17*a*
1a		Pyrex radio																					2, 11*c*
2	479/702	Chance, fluor crown*	7423	(9)	54.8	18.7		20.3						0.3				0.2					11*a*, 11*c*, 13*c*
3	496/644	Schott, borosilicate crown	O802	(66)	71.	14	10							5.0									2, 4, 5, 7, 9, 11*c*
4	494/646	Schott, borosilicate crown	O2259	(55)	69.59	14	8	3.0						8.0		0.01		0.4					
5	498/653	Chance, borosilicate crown	3484	(9)	59.5	21.5		14.4	0.3		2.3			1.9				0.1					10, 13
6	500/647	Schott, borosilicate thermometer	59^{III}	(66)	72	12	11.0							5.0									2, 7, 12*b*
6a		Same, analysis		(43)	72.86	10.43	9.82	0.10	0.35				0.20	6.24	Tr.	Tr.							
7	506/602	Schott, crown	O714	(68)	74.6		9.0	11.0	5.0							0.1		0.3					2, 4
8	508/604	Schott, Jena geräte		(48)	64.7	10.9	7.5	0.37	0.63		10.9		0.21	4.2	0.25	0.01		0.14					7, 12*b*
9	509/641	Chance, borosilicate crown	O646	(9)	69.6	6.7		20.5	2.9					0.3				0.1					13
10	510/621	Chance, borosilicate crown	4990	(9)	71.1	2.7		18.8	6.8					0.3				0.2					13
11	510/	Schott, silicate crown	O2161	(35)	69.15	1.0	6.5	15.0			11.0					0.05		0.3					10
12	511/640	Schott, borosilicate crown	O144	(68)	70.4	7.4	5.3	14.5	2.0							0.1		0.2					2, 4, 5, 7, 10, 12*b*, 14, 17*a*, 17*b*
12a		Same, E. T. Allen, analyst		(3)	72.15	5.88	5.16	13.85	2.04	0	0	Tr.	0.07	0.04	0.01	0		0.20	0.08	0.06	0.12	0.08	
13	511/605	Schott, borosilicate crown	O374	(68)	68.1	3.5	5.0	16.0			7.0							0.4					7
14	513/637	Schott, borosilicate crown	O627	(68)	68.2	10.0	10.0	9.5			2.0							0.2					2, 15
15	513/573	Schott, zinc silicate crown	O709	(66)	70.6		17.0				12.0							0.4					2, 4, 11*b*
16	515/579	Chance, zinc crown	1066	(9)	69.7		11.0	1.7	0.4		16.5			0.3				0.4					13
17	516/640	Schott, borosilicate crown, analysis	O3832	(3)	69.58	9.91	8.44	8.37	0.07	2.54	0	0	0.07	0.04	0.01	0		0.22	0.09	0.06	0.08	0.06	5, 7, 9, 11*a* 11*c*
18	516/638	Chance, borosilicate crown	6493	(9)	67.1	7.2		16.2	2.0	7.2				0.3				0.1					13
19	516/620	Borosilicate crown		(1)	67	12	9	8		4													6, 16
20	516/608	Chance, hard crown	1203	(9)	69.5			19.0	11.1					0.3				0.2					13
21	516/536	Schott, borosilicate crown	O608	(68)	53.5	20.0		6.5									20.0						2
22	517/609	Schott, borosilicate crown	O40	(68)	69.0	2.5	4.0	16.0	8.0							0.1		0.4					2, 4, 7, 11*c*
23	517/602	Schott, silicate crown	O60	(66)	64.6	2.7	5.0	15.0		10.2	2.0					0.1		0.4					2, 4, 7, 12*b*, 15, 17*a*
24	517/589	Schott, silicate crown	O203				Composition unknown, but probably differs but little from 23 and 25																5, 7, 14
25	517/558	Schott, light barium crown	O1092	(53)	65.4	2.5	5.6	15.0		9.6	2.0					0.1		0.4					14, 17*c*
26	518/609	Bureau of Standards, light crown		(48)	68.6	3.5	12.0	5.0		9.7	1.0							0.2					7
27	518/605	Chance, hard crown	605	(9)	69.6			18.4	11.5					0.3				0.2					13
28	518/599	Bureau of Standards, light crown		(48)	67.0	3.5	12.0	5.0		10.6	1.5							0.4					7
29	519/603	Chance, hard crown	9322	(9)	72.0		6.1	10.1	11.4					0.3				0.2					13
30	520/618	Bureau of Standards, borosilicate crown		(48)	66.5	7.8	9.8	5.9		7.8	2.0							0.2					7
31	520/520	Schott, high dispersion crown	O381(1151)	(53)	68.7		15.7				2.0	13.3				0.1		0.2					11*a*, 14, 17*c*
32	522/520	Schott, high dispersion crown	O381(1250)	(68)	66.8		16.0				3.8	11.6		1.5		0.1		0.2					14
33	522/515	Schott, high dispersion crown	O381(1168)	(68)	68.2		16.5				2.0	13.1						0.2					5, 7, 11*c*
34	522/522	E. Posnjak, analyst	O381	(67)	67.40		15.15	0.14	0.39		3.85	10.71		1.72	0.02	0.04		0.14				0.15	
35	522/596	Schott, ordinary silicate crown	O1282	(35)	62.5	2.0	5.0	15.0		11.0	3	1.0				0.1		0.4					10
36	523/590	Ordinary crown		(1)	73.1		14.0	1.0	12.0														6, 16
37	524/522	Chance, telescope flint	4277	(9)	52.4	18.3	2.3	4.3	0.3					1.9			20.4	0.1					11*a*, 13
38	522/511	Schott, telescope flint	O2001				Of unknown composition, but probably differs but little from preceding																11*c*, 14, 17*b*
39	527/546	Schott, telescope crown	O2388				Of unknown composition																14, 17*a*
40	529/516	Chance, extra light flint	7863	(9)	66.8		9.2	3.9	0.4		5.2	7.1		0.3			7.0	0.1					13
41	537/512	Schott, borosilicate flint	O152(1809)	(30)	35.4	34.3	7.4					18.7	0.5	3.7									11*a*, 16
42	540/598	Schott, light barium flint	O227	(68)	59.5	3.0	3.0	10.0		19.2	5.0							0.3					14
42a	541/596	Same, analysis		(3)	59.13	3.04	3.16	9.70	0.13	19.25	5.00	0		0.11	0.02	0		0.34					
43	541/594	Chance, light barium crown	3463	(9)	57.1	1.8		13.7	0.3	26.9				0.2				0.1					13
44	541/469	Schott, light flint	O726		62.6		4.5	8.5		24.1								0.3					12*b*
45	545/503	Schott, light borosilicate flint	O658	(66)	32.75	31	1	3				25.0		7		0.06		0.25					4, 7, 10, 15, 16
46	547/458	Chance, light flint	458	(9)	59.7			12.6	0.3			26.9		0.3				0.1					13
47	549/461	Schott, extra light flint	O378	(68)	59.3		5.0	8.0				27.5						0.2					5, 7
48	549/455	Chance, light flint	1018	(9)	60.6			13.9	0.3	2.5		22.5		0.3				0.1					13
49	552/514	Chance, light barium flint	1078	(9)	56.4			12.0	0.3	15.1	4.1	11.1		0.2			0.7						13
50	552/517	Chance, light barium flint	5062	(9)	55.9			13.3	0.3	14.8	4.1	10.7		0.2			0.7						13
51	552/510	Bureau of Standards, barium flint		(48)	58.8	1.7	1.7	8.3		14.3	2.5	12.7											7
52	553/530	Schott, barium flint	O846	(68)	56.2		1.5	11.0		15.0	9.0	7.0						0.3					10, 12*b*, 17*a*

* Contains also 7.5 % F.

Ind. No.	Type	Name		Lit.	SiO_2	B_2O_3	Na_2O	K_2O	CaO	BaO	ZnO	PbO	MgO	Al_2O_3	Fe_2O_3	Mn_2O_3	Sb_2O_3	As_2O_5	As_2O_3	Cl	SO_3	H_2O	Table No.
53	553/461	Chance, light barium flint	7983	(9)	57.7			12.0	0.3	4.5		24.9		0.2			0.3	0.1					13
54	561/555	Schott, light barium flint	O463	Of unknown composition, but probably differs but little from 58																			5, 7, 14
55	563/429	Chance, light flint	8653	(9)	55.9			11.1	0.3			32.9		0.2				0.1					13
56	568/440	Chance, light barium flint	665	(9)	52.3			9.9	0.3	7.4		29.9		0.2				0.2					13
57	563/497	Schott, light barium flint	O543	(68)	51.6		1.5	9.5		14.0	12.0	11.0						0.3					5, 14
58	566/550	Chance, light barium flint	4469	(9)	49.3		3.2	9.5	0.3	27.2	8.6	0.7		0.2			0.8	0.1					11*c*, 13
59	568/530	Schott, light barium flint	O602	(68)	51.2		5.5	5.0		20.0	14.0	4.0						0.3					17*b*
60	571/430	Schott, light flint	O154	(68)	54.3	1.5	3.0	8.0				33.0						0.2					2, 4, 7, 11*a*, 15, 16
60a		Same, analysis		(3)	54.75	0.45	4.31	7.99	0.05	1.64	0.96	29.30	0	0.04	0.02	0		0.14	0.06	0.06		0.20	
61	572/504	Schott, light barium flint	O527	(68)	51.7		1.5	9.5		20.0	7.0	10.0						0.3					7, 15
62	573/580	Schott, light barium crown	O211	(68)	48.8	3.0	1.0	7.5		29.0	10.3							0.4					2
63	573/576	Schott, light barium crown	O211	(68)	48.1	4.5	1.0	7.5		28.3	10.1					0.1		0.1					2, 4, 5, 11*c*, 15
63a	573/574	Same, E. T. Allen, analyst		(67)	47.73	3.90	1.14	7.16	0.15	29.88	8.61		0.02	0.65	0.01			0.38		0.03	0.04	0.14	
64	573/567	Bureau of Standards, barium crown		(48)	47.6	4.0	2.0	6.0		29.2	9.9							1.4					7
65	573/420	Light flint		(1)	54		6	5				35.0											6, 16
66	574/577	Chance, medium barium crown	9002	(9)	45.6	4.4		3.9	0.3	32.5	7.9			4.9				0.6					13
67	574/570	Light barium crown		(1)	47	4	3	5		29	11			1									6, 16
68	574/571	Schott, light barium crown	O1143	(68)	47.8	4.5	1.0	7.5		28.5	10.3					0.1		0.3					14, 17*c*
69	575/414	Chance, light flint	1017	(9)	52.8			10.1	0.3			36.5		0.2				0.1					13
70	576/408	Schott, light flint	O184	(68)	53.7		1.0	8.3				36.6				0.1		0.3					5, 11*b*, 11*c*, 12*b*, 14, 17*c*
71	579/541	Schott, light barium crown	O722	(68)	48.8	3.0	0.8	6.5		21.0	15.5	4.1						0.3					5, 7, 14, 17*a*
71a	580/538	Same, analysis		(3)	45.02	4.50	0.64	6.80		22.39	15.53	4.70		0.09		0		0.55	0.06				
72	579/408	Chance, light flint	407	(9)	52.5			9.5	0.3		37.5			0.2				0.1					10, 13
73	581/442	Schott, ordinary light flint	O276	(35)	52.45		4.5	8.0			34.8					0.05		0.2					
74	581/419	Bureau of Standards, light flint		(48)	53.9		1.0	7.6	2.0			35.2						0.3					7
75	583/469	Schott, light barium flint	O578	(68)	49.1		1.0	8.5		13.0	8.5	19.3				0.1		0.5					5, 7, 10, 14, 17*b*
75a	583/463	Same, E. Posnjak, analyst		(3)	49.80		1.24	8.20		13.36	8.03	18.74		0.05	0.01	0		0.51	0.01			0.08	
76	583/466	Chance, light barium flint	466	(9)	47.5		3.0	0.91	0.3	15.3	8.3	16.3		0.2				0.1					13
77	584/561	Chance, medium barium crown	7472	(9)	42.6	5.1		9.3	0.2	31.4	10.5			0.2			0.8						13
78	585/405	Bureau of Standards, light flint		(48)	54.0		1.0	6.0	2.0			36.7						0.3					7
79	588/611	Chance, dense barium crown	9753	(9)	32.3	19.0		0.2	0.2	42.3				5.7				0.5					13
80	591/605	Schott, dense barium crown	O2122	(68)	37.5	15.0				41.0				5.0				1.5					5, 7, 14
81	604/438	Schott, barium flint	O1266	(68)	45.2			7.8		16.0	8.3	22.2				0.1		0.4					11*a*, 17*a*
82	606/440	Barium flint		(1)	46		3	4		15	8	24											6, 16
83	608/570	Dense barium crown		(1)	40	6				43	8			3									6, 16
84	610/574	Schott, heaviest baryta crown	O1029	(68)	34.5	10.1				42.0	7.8			5.0		0.1		0.5					2, 5, 11*a*, 11*c*, 14, 15, 17*a*, 17*b*
85	610/568	Same, analysis	O1209	(3)	40.17	5.96	0.13	0.03	0.03	42.35	8.17	0		2.79	0.02	0		0.49	0.03				12*b*
86	612/590	Chance, dense barium crown	4873	(9)	36.2	7.7		0.2	0.2	44.6	6.7			3.5			0.3	0.7					13
87	612/592	Schott, heaviest baryta crown	O2071	(68)	31.0	12.0				48.0				8.0				1.0					5, 7, 10
88	609/568	Same, analysis		(3)	34.56	10.96	0.21	0.09		46.91	1.14	0		5.02		0.05		0.55	0.04				
89	613/598	Chance, dense barium crown	8065	(9)	31.3	15.4		0.2	0.2	48.7				3.5			0.4	0.2					13
90	613/563	Chance, dense barium crown	2065	(9)	36.7	5.9		0.9	0.2	45.1	6.8			3.6				0.8					5, 11*a*, 13
91	613/369	Schott, ordinary silicate flint	O118	(68)	46.6		1.5	7.8				43.8						0.3					5, 7, 9, 11*a*, 11*c*, 12
91a	614/369	Same, E. T. Allen, analyst		(67)	45.64		1.77	8.66	0.05			43.45		0.03				0.22					
92	613/369	Chance, dense flint	4743	(9)	48.0		5.2	1.2	0.3			45.1		0.2				0.1					13
93	613/370	Chance, dense flint	3743	(9)	47.5		5.1	1.2	0.3			45.6		0.2				0.1					13
94	615/561	Chance, dense barium crown	1065	(9)	36.2	4.7		1.8	0.2	45.9	6.7			3.5			0.4	0.7					13
95	616/370	Medium flint		(1)	45		3	4				48											6, 16
96	621/361	Schott, ordinary silicate flint	O103	(68)	44.6		0.5	8				46.6						0.3					10, 11*a*, 11*c*, 12*b*, 14, 16, 17*b*
97	621/361	Chance, dense flint	361	(9)	46.3		5.0	1.1	0.3			47.0		0.2				0.1					13
98	627/391	Schott, baryta flint	O748	(68)	42.8		0.7	7.5		10.8	5.1	32.6						0.5					5, 7, 10, 14, 17*a*
99	632/357	Schott, ordinary silicate flint	O919	(67)	44		1	7				48											10, 17*a*
100	645/341	Schott, heavy silicate flint	O102	(66)	41			7				51.7				0.1		0.2					2, 4, 5, 16, 17*b*
100a	649/338	Same, E. Posnjak, analyst		(67)	40.99		0.61	6.93	0.13			51.13		0.04	0.02			0.22				0.08	

Ind. No.	Type	Name		Lit.	SiO_2	B_2O_3	Na_2O	K_2O	CaO	BaO	ZnO	PbO	MgO	Al_2O_3	Fe_2O_3	Mn_2O_3	Sb_2O_3	As_2O_5	As_2O_3	Cl	SO_3	H_2O	Table No.
101	647/337	Chance, extra dense flint	337	(9)	40.6			7.5	0.2			51.5		0.2				0.1					13
102	650/322	Schott, heavy silicate flint	O102	(53)	40.0		0.5	6.5				52.6				0.09		0.3					5, 7, 9, 11*c*, 14, 17*c*
103	655/330	Heavy flint		(1)	42		3	3				52											6, 16
104	668/356	Chance, very dense barium flint	4675	(9)	36.6			4.9	0.2	13.6	4.7	39.2		0.2			0.6	0.2					11*c*, 13
105	680/317	Schott, heavy silicate flint	O192	(68)	38.0			5.0				56.8				0.04		0.2					10, 16, 17*a*
106	717/295	Chance, very dense flint	4141	(9)	35.1			2.8	0.1			61.8		0.1									13
107	717/295	Schott, heavy silicate flint	O41	(68)	33.7			4				62.0						0.3					5, 7, 11*a*, 16
108	751/276	Schott, heavy silicate flint	O500	(66)	29.3			3				67.5						0.2					2, 4, 14, 16, 17*c*
109	755/275	Schott, heavy silicate flint	O165	(68)	28.4			2.5				69						0.1					7, 9, 15
110	756/270	Extra dense flint		(1)	28			3				69											6, 16
111	778/265	Schott, very heavy silicate flint	O198	(68)	27.3			1.5				71						0.1					5, 7, 11*c*
112	890/226	Schott, very heavy silicate flint	S163	(68)	22.0							78.0											14, 15, 17*c*
113	905/217	Schott, heaviest silicate flint	S208	(66)	20							80											2, 11*a*
114	963/197	Schott, heaviest silicate flint	S57	(68)	18							82											7, 14, 15, 16
115		Kavalier combustion tube		(7)	79.57		0.66	11.60	7.80				0.11	0.32	0.04								
116		Experimental glass #7	165^{III}	(66)	73.8		10.5		7.0		5.0			3.5		0.2							2, 4
117		Experimental glass #34		(66)	70.2	12.0	10.3						3.0	4.5									2, 4
118		Experimental glass #90		(34)	69.5	2.0	7.0	16.0				2.5		2.5				0.4					2, 4
119		Experimental glass #87		(34)	68.2	10	10	9.5			2.0							0.2					4
120		Experimental glass #8	1419	(34)	67.9		16.8				5.8	8.1		1.0		0.1		0.3					2, 4
121		Experimental glass #84		(34)	67.7	8.0	10.0				9.0		5					0.3					4
122		Normal thermometer	16^{III}	(66)	67.3	2	14		7		7			2.5		0.2							2, 4, 7, 12*b*
122a		Same, analysis		(43)	66.58	0.91	14.80	Tr.	7.18		6.24		0.17	3.84	Tr.	0.28							
123		Jena combustion, analysis		(7)	66.90	7.22	1.25	2.40	7.94	7.27			0.61	6.38	0.22								
124		Experimental glass #3	172^{III}	(34)	64.4	12	8						11	4.5		0.1							2
125		Experimental glass #10	290	(66)	58.7			33	8									0.3					2, 4
126		Experimental glass #4	164^{III}	(34)	55.0		14	14						17									2
127		Experimental glass #32		(66)	54.8			28			17							0.2					2, 4
128		Experimental glass #12	121^{III}	(34)	51.3	14				25	5			4.5				0.2					2
129		Experimental glass #24		(66)	44.2		0.5	8				47				0.1		0.2					2, 4
130		Experimental glass #23		(66)	34.5	10.2				42	7.8			5				0.5					4
131				(6)	70.0		16.8				4.5	6.6		1.5		0.1		0.5					12*b*
132			VS1419	(6)	67.9		16.8				5.8	8.1		1.0		0.1		0.3					12*b*
133			O1722	(6)	69.64		17.0			5.0	5.3	2.6				0.06		0.4					12*b*
134	507/614	Schott, light borate crown	S205	(68)		69.1	8.0			4.7				18.0				0.2					2, 4, 7, 14, 15, 16
135	510/600	Schott, borate crown	S204	(68)		63.8	8.0	3.5		3.5		3.0		18.0				0.2					14, 17*c*
136	519/609	Schott, borate crown	VS458	(68)		64.0								30					Li_2O 6.0				7, 11*b*
137	523/614	Schott	S185	(68)		71.8								22.4					5.8				2
138	573/469	Schott, borate flint	VS428	(68)		56.0						32.0		12.0									7
139	658/489	Schott, zinc borate	S665	(68)		41					59												2, 7, 14
140	666/392	Schott, borate flint	S120	(68)		42.8						52		5.0				0.2					2
141	516/703	Schott, light phosphate crown	O225	(68)	P_2O_5 70.5	3.0		12.0					4.0	10.0				0.5					2, 7, 9, 15
142	522/697	Schott, light phosphate crown	S219	(66)	69.5	3.0		12.0					4.0	10.0				1.5					2
143	558/670	Schott, phosphate crown	S206	(66)	59.5	3.0				28.0				8.0				1.5					2, 4, 7, 15
144	562/646	Schott, medium phosphate crown	S179	(53)	57	3.0				37				1.5				1.5					14, 17*c*
145	562/665	Schott, phosphate crown	S40	(51)	59.5	3.0				28				5.0				1.5	Di_2O_3 3.0				15, 7
146	567/656	Schott, phosphate crown	S95	(66)	56.0	3.0				38				1.5				1.5					2

MECHANICAL PROPERTIES OF GLASS

Density

The density of glass is dependent not only on its composition but also on its thermal history; variation in the latter factor may cause differences of ±0.002. Figures 1–5 give the density-composition relations for a number of annealed experimental glasses. The density of four series of glasses of the general formula 100 $SiO_2 \cdot 20$ or 40 Na_2O (or 20 or 40 K_2O) $\cdot xCaO$ can be represented by the equation $d = mx + b$, in which x = weight % CaO. Values of m, b and the range of x are: For 20 Na_2O: 0.0124, 2.368, 3.7 – 23.7 %; for 40 Na_2O: 0.0092, 2.475, 3.2 – 21 %; for 20 K_2O: 0.0097, 2.386, 3 – 22 %; for 40 K_2O: 0.0089, 2.464, 2.7 – 18.6 % (45). The density of multicomponent commercial and experimental glasses is given in Table 2 and of optical glasses in Table 13.

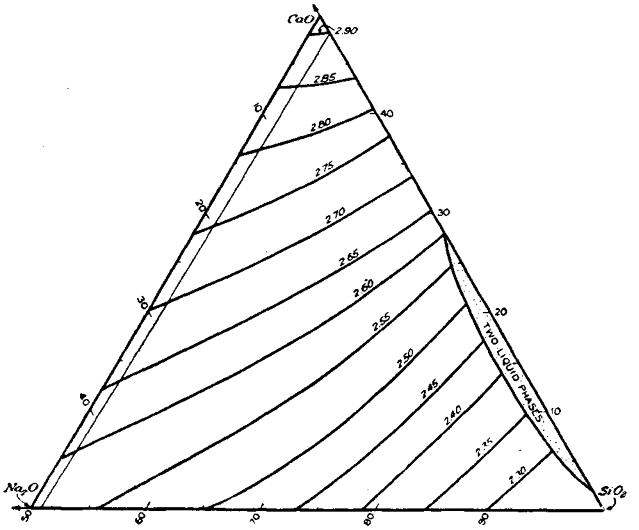


FIG. 1.—Density of the ternary Na_2O-CaO-SiO_2 glasses. Composition in weight % (41).

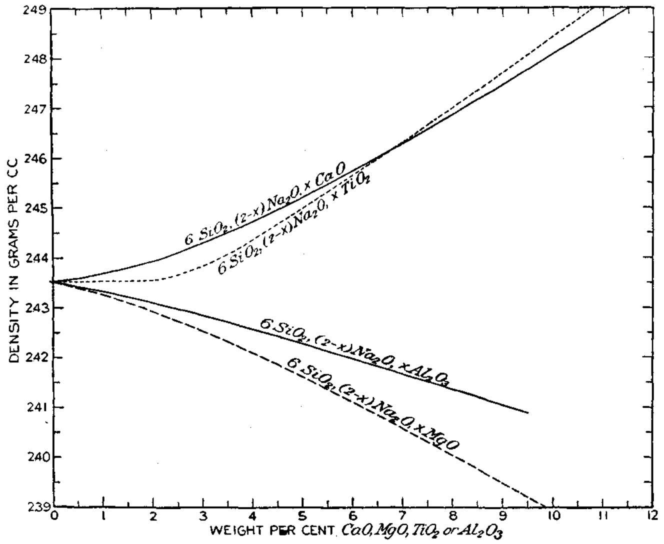


FIG. 2.—Density of some glasses obtained from $Na_2O.3SiO_2$ by substitution of CaO, MgO, Al_2O_3 or TiO_2 for Na_2O. Exact compositions are given in the originals (19, 20, 24, 55).

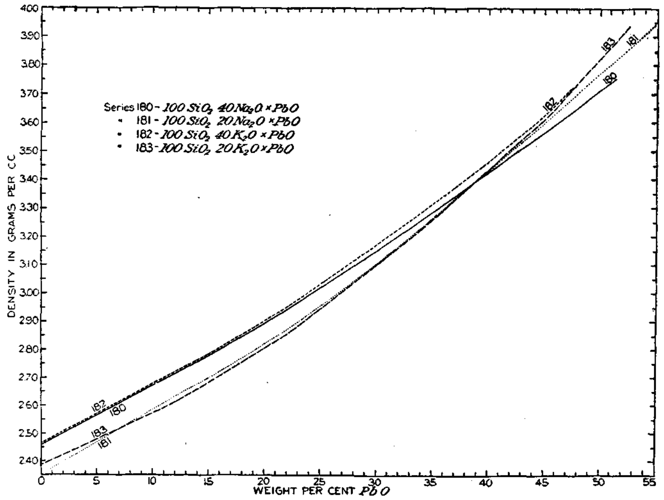


FIG. 3.—Density of some alkali-lead oxide glasses of the approximate composition shown (46).

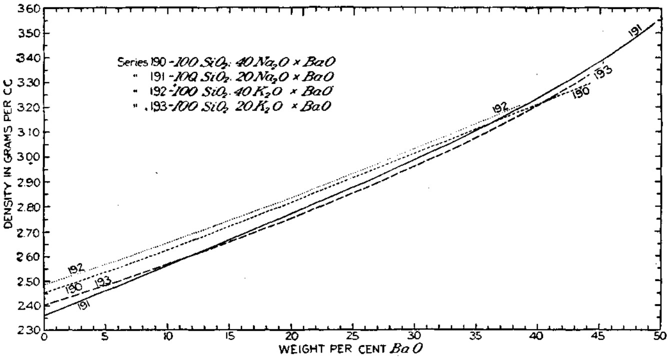


FIG. 4.—Density of some alkali-barium oxide glasses of the approximate composition shown (47).

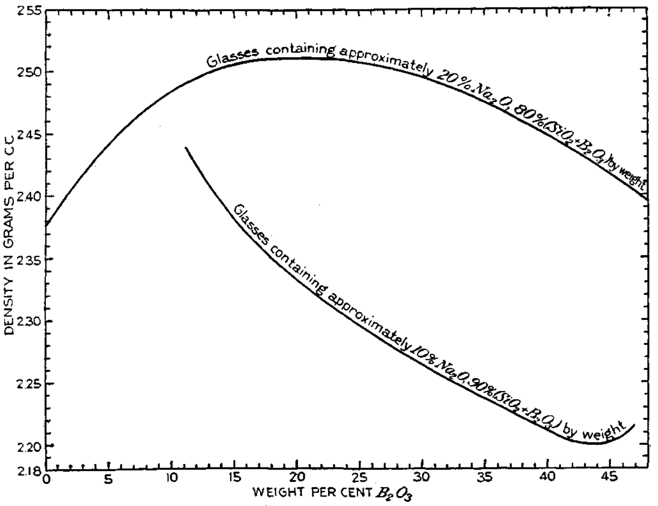


FIG. 5.—Density of some Na_2O-B_2O_3-SiO_2 glasses. Exact compositions are given in the original (28).

Table 2.—Properties of Some Multicomponent Glasses

Serial No.	Ind. No.	Type	Density g/cm^3	Young's modulus	Poisson's ratio	Tensile strength	Compressive strength	Thermal expansion $\frac{10^6}{l}\frac{\Delta l}{\Delta t}$	Specific heat g-cal/g
				Unit = 1 kilo-megabarye; 1 megabarye = 14.50 lb./in.^{2} = 1.020 kg/cm^2					
1	1	Pyrex laboratory	2.25 (12)	611(12)				3.2 (19–350°)(12)	0.20(12)
1a	*1a*	Pyrex radio						3.0	
2	3	496/644	2.370(66)	715(65)	0.197(59)	0.68(66)	12.4(66)		0.204(65)
3	6	Thermometer, 59^{III}	2.370(66)	711(65)				5.90 (0–100)(34)	
4	7	506/602	2.5 (68)	644(65)	0.221(59)				
5	12	511/640	2.47 (68)	731(65)	0.210(59)				
6	14	513/637	2.47 (68)	781(65)	0.213(59)			7.97 (17.5–94.7)(51)	
7	15	513/573	2.572(66)	637(65)	0.226(59)	0.83(66)	9.6(66)		
8	21	516/536	2.6 (68)		0.219(59)				
9	22	517/609	2.49 (68)	704(65)				8.83 (18.7–90.5)(34)	
10	23	517/602	2.580(66)	647(65)	0.231(59)	0.66(66)	9.0(66)	9.63 (17–95.5)(51)	
11	60	571/430		598(65)	0.222(59)			7.93 (12.9–97.6)(51)	
12	62	573/580	3.21 (68)					7.90 (18.9–93.1)(51)	
13	63	573/576	3.21 (68)	727(65)	0.252(59)				
14	84	610/574	3.532(66)	783(65)	0.271(59)	0.73(66)	8.3(66)		0.140(65)
15	100	645/341	3.879(66)	535(65)	0.224(59)	0.53(66)	8.3(66)		
16	108	751/276	4.731(66)	537(65)	0.239(59)	0.52(66)	6.6(66)		
17	113	905/217	5.944(66)	499(65)	0.261(59)	0.35(66)	5.9(66)	9.33 (24.5–84)(51)	
18	116	165^{III}	2.479(66)	717(65)		0.82(66)	11.1(66)		0.196(65)
19	117		2.378(66)	704(65)		0.80(66)	9.7(66)		
20	118			621(65)	0.221(59)				
21	119			782(65)					
22	120		2.629(66)	651(65)		0.66(66)	9.7(66)		
23	122	Thermometer, 16^{III}	2.585(66)	732(65)	0.228(59)			8.03 (14.6–92.2)(34)	
24	124		2.424(66)						0.209(65)
25	125		2.518(66)	589(65)	0.253(59)	0.77(66)	6.7(66)		0.189(65)
26	126		2.480(66)						0.204(65)
27	127		2.668(66)	573(65)	0.261(59)	0.81(66)	7.2(66)		
28	128		2.848(66)	709(65)				4.57 (12.69–89.8)(34)	0.162(65)
29	129		3.578(66)	528(65)		0.60(66)	7.6(66)		
		Borate glasses							
30	134	507/614	2.243(66)	461(65)	0.274(59)	0.57(66)	8.0(66)	6.71 (14.4–94.4)(51)	0.218(65)
31	137	523/614	2.238(66)		0.273(59)				0.232(65)
32	139	653/508	3.527(66)	801(65)	0.319(59)			3.33 (10.35–92.9)(51)	0.166(65)
33	140	666/392	3.691(66)						0.136(65)
		Phosphate glasses							
34	141	516/700	2.588(66)					9.30 (17.7–92.7)(51)	0.190(65)
35	142	522/697	2.588(66)	664(65)	0.235(59)	0.55(66)	7.0(66)		
36	143	558/670	3.070(66)	620(65)	0.253(59)	0.75(66)	7.4(66)	8.70 (20.3–92.2)(51)	0.159(65)
37	146	567/656	3.238(66)		0.272(59)				0.146(65)

Viscosity

For definition of viscosity see vol. 1, p. 42. The variation of viscosity with composition and with temperature in the ternary system Na_2O-CaO-SiO_2 is shown in Figs. 6–12; the effect of replacement of CaO by MgO or by Al_2O_3, in Figs. 13 and 14 respt.; and the temperature-viscosity curves of a number of experimental glasses are shown in Fig. 15 and of optical glasses in Fig. 16.

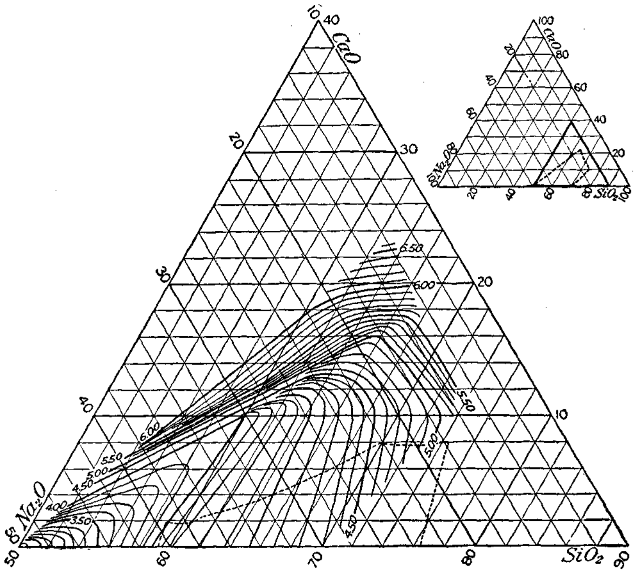


FIG. 6.—Log isokoms (lines of constant viscosity) in the system Na_2O-CaO-SiO_2, at 900°. Viscosity in log poises; composition in weight %. The broken line is the liquidus curve at 900°. *Cf.* Fig. 20 (61).

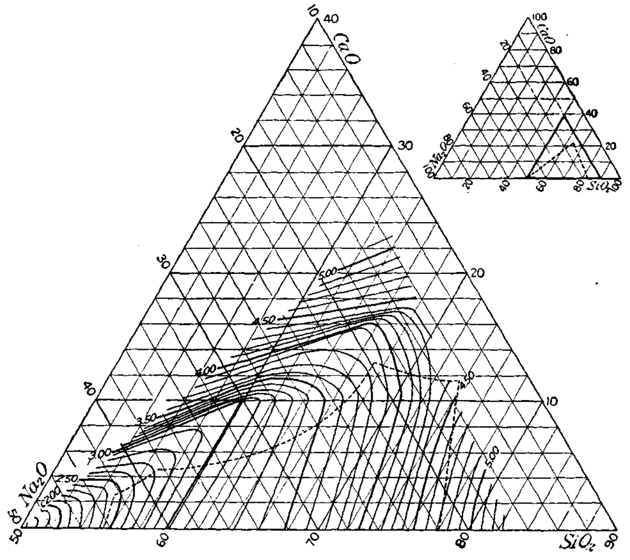


FIG. 7.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1000°. The broken line is the liquidus curve at 1000° (61).

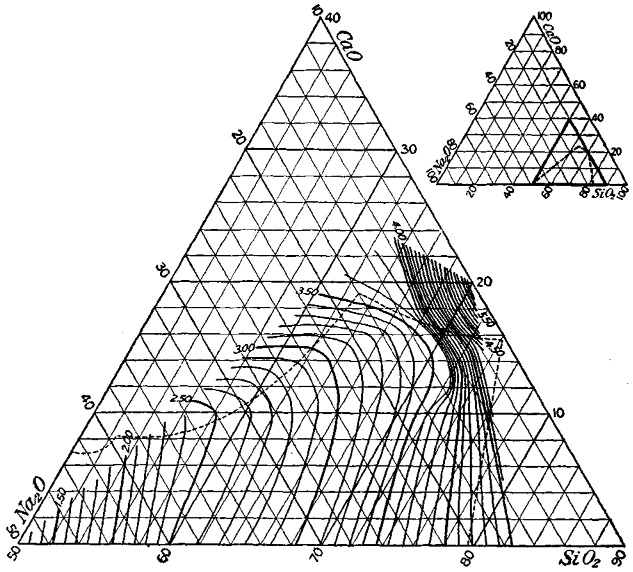


FIG. 8.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1100°. The broken line is the liquidus curve at 1100° (61).

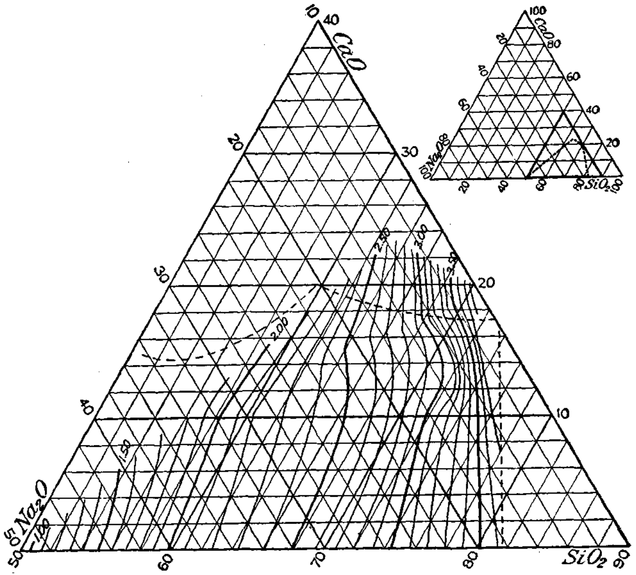


FIG. 9.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1200°. The broken line is the liquidus curve at 1200° (61).

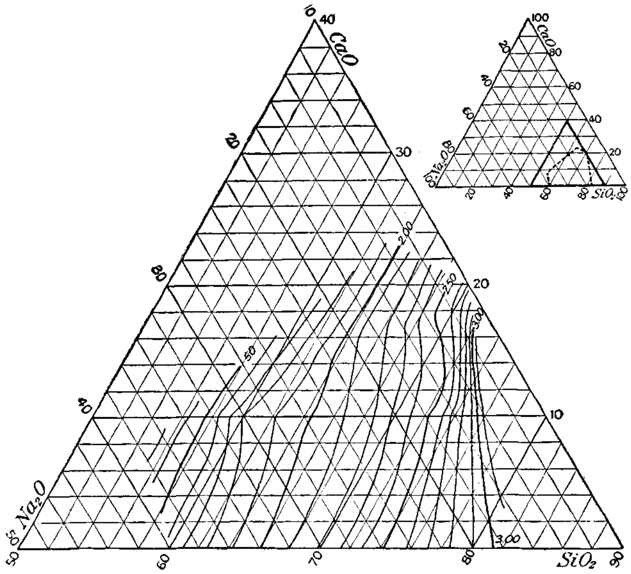


FIG. 10.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1300°. The mixtures at this temperature are all above the liquidus surface, except a few high in SiO_2 (61).

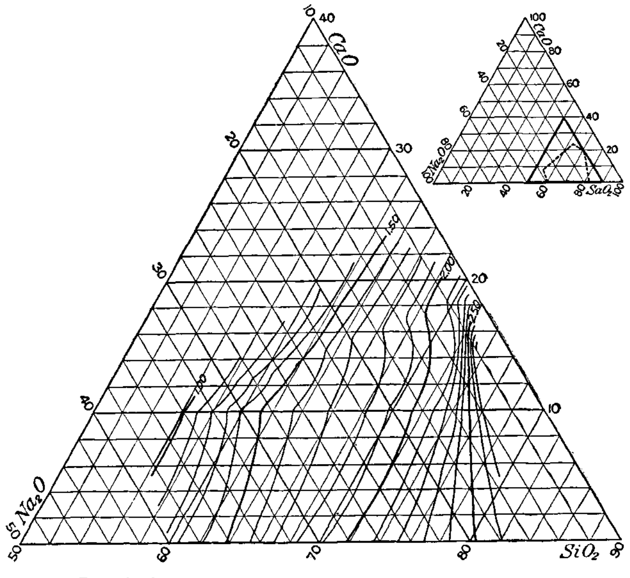


FIG. 11.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1400° (61).

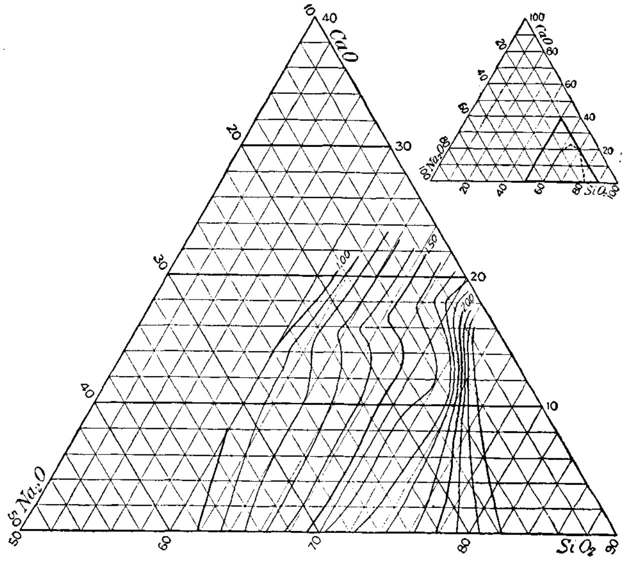


FIG. 12.—Log isokoms in the system Na_2O-CaO-SiO_2 at 1500° (61).

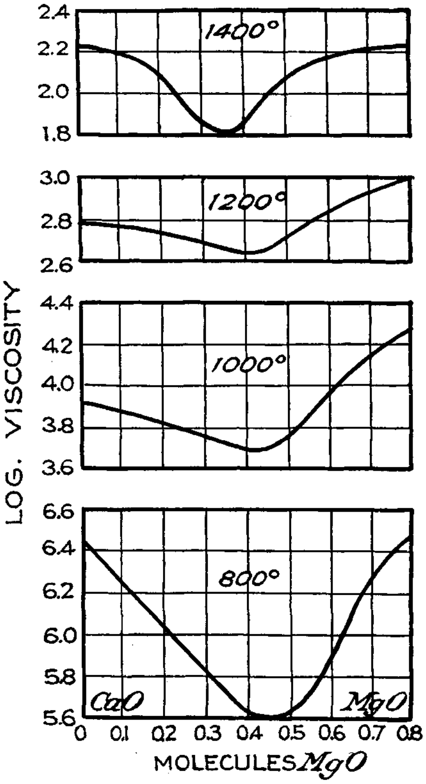


FIG. 13.—Effect on viscosity of replacing CaO by MgO in the mixture $1.2Na_2O \cdot 0.8 CaO \cdot 6SiO_2$, at different temperatures. Viscosity in poises (14.1).

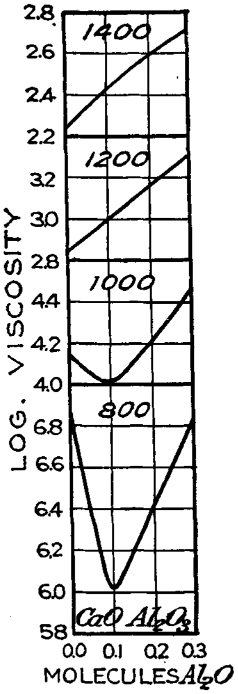
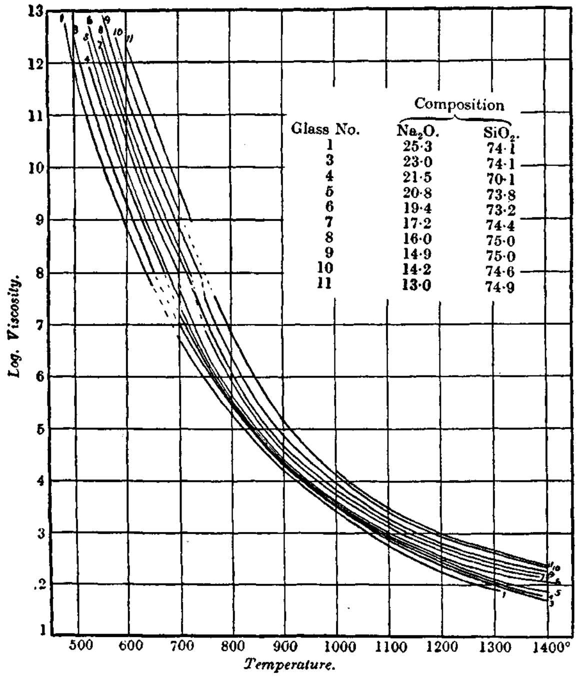


FIG. 14.—Effect on viscosity of replacing CaO by Al_2O_3 in the mixture $1.1Na_2O \cdot 0.9 CaO \cdot 6SiO_2$, at different temperatures (14.1).



Glass No.	Composition Na$_2$O.	SiO$_2$.
1	25·3	74·1
3	23·0	74·1
4	21·5	70·1
5	20·8	73·8
6	19·4	73·2
7	17·2	74·4
8	16·0	75·0
9	14·9	75·0
10	14·2	74·6
11	13·0	74·9

Fig. 15.—Variation of log viscosity, in poises, with temperature, of a number of experimental glasses (14).

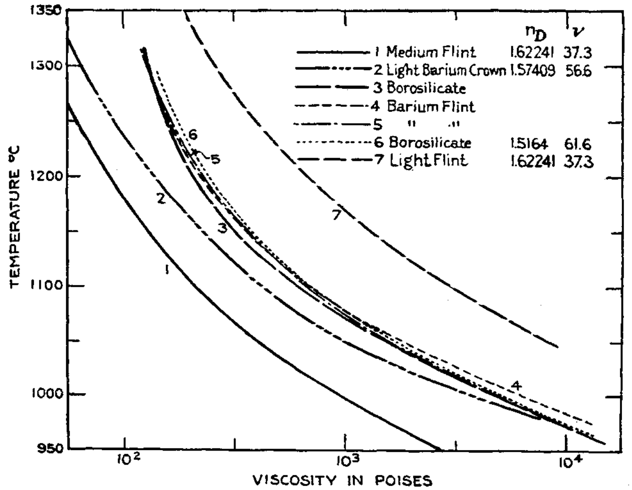


Fig. 16.—Variation of viscosity with temperature in a number of optical glasses (61,1).

Surface Tension

The variation of surface tension with composition in the ternary Na$_2$O-CaO-SiO$_2$ glasses at constant temperature is shown in Figs. 17 and 18; the variation with temperature in Fig. 19.

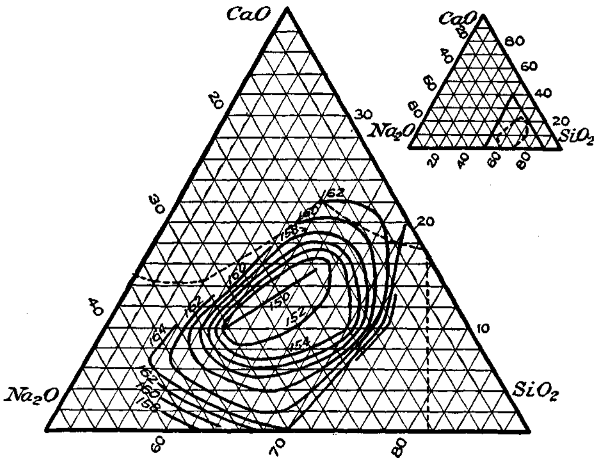


Fig. 17.—Surface tension of Na$_2$O-CaO-SiO$_2$ mixtures at 1206° (61).

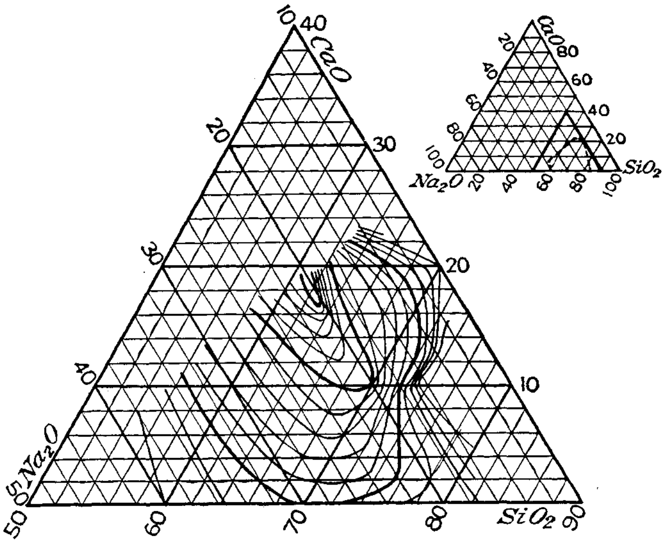


Fig. 18.—Surface tension of Na$_2$O-CaO-SiO$_2$ mixtures at 1454° (61).

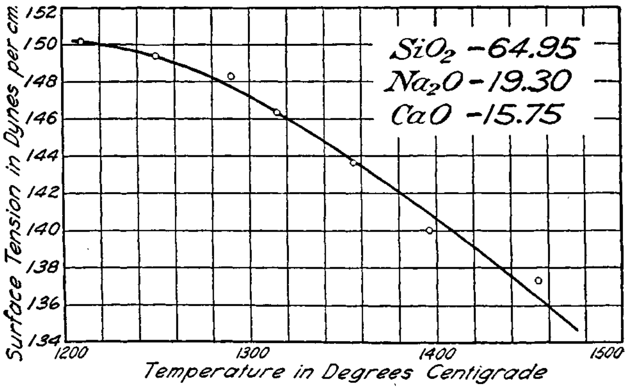


Fig. 19.—Variation of surface tension with temperature (61).

Strength

The strength of glass is so greatly influenced by its thermal history (33) and the condition of its surface (38) that the values given are of uncertain significance and should be used only with an ample factor of safety.

Values of tensile and compressive strength of a number of glasses are given in Table 2. The strength of glass fibers as a function of thickness is given by Griffith (33). The following summarizes the data for tubes, determined on a glass of unknown composition.

TABLE 3.—BURSTING STRENGTH OF GLASS TUBES (44)

Maximum fiber stress, T_m, calculated from the formula

$$T_m = \frac{1}{4}\left[5P_m + 7\left(\frac{P_m - 1}{\left(\frac{R}{R'}\right)^2 - 1}\right) - 1\right] \text{(unit} = 10^6 \text{ barye)}$$

Shape of tubes	Range of radii, R, mm		Number tubes tested	Range of bursting pressures, P_m	Max. fiber stress, T_m	Mean var. from mean, %
	External, R	Internal, R'				
Thick walled..	9–18	3–6	9	230–380	470	14
Capillary.....	5–7	0.24–1.0	16	420–1200	902	27
Thin walled..	3.8–7.8	3.4–7.3	17	54–377	628	20

Elastic Properties

Young's modulus, E, and Poisson's ratio, σ, for a number of commercial and experimental glasses are given in Table 2; the rigidity and bulk moduli, C and K, are related to these through the equation $C = E/2(1 + \sigma)$ and $K = E/3(1 - 2\sigma)$. The variation of E, in kilo-megabaryes, with weight % of CaO is given by the equation $E = 13.9y + 565.6$, in the range 0–11% CaO (10a). The variation of Young's modulus with temperature is shown in Table 4.

TABLE 4.—THE EFFECT OF TEMPERATURE ON ELASTICITY (66)

$E_t = E_{20}\ [1 - \alpha(t - 20)^{\beta}]$; range, room temp. to $t_{\max}$. (unit: 10^9 barye)

Ind. No.	Glass Type	$E_{20°}$	$\log_{10}\alpha$	$\log_{10}\beta$	$t_{\max}$
3	496/644	752	$\overline{9}.018$	0.428	482
7	506/602	655	$\overline{4}.618$	0	448
12	511/640	740	$\overline{4}.352$	0	475
15	513/573	684	$\overline{5}.912$	0.065	409
22	517/609	709	$\overline{4}.369$	0	433
23	517/602	654	$\overline{4}.575$	0	394
45	545/503	549	$\overline{15}.452$	0.706	383
60	571/430	609	$\overline{10}.973$	0.499	374
63	573/575	744	$\overline{6}.923$	0.165	427
100	645/341	540	$\overline{24}.492$	0.945	340
108	751/276	539	$\overline{8}.634$	0.401	357
116		738	$\overline{5}.543$	0.082	460
117		721	$\overline{5}.114$	0	482
118			$\overline{4}.616$	0	434
119		817	$\overline{4}.248$	0	447
120		652	$\overline{15}.401$	0.717	433
121		741	$\overline{11}.092$	0.553	407
122		730	$\overline{6}.435$	0.232	426
125		604	$\overline{5}.696$	0.113	455
127		577	$\overline{4}.193$	0	417
129		532	$\overline{13}.897$	0.643	413
130		798	$\overline{5}.330$	0.094	486
134	507/614	492	$\overline{4}.449$	0	281
143	558/670	631	$\overline{6}.230$	0.255	412

THERMAL PROPERTIES OF GLASS

Melting Point Diagrams

The melting point diagrams showing the compositions of the crystalline solid phases which may exist in equilibrium with liquid and the relation between equilibrium temperature and composition of that liquid are not known for most of the glass-forming systems. Figures 20 and 21 give these for the ternary system $Na_2O \cdot SiO_2$-$CaO \cdot SiO_2$-SiO_2 and the binary system PbO-SiO_2.

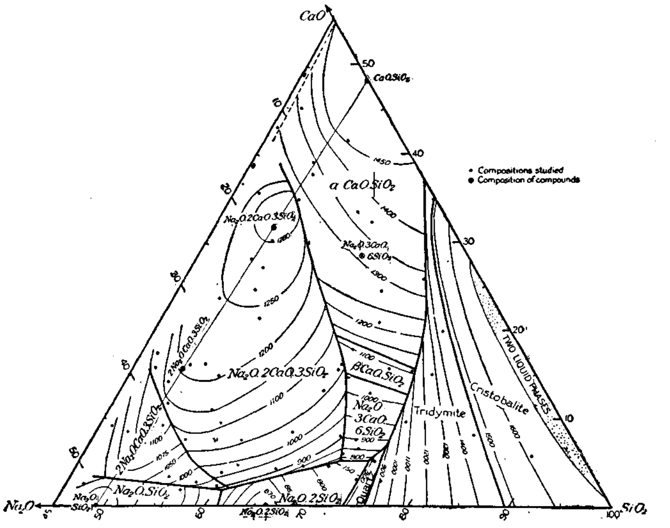


FIG. 20.—Melting point diagram of the system Na_2O-CaO-SiO_2. Composition in weight % (39).

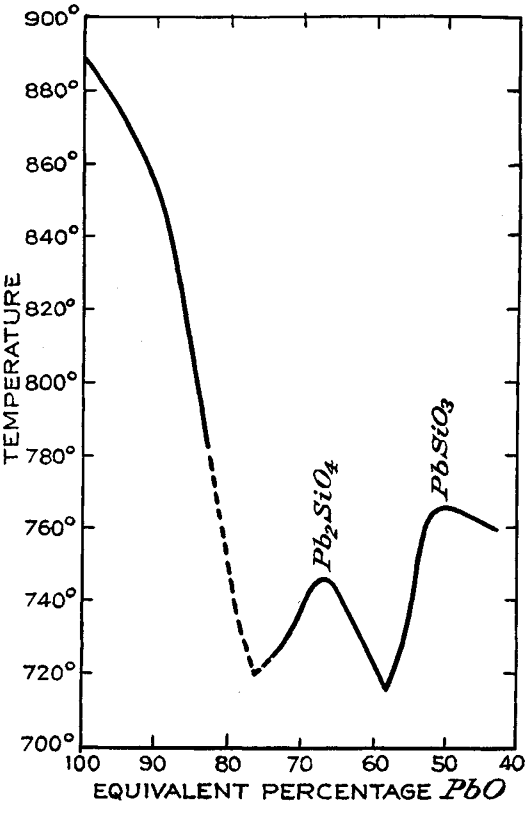


FIG. 21.—Melting point diagram of the system PbO-SiO_2 (11).

Table 5.—Thermal Constants of Representative Glasses

Glasses are undercooled liquids, and hence have no melting points. Following are some of the empirical definitions that have been proposed for characterizing glasses as to their thermal behavior, and the corresponding temperatures for some representative glasses. (*a*) Annealing temperature (62): the temperature at which the ratio of final to initial strain is a minimum, when heating and cooling are carried out in a prescribed manner; *v. also* Table 6 and Figs. 22, 23 and 24. (*b*) Deformation temperature (62): the lowest temperature at which, after 6 hr, one observes a deformation of the polished faces of a 20 mm cube embedded in kieselguhr with a diagonal vertical. (*c*) Cohesion temperature (69): the lowest temperature at which 2 plane polished pieces, 2 mm thick, 10 mm diameter, will coalesce in 30 min. (*d*) Softening temperature, for pyrex (12): the temperature at which a rod 9 in. long and 0.6 mm diameter lengthens under its own weight at the rate of 1 mm per min when heated in an electric furnace throughout its upper 9.5 cm of length. For the rest of the glasses (69), the constant t_o in the empirical 3-constant equation $(t_o - t)(S + S_o) = C$, expressing the relation between the stress, S (measured by birefringence), produced by quickly cooling a cm cube from the temperature t. (*e*) Flow temperature (63): the temperature at which a 25 mm cube embedded in kieselguhr with diagonal vertical flows until the corner cannot be detected, in the given time.

Table 5.—Constantes thermiques des verres représentatifs

Les verres sont des liquides surfondus, et par conséquent ne possèdent pas de point de fusion. Dans ce qui suit, on trouvera quelques-unes des définitions empiriques qui ont été proposées pour caractériser les verres en se basant sur la façon dont ils se comportent au point de vue thermique, et les températures correspondantes pour quelques verres représentatifs. (*a*) Température de recuit (62): c'est la température à laquelle le rapport de la tension finale à la tension initiale devient minimum, lorsque la conduite du chauffage et du refroidissement est effectuée d'une manière prescrite; voir aussi Table 6. (*b*) Température de déformation (62): c'est la température la plus basse à laquelle on observe, après six heures, une déformation des faces polies d'un cube de 20 mm de côté, disposé dans du kieselguhr avec une diagonale verticale. (*c*) Température de cohésion (69): c'est la température la plus basse à laquelle deux pièces polies planes de 2 mm d'épaisseur et de 10 mm de diamètre s'accoleront en trente minutes. (*d*) Température de ramollissement; pour le Pyrex (12): c'est la température à laquelle une baguette de 23 cm de long. et de 0,6 mm de diamètre s'allonge sous son propre poids à raison de 1 mm par min, la baguette étant chauffée dans un four électrique sur une longueur de 9,5 cm. Pour le reste des verres (69), la constante t_o dans l'équation empirique à 3 constantes $(t_o - t)(S + S_o) = C$, exprimant la relation entre la tension, S (mesurée par biréfringence), produite par un refroidissement rapide d'un cube de 1 cm de côté de la température t. (*e*) Température d'écoulement (63): c'est la température à laquelle un cube de 25 mm de côté, disposé dans du kieselguhr, avec une diagonale verticale, s'écoule d'une façon telle que le coin ne peut plus être décelé dans un temps donné.

Tafel 5.—Thermische Konstanten typischer Glassorten

Gläser sind unterkühlte Flüssigkeiten und haben deshalb keinen Schmelzpunkt. Im folgenden sind einige empirische Definitionen angegeben, welche zur Charakterisierung des thermischen Verhaltens von Gläsern herangezogen werden. Auf die entsprechende Temperatur so bezogen, ist das thermische Verhalten einiger typischer Glassorten ebenfalls angegeben. (*a*) Kühltemperatur (62): Die Temperatur bei welcher das Verhältnis der Endspannung zur Anfangsspannung ein Minimum ist, wenn Erwärmung und Kühlung in vorgeschriebener Weise erfolgt. Siehe Tafel 6 und Fig. 22, 23 und 24. (*b*) Deformations-Temperatur (62): Die tiefste Temperatur bei welcher nach 6 Stunden eine Deformation der polierten Flächen eines 20 mm Würfels bemerkt wird, welcher in Kieselgur eingebettet ist (mit vertikaler Diagonale). (*c*) Kohäsions-Temperatur (69): Die tiefste Temperatur bei welcher zwei plan geschliffene Flächen, 2 mm dick, 10 mm Durchmesser in 30 Minuten zusammenschmelzen. (*d*) Erweichungs-Temperatur für Pyrex-Glas (12): Die Temperatur bei welcher ein Stab von 23 cm Länge und 0,6 mm Durchmesser, bei der Erhitzung der ersten obern 9,5 cm seiner Länge, im elektrischen Ofen, unter dem eigenen Gewicht eine minutliche Verlängerung um 1 mm erfährt. Für den Rest der Gläser (69) ist t_o die Konstante der empirischen Gleichung (drei Konstanten) $(t_o - t)(S + S_o) = C$, welche die Beziehung zum Druck S herstellt, der durch eine rasche Kühlung von der Temperatur t herunter in einem 1 cm Würfel erzeugt wird (Druckmessung nach der Doppelbrechung). (*e*) Fluss-Temperatur (63). Ist die Temperatur bei welcher ein 25 mm Würfel in Kieselgur eingebettet (diagonal, vertikal) zerfliesst, so, dass in der gegebenen Zeit die Ecken nicht mehr erkannt werden können.

Tabella 5.—Costanti termiche di vetri tipici

I vetri sono liquidi sopraraffreddati e non hanno perciò punto di fusione.

Qui sono indicate alcune delle proprietà proposte per caratterizzare i vetri dal punto di vista del loro comportamento termico, e sono riportate le temperature corrispondenti per alcuni vetri tipici. (*a*) Temperatura di (ricottura) (62): la temperatura alla quale è minimo il rapporto fra tensione finale e iniziale, quando riscaldamento e raffreddamento vengono eseguiti in una maniera prescritta. Vedi pure Tabella 6, e Fig. 22, 23 e 24. (*b*) Temperatura di deformazione (62): la temperatura più bassa alla quale, dopo sei ore, si osserva deformazione delle facce pulimentate di un cubo di 20 mm immerso nella farina fossile con una diagonale in posizione verticale. (*c*) Temperatura di adesione (69): la temperatura più bassa alla quale aderiscono in 30 minuti due pezzi pulimentati a superficie piana di 2 mm di spessore e 10 di diametro. (*d*) Temperatura di rammollimento. Per il Pyrex (12) è la temperatura alla quale una bacchetta di 23 cm di lunghezza e 0,6 mm di diametro si distende sotto il proprio peso alla velocità di 1 mm per minuto quando sia scaldata in un forno elettrico lungo i 9,5 cm superiori di lunghezza; per gli altri vetri (69) è la costante t_o nella equazione empirica a 3 costanti $(t_o - t)(S + S_o) = C$, esprimente la relazione tra sforzo, S (misurato dalla birifrangenza), prodotto raffreddando rapidamente un cubo di un centimetro dalla temperatura t. (*e*) Temperatura di scorrimento (63): la temperatura alla quale un cubo di 25 mm immerso in farina fossile con una diagonale disposta verticalmente, scorre fino a non potersi più distinguere il vertice nel tempo indicato.

Ind. No.	Annealing (*a*)	Deformation (*b*)	Cohesion (*c*)	Softening (*d*)	Flow temperatures (*e*)		
					30 min	2 hr	6 hr
1				815(12)			
3		570(62)	603(69)	648(69)			
12					850(63)	815(63)	755(63)
17	495(62)	605(62)	583(69)	565(69)	810(63)	795(63)	780(63)
24			555	647			
47			505	498(40)	740	725	685
57			632	640			
63			632	639	910	885	860
70			484	499			
71		590	632	642	845	805	785
80	585	645	694	681	845	830	795
87		650	694	735	870	835	820
90	565	645	686	681	840	815	800
91	410	460	486	490	730	695	680
98		585	547	595	780	730	685
100	390	430	493	491	660	645	630
107			465	473			
111			457	469			

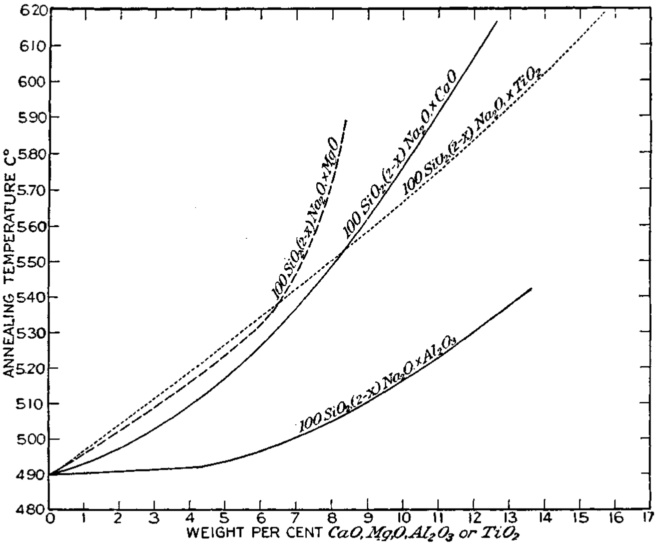


FIG. 23.—Annealing temperatures of glasses derived from $Na_2O \cdot 3SiO_2$, by substitution of CaO, MgO, Al_2O_3 or TiO_2 for Na_2O. Exact compositions are given in the original (15, 17, 21, 55).

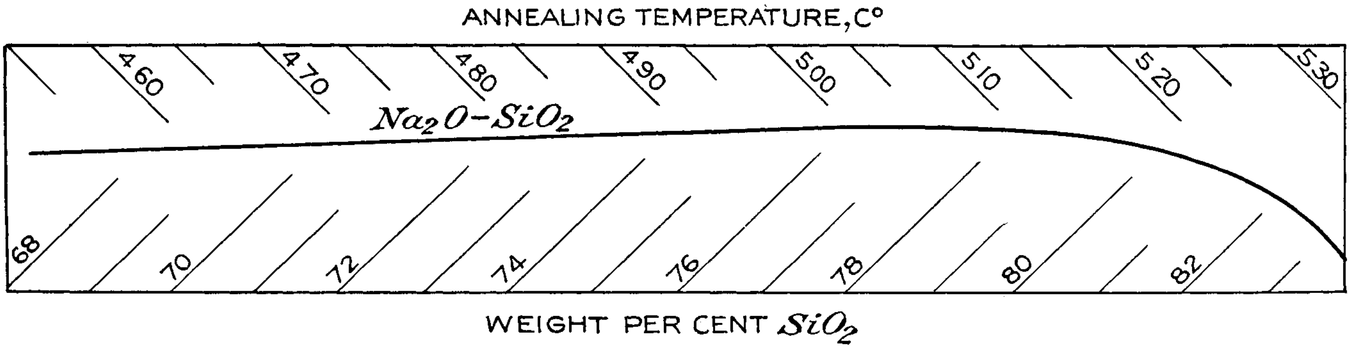


FIG. 22.—Annealing temperature of Na_2O-SiO_2 glasses (14).

Annealing Temperature

Figures 22, 23 and 24 show the relation between annealing temperature and composition of a number of experimental glasses; in these, the annealing temperature is that at which strain disappears rapidly. Table 6 gives the annealing constants of a number of optical glasses.

TABLE 6.—ANNEALING TEMPERATURES

Values of M_1 and M_2 in equation $\log_{10} A = M_1\Theta - M_2$, in which Θ = temp., °C, and M_1 and M_2 are experimental constants, from which may be calculated the annealing constant A. The annealing temperature is defined as that temperature at which the strain will decrease from 50 to 2.5$\mu\mu$ in 2 min, calculated from the formula $At = 1/\Delta n - 1/\Delta n_o$ in which t = time in min, Δn = birefringence in $\mu\mu$.

Ind. No.	Type	M_1	M_2	Annealing temp., °C
19	516/620	0.030	18.68	599
36	523/590	0.029	17.35	573
65	573/420	0.033	15.92	461
67	574/570	0.032	20.10	606
82	606/440	0.028	16.28	556
83	608/570	0.038	24.95	638
95	616/370	0.038	18.34	464
103	655/330	0.037	17.51	454
110	756/270	0.033	15.03	434

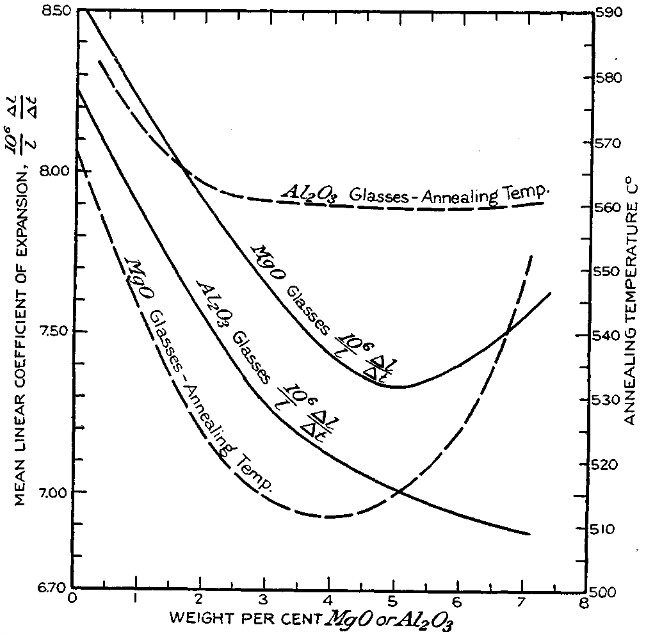


FIG. 24.—Annealing temperatures and thermal expansions of glasses derived from $1.2Na_2O \cdot 0.8CaO \cdot 6SiO_2$ by substitution of CaO by MgO; and from $1.1Na_2O \cdot 0.9CaO \cdot 6SiO_2$ by substitution of CaO by Al_2O_3 (21, 25).

Coefficient of Expansion

The linear coefficient of expansion, $\alpha = 10^6 \Delta l / l \Delta t$, of multicomponent commercial and experimental glasses is given in Tables 2 and 7 and for a systematic series of experimental glasses in Figs. 24–28.

TABLE 7.—COEFFICIENT OF THERMAL EXPANSION
(*V. also* Table 2) $l = l_o\ (1 + 10^{-6}\alpha t)$

Ind. No.	α	Range, °C	Lit.	Ind. No.	α	Range, °C	Lit.
13	9.12	18–97	(34)	71	7.02		(69)
17	7.79		(69)	74	8.8	22–451	(48)
23	9.20	37 (mean)	(34)		34.7	494–512	(48)
	10.04	93 (mean)	(34)	75	8.23		(69)
	10.61	151 (mean)	(34)	78	7.0	23–420	(48)
	11.11	212 (mean)	(34)		2.92	495–511	(48)
24	9.00		(69)	80	5.87		(69)
26	10.2	22–426	(48)	87	6.48		(69)
	55.5	502–522	(48)	91	7.88	11–99	(51)
28	10.4	24–422	(48)	98	8.76		(69)
	54.8	494–507	(48)	102	8.75		(69)
30	9.00	22–498	(48)	107	8.33		(69)
	39.3	539–562	(48)	109	8.03	20–94	(34)
33	9.03	16–94	(34)	111	8.18		(69)
45	5.23	7–92	(34)	114	9.34	18–99	(51)
47	8.14		(69)	134	6.74	14–94	(34)
51	8.8	22–494	(48)	136	5.60	0–100	(34)
	33.1	519–550	(48)	138	5.37	0–100	(34)
54	7.74		(69)	141	9.30	18–93	(34)
61	9.00	10–93	(34)	145	8.71	21–100	(51)
64	9.0	23–499	(48)	122	*	−253 to +100	(2)
	64.9	569–610	(48)				

* $l = l_o\{1 + 10^6\ [716.8\ (T/100) + 48.33\ (T/100)^2 + 9.02\ (T/100)^3 + 10.9\ (T/100)^4]\}$.

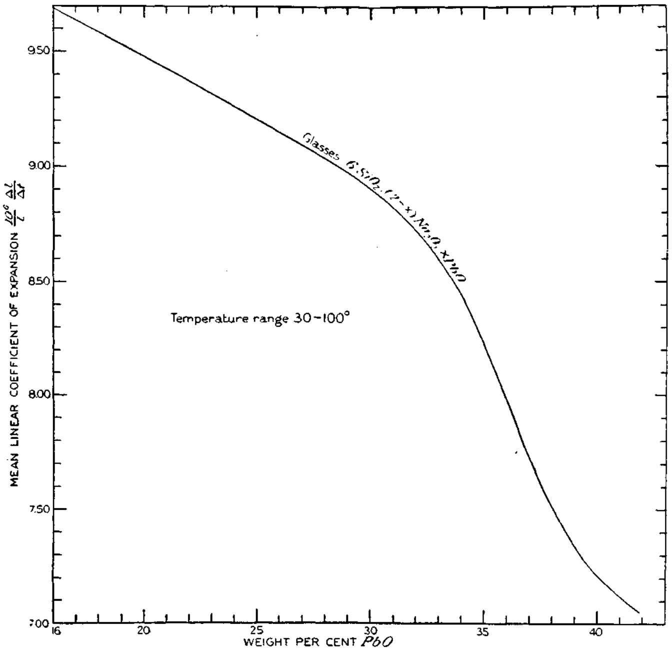


FIG. 27.—Thermal expansion of glasses derived from $Na_2O \cdot 3SiO_2$ by substitution of PbO for Na_2O (42).

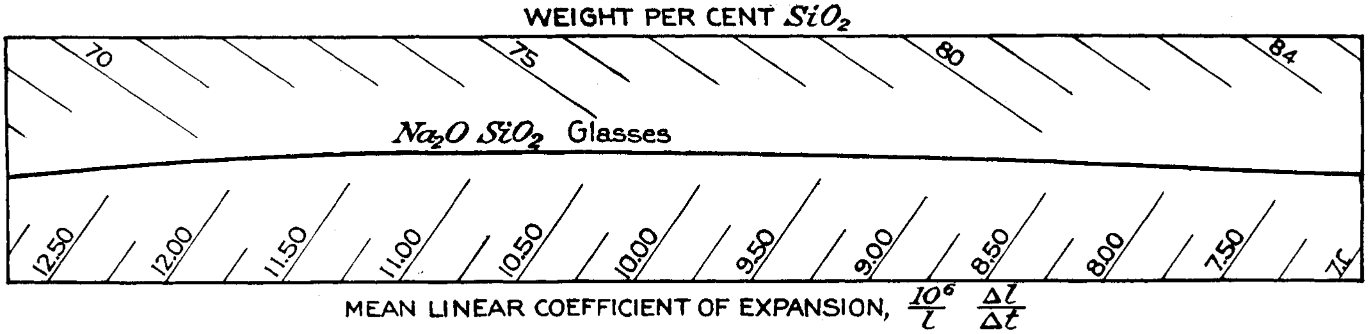


FIG. 25.—Thermal expansion of Na_2O-SiO_2 glasses (22).

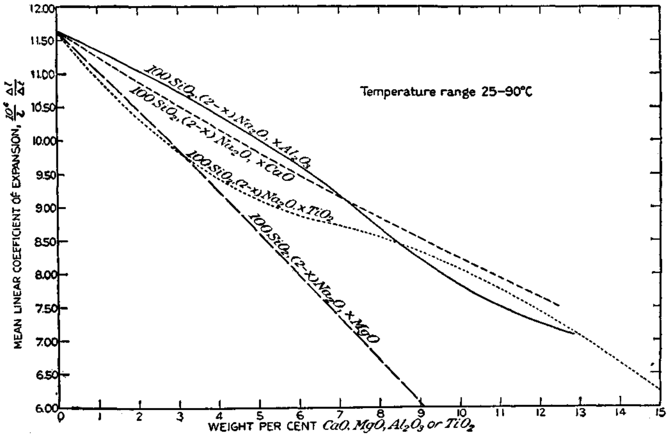


FIG. 26.—Thermal expansion of glasses derived from $Na_2O \cdot 3SiO_2$ by substitution of CaO, MgO, Al_2O_3 or TiO_2 for Na_2O. Exact compositions are given in the original (16, 18, 23, 55).

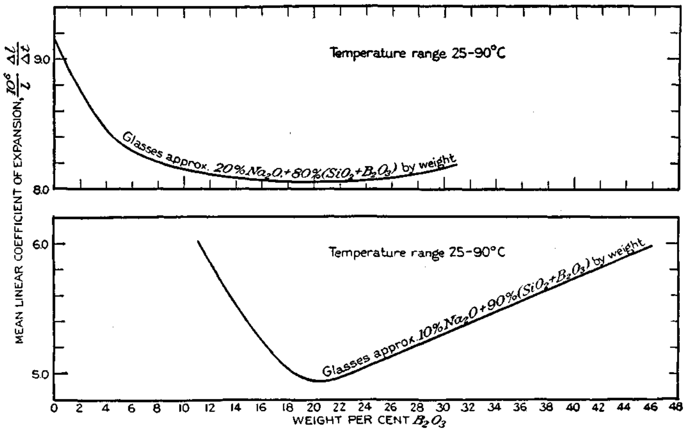


FIG. 28.—Thermal expansion of Na_2O-B_2O_3-SiO_2 glasses (28).

SPECIFIC HEAT

The specific heats of commercial and experimental glasses are given in Table 2; Table 8 gives the specific heats of mineral glasses.

TABLE 8.—MEAN SPECIFIC HEATS OF SILICATE GLASSES
g cal_{15}/g per °C; *v. also* Table 2

These determinations are the most accurate in the literature and the compositions are well established (64).

Glass	0–100°	0–300°	0–500°	0–700°	0–900°	0–1100°
Anorthite, An $CaO \cdot Al_2O_3 \cdot 2SiO_2$	0.1881	0.2152	0.2306	0.2406		
Andesine, $Ab_1\ An_1$	0.1932	0.2211		0.2484	0.2615	
Albite, Ab $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$	0.1977	0.2238	0.2410		0.2640	
Microcline $K_2O \cdot Al_2O_3 \cdot 6SiO_2$	0.1919	0.2163	0.2321	0.2431	0.2515	0.2598
Wollastonite $CaO \cdot SiO_2$	0.1852	0.2078	0.2208	0.2355		
Diopside $CaO \cdot MgO \cdot 2SiO_2$	0.1938	0.2189	0.2333	0.2439		
Magnesium metasilicate $MgO \cdot SiO_2$	0.2040	0.2302	0.2474	0.2598		

Thermal Conductivity

TABLE 9.—THERMAL CONDUCTIVITY (29)

Ind. No.	Glass type	g-cal cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$			
		−190°	−78°	0°	100°
3	496/644	1.181	2.532	2.796	3.243
17	516/640	1.195		2.825	
91	613/369	0.865		1.900	
102	649/338	0.851		1.867	
109	754/275	0.807		1.698	1.812
141	516/692	0.877		1.796	2.007

ELECTRICAL PROPERTIES

TABLE 10.—MAGNETIC SUSCEPTIBILITY (35)

Magnetic susceptibility, κ, in units of 10^6 cgs, as function of magnetic field-strength, H, in gausses

Ind. No.	κ			Ind. No.	κ		
	H = 1350	H = 1800	H = 2200		H = 1350	H = 1800	H = 2200
4	−0.90	−0.90	−0.90	52	−0.93	−0.93	−0.93
11	−0.85	−0.865	−0.885	72	−0.91	−0.92	−0.93
12	−0.93	−0.93	−0.93	75		−0.38	−0.395
35	−0.59	−0.60	−0.607	87	−0.95	−0.95	−0.95
45	−0.78	−0.78	−0.78	105	−1.01	−1.01	−1.01

TABLE 11.—DIELECTRIC PROPERTIES

The factors which measure the value of a dielectric are: (*a*) dielectric constant, ϵ; (*b*) dielectric strength, measured by the sparking voltage, and varying with the thickness of material tested; and, (*c*) the energy taken up by the dielectric, measured either by the phase angle, PA, between displacement current and charging current, or by the power factor, *PF*, the cosine of the phase angle.

(*a*) Dielectric constant, ϵ

Ind. No.	Glass type	ϵ	Lit.	Ind. No.	Glass type	ϵ	Lit.
1	Pyrex	4.83*	(12)	81	604/438	7.71	(54.1)
(Near 2)	464/657	5.81	(54.1)	84	610/574	8.20	(54.1)
17	516/640	6.2	(13)	90	614/564	7.6	(13)
31	520/520	6.92	(54.1)	91	613/369	7.47	(54.1)
37	523/513	4.8	(13)	96	620/362	6.8	(13)
41	537/512	6.7	(13)	107	717/295	8.5	(13)
60	569/426	6.5	(13)	(Near 113)	917/	16.2	(54.1)

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* (50 000 cycles.)

(*b*) Dielectric strength. Unit: 10^3 volts cm^{-1}

Ind. No.	Glass type	Thickness tested, mm	*D. S.*	Lit.
1	Pyrex	6.35	134	(12)
15	513/573	0.41	429	(13)
		1.42	220	(13)
		2.28	179	(13)
70	576/408	0.41	1000	(13)
136	519/609	1.49	240	(13)
		1.60	252	(13)

(*c*) Energy adsorption in dielectric

Ind. No.	Type	*PF*, %	Ind. No.	Type	PA min
1	Pyrex lab.	0.52	58	570/560	2.81
1a	Pyrex radio	0.18	63	573/575	2.68
		PA min	70	577/414	1.82
(Near 2)	464/656	6.14	84	611/572	1.90
3	501/659	11.46	91	613/369	1.54
17	516/640	6.80	96	620/363	1.39
22	519/604	7.85	102	649/338	1.40
33	526/513	22.6	104	657/363	1.48
38	529/518	2.94	111	778/265	2.60

TABLE 12.—ELECTRICAL RESISTIVITY AND CONDUCTIVITY

(*a*) Resistivity

Ind. No. 1, Pyrex: Surface resistivity (12): 10^{14} ohm at 34% humidity, 5×10^8 ohm at 84% humidity. Volume resistivity (12): 10^{14} ohm-cm.

(*b*) Conductivity, κ. Unit: 10^{12} ohm^{-1} cm^{-1}

Ind. No.	100°	125°	150°	175°	200°	Lit.
12	0.012	0.0703	0.334	1.59	6.90	(6)
23	0.0132	0.0672	0.425	2.32		(6)
44	0.00542	0.0418	0.221	1.57	7.69	(6)
52	0.0190	0.0416	0.0968	0.5076	2.38	(6)
70	0.0025	0.015	0.0684	0.668	2.544	(6)
85	0.00256	0.0134	0.0406	0.106	0.374	(6)
96	0.00233	0.00994	0.039	0.116	0.393	(6)
131	132	462	2 650	8 700	26 300	(6)
132	103	456	1 692	5 854	17 800	(6)
133	542	302	1 400	4 740		(6)

Unit: 10^7 ohm^{-1} cm^{-1}

Ind. No.	t°	κ	t°	κ	t°	κ	t°	κ	
6	250	129	402	4008	502	13 000	602	50 000	(5)
8	250	6.77	400	415.8	489	2 100			(5)
122	250	2.5	409	90.8	500	345	600	1 178	(5)

OPTICAL PROPERTIES

The relations between composition and optical properties in several systematic series are shown in Figs. 29–36. The properties of typical optical glasses are shown in Table 13, which, together with the compositions, was furnished by Chance Bros. and Co., Ltd. Table 14 gives the index for the infra-red and ultra-violet; Table 15, the effect of temperature on index; Table 16, the effect of pressure and strain; and Table 17, the absorption of light by various glasses.

TABLE 13.—DISPERSIONS OF TYPICAL OPTICAL GLASSES (9)

Ind. No.	n_D	Mean dispersion $n_F - n_C$	$\nu = \left(\frac{n_D - 1}{n_F - n_C}\right)$	Partial dispersions and relative partial dispersions D–C	F–D	G′–F	Sp. gr.
2	1.4785	0.00682	70.2	0.00202 .296	0.00480 .704	0.00363 .532	2.47
5	1.4980	.00763	65.3	.00227 .298	.00536 .702	.00425 .557	2.40
9	1.5087	.00793	64.1	.00237 .299	.00556 .701	.00445 .561	2.46
18	1.5160	.00809	63.8	.00242 .299	.00567 .701	.00454 .561	2.54
10	1.5100	.00821	62.1	.00246 .299	.00575 .701	.00462 .562	2.50
79	1.5881	.00962	61.1	.00287 .298	.00675 .702	.00541 .563	3.31
20	1.5155	.00848	60.8	.00250 .295	.00598 .705	.00482 .568	2.48
27	1.5175	.00856	60.5	.00254 .297	.00602 .703	.00484 .565	2.49
29	1.5186	.00860	60.3	.00254 .295	.00606 .705	.00489 .569	2.49
89	1.6130	.01025	59.8	.00302 .294	.00723 .706	.00582 .568	3.58
43	1.5407	.00910	59.4	.00268 .295	.00642 .705	.00517 .568	2.90
86	1.6118	.01037	59.0	.00305 .294	.00732 .706	.00590 .569	3.56
16	1.5149	.00890	57.9	.00265 .298	.00625 .702	.00506 .569	2.62
66	1.5744	.00995	57.7	.00292 .293	.00703 .707	.00567 .570	3.23
90	1.6134	.01090	56.3	.00319 .292	.00771 .708	.00626 .575	3.58
94	1.6150	.01097	56.1	.00323 .292	.00776 .708	.00630 .575	3.58
77	1.5837	.01041	56.1	.00304 .292	.00737 .708	.00596 .573	3.29
58	1.5661	.01029	55.0	.00301 .293	.00728 .707	.00591 .574	3.14
37	1.5237	.01003	52.2	.00295 .294	.00708 .706	.00577 .575	2.67
50	1.5515	.01067	51.7	.00310 .291	.00757 .709	.00619 .581	2.99
40	1.5290	.01026	51.6	.00300 .292	.00726 .708	.00593 .578	2.56
49	1.5523	.01075	51.4	.00313 .291	.00762 .709	.00624 .581	3.06
76	1.5833	.01251	46.6	.00362 .289	.00889 .711	.00738 .590	3.30
53	1.5534	.01201	46.1	.00347 .289	.00854 .711	.00711 .592	2.96
46	1.5472	.01196	45.8	.00348 .291	.00848 .709	.00707 .591	2.93
48	1.5491	.01206	45.5	.00348 .289	.00858 .711	.00714 .592	2.95
56	1.5677	.01291	44.0	.00371 .288	.00920 .712	.00763 .591	3.08
55	1.5632	.01312	42.9	.00375 .286	.00937 .714	.00781 .595	3.07
69	1.5746	.01388	41.4	.00396 .285	.00992 .715	.00830 .598	3.18
72	1.5787	.01420	40.8	.00406 .286	.01014 .714	.00851 .599	3.26
93	1.6125	.01655	37.0	.00471 .285	.00184 .715	.01003 .606	3.54
92	1.6134	.01662	36.9	.00473 .285	.01189 .715	.01008 .606	3.55
97	1.6214	.01722	36.1	.00491 .285	.01231 .715	.01047 .608	3.63
104	1.6683	.01876	35.6	.00533 .284	.01343 .716	.01147 .611	3.98
101	1.6469	.01917	33.7	.00541 .282	.01376 .718	.01170 .610	3.87
106	1.7167	.02430	29.5	.00686 .282	.01744 .718	.01511 .622	4.47

The order is that of decreasing ν.

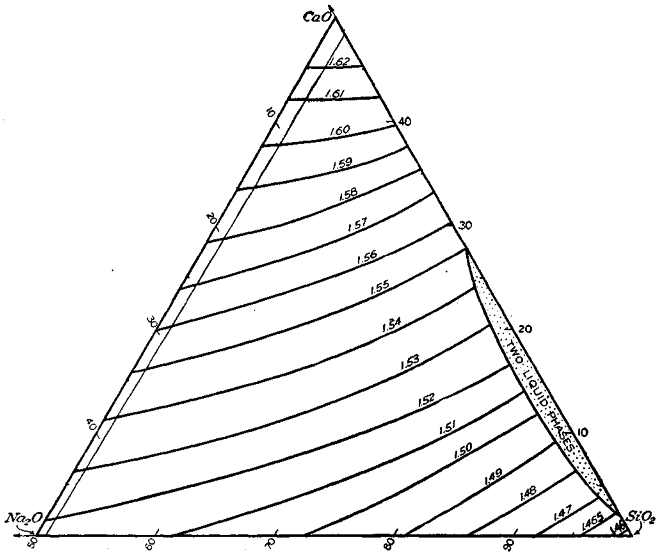

FIG. 29.—Refractive index of Na_2O-CaO-SiO_2 glasses (41).

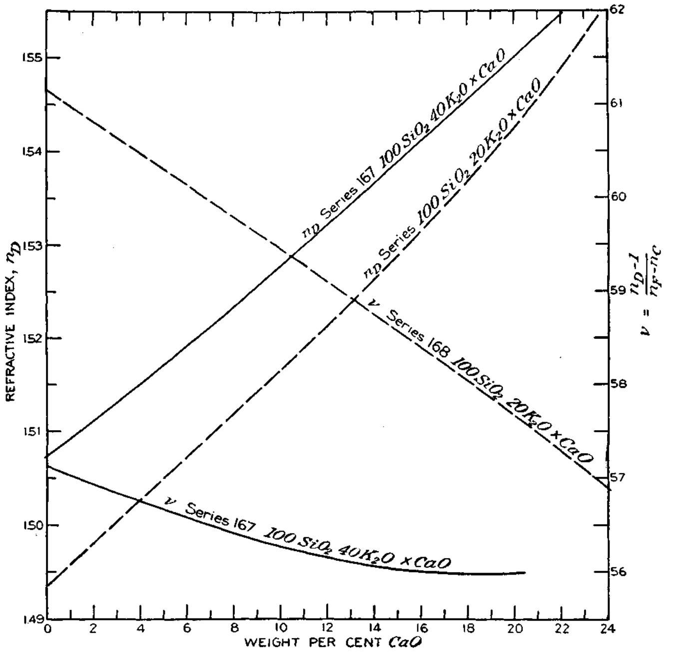

FIG. 30.—Refractive index and γ-value of K_2O-CaO-SiO_2 glasses of the approximate composition shown (45).

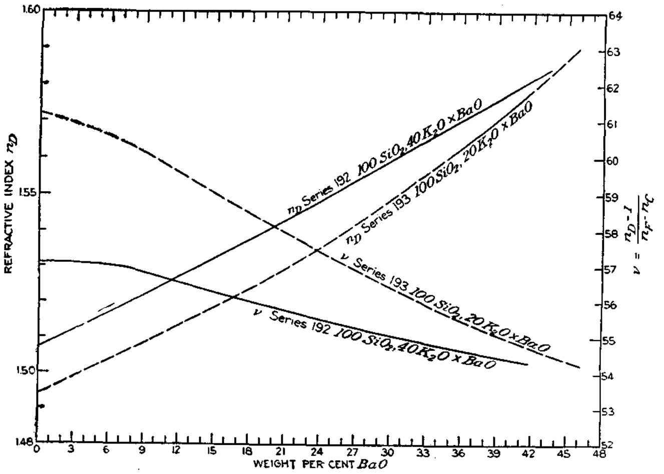

FIG. 31.—Refractive index and γ-value of Na_2O-BaO-SiO_2 glasses of the approximate composition shown (46).

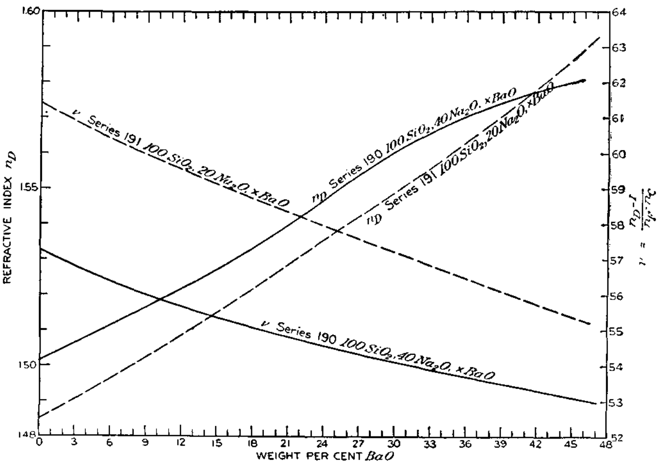

FIG. 32.—Refractive index and γ-value of K_2O-BaO-SiO_2 glasses of the approximate composition shown (46).

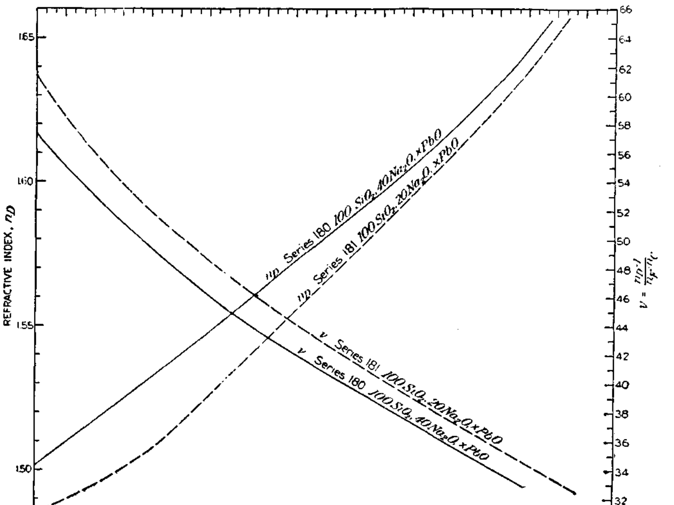

FIG. 33.—Refractive index and γ-value of Na_2O-PbO-SiO_2 glasses of the approximate composition shown (47).

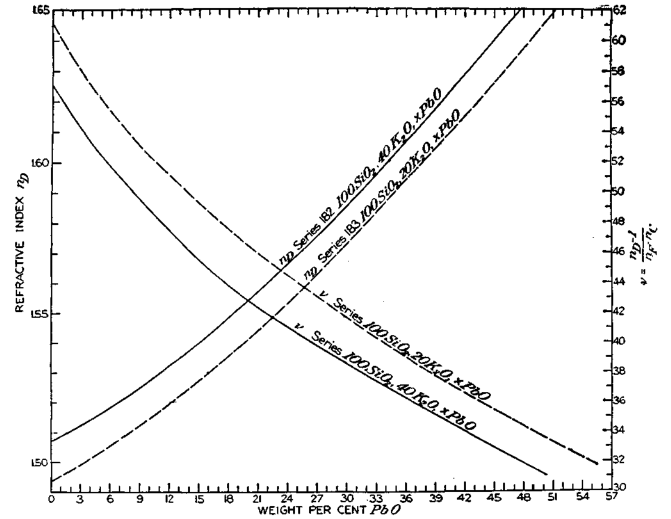

FIG. 34.—Refractive index and γ-value of K_2O-PbO-SiO_2 glasses of the approximate composition shown (47).

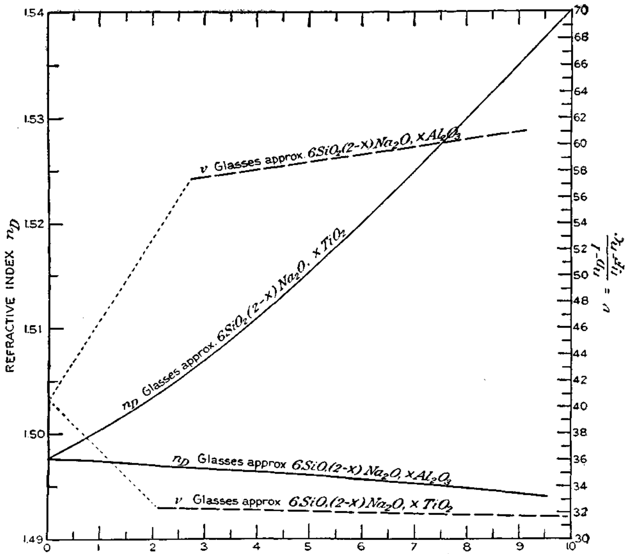

FIG. 35.—Refractive index and γ-value of glasses derived from $Na_2O \cdot 3SiO_2$ by substitution of Al_2O_3 or TiO_2 for Na_2O. Exact compositions are given in the original (10, 55).

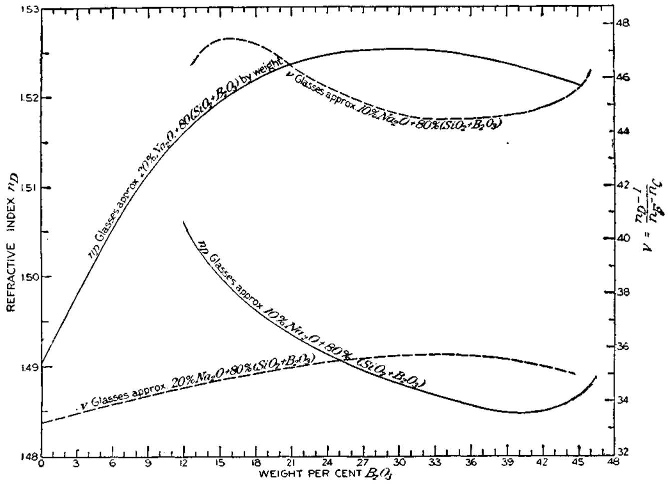

FIG. 36.—Refractive index and γ-value of Na_2O-B_2O_3-SiO_2 glasses. Exact compositions are given in the original (28)

TABLE 14.—REFRACTIVE INDICES FOR VARIOUS WAVE LENGTHS

Source	Wave length μμ	Index number (from Table 1) and Lit.												
		134(60)	135(53)	12(60)	24(60)	25(60)	31(53)	32(55)	38(60)	39(60)	42(60)	54(60)	144(53)	57(60)
	2200					1.4943								
	2000		1.4845			1.4967	1.4973						1.5390	
	1800		1.4884			1.4988	1.4999						1.5424	
	1600		1.4919			1.5008	1.5024						1.5452	
	1400		1.4950			1.5027	1.5048						1.5476	
	1200		1.4979			1.5048	1.5069						1.5497	
	1000		1.5009			1.5071	1.5096						1.5522	
	800		1.5044			1.5103	1.5131						1.5555	
K_{α}(A^{1})	768		1.50426			1.51143	1.51368	1.51410					1.55651	
H_{α}(C)	656.3	1.50486	1.50742	1.50883	1.51436	1.51446	1.51712	1.51742	1.51932	1.52441	1.53755	1.55771	1.55957	1.56014
Cd$_1$	643.9	1.50525		1.50917	1.51482				1.51979	1.52490	1.53797	1.55821	1.55821	1.56068
Na(D)	589.0	1.50734	1.51007	1.51124	1.51693	1.51698	1.52002	1.52046	1.52231	1.52704	1.54025	1.56075	1.56207	1.56343
Cd$_2$	537.9	1.50976		1.51362	1.51957				1.52536	1.52961	1.54297	1.56375		1.56671
Tl$_{\alpha}$	534.9		1.51287			1.51971	1.52327	1.52363					1.56476	
Cd$_3$	533.8	1.51004		1.51386	1.51982				1.52568	1.52989	1.54321	1.56407		1.56689
Cd$_4$	508.6	1.51154	1.51447	1.51534	1.52143	1.52132	1.52525	1.52567	1.52754	1.53146	1.54489	1.56596	1.56643	1.56914
H_{β}(F)	486.1		1.51610	1.51690		1.52299	1.52715	1.52752	1.52954	1.53303			1.56794	1.57148
Cd$_5$	479.9	1.51362	1.51662	1.51732	1.52361	1.52354	1.52782	1.52824	1.53007	1.53362	1.54714	1.56844	1.56847	1.57193
Cd$_6$	467.8	1.51461	1.51769	1.51828	1.52466	1.52451	1.52903	1.52946	1.53129	1.53464	1.54825	1.56968	1.56949	1.57333
Cd$_7$	441.6	1.51704		1.52066	1.52725				1.53436	1.53721	1.55093	1.57268		1.57667
H_{γ}(G^{1})	434.0	1.51775	1.52092	1.52136		1.52778	1.53312	1.53341	1.53521	1.53790			1.57273	1.57764
Cd$_8$	398.8	1.52210		1.52546	1.53261				1.54075	1.54245	1.55646	1.57896		1.58375
Cd$_9$	361.2	1.52852	1.53195	1.53156	1.53943	1.53897	1.54664	1.54726	1.54897	1.54911	1.56354	1.58704	1.58330	1.59300
Cd	353.6	1.53010			1.54111					1.55071	1.56525			1.59526
Cd$_{10}$	346.7	1.53157	1.53509	1.53445	1.54272	1.54215	1.55068	1.55132	1.55300	1.55225	1.56689	1.59093	1.58632	1.59754
Cd$_{11}$	340.4	1.53307	1.53660	1.53586	1.54432	1.54369	1.55262	1.55330	1.55504	1.55379	1.56852	1.59279	1.58776	1.59978
Cd	334.5	1.53490							1.55746	1.55564	1.57046	1.59452		1.60248
Cd$_{12}$	328.4	1.53721		1.53982	1.54879				1.56043	1.55804	1.57296	1.59796		1.60593
Cd	326.4	1.53811							1.56157					1.60748
Cd	326.1		1.54046			1.54755	1.55770	1.55838					1.59138	
Cd	323.6	1.53896								1.56004		1.60033		1.60900
Cd	322.1	1.53932		1.54168					1.56311	1.56086	1.57511	1.60081		1.61015
Cd	321.0			1.54204										
Cd	320.2	1.53982		1.54238	1.55089					1.56175	1.57593			1.61189
Cd	318.5	1.54079			1.55175				1.56518	1.56193	1.57830	1.60263		
Cd	315.7			1.54475	1.55414				1.56675			1.60475		
Cd$_{13}$	313.3		1.54444	1.54536	1.55450	1.55159	1.56307	1.56381		1.56343	1.57870			
Cd$_{14}$	308.1		1.54625	1.54839	1.55875	1.55343	1.56558	1.56632		1.56661	1.58293			
Cd	306.5								1.56714	1.56714				
Cd	298.0		1.55005			1.55723	1.57093	1.57176						
Cd	288.0		1.55437			1.56161								
Cd	283.7		1.55648			1.56372								
Cd	276.3		1.56027			1.56759								
	2400			1.5440							1.6131			1.8286
	2200			1.5463							1.6150		1.7082	1.8310
	2000		1.5515	1.5487							1.6171		1.7104	1.8316
	1800		1.5541	1.5512							1.6193		1.7127	1.8364
	1600		1.5565	1.5535							1.6217		1.7151	1.8396
	1400		1.5588	1.5559							1.6246		1.7180	1.8433
	1200		1.5611	1.5585							1.6277		1.7215	1.8481
	1000		1.5637	1.5615							1.6315		1.7264	1.8541
	800		1.5673	1.5659							1.6373		1.7339	1.8650
K_{α}(A^{1})	768	1.56731	1.56782	1.56669		1.57508		1.60277			1.63820		1.73530	1.86702
H_{α}(C)	656.3	1.57073	1.57120	1.57119	1.57568	1.57934	1.58848	1.60644	1.61574	1.62285	1.64440	1.65326	1.74368	1.87893
Cd$_1$	643.9				1.57619		1.58896		1.61656	1.62356		1.65435		
Na(D)	589.0	1.57363	1.57422	1.57524	1.57893	1.58282	1.59144	1.60956	1.62073	1.62750	1.64985	1.65762	1.75130	1.88995
Cd$_2$	537.9				1.58211		1.59433		1.62578	1.63226		1.66146		
Tl$_{\alpha}$	534.9	1.57687	1.57746	1.57973		1.58689		1.61292			1.65601		1.75995	1.90262
Cd$_3$	533.8				1.58244		1.59463		1.62630	1.63274		1.66185		
Cd$_4$	508.6	1.57883	1.57938	1.58247	1.58444	1.58941	1.59644	1.61504	1.62952	1.63577	1.65979	1.66423	1.76539	
H_{β}(F)	486.1	1.58079	1.58126	1.58515	1.58646	1.59178	1.59825	1.61706			1.66367	1.66670	1.77091	1.91890

Source	Wave length μμ	Index number (from Table 1) and Lit.												
		68(55)	68(53)	70(54)	71(60)	75(55)	80(60)	84(55)	96(60)	98(60)	102(53)	139(60)	108(53)	112(53)
Cd_5	479.9	1.58132	1.58188	1.58594	1.58715	1.59257	1.59878	1.61770	1.63396	1.63992	1.66482	1.66742	1.77256	
Cd_6	467.8	1.58253	1.58306	1.58772	1.58848	1.59419	1.59996	1.61891	1.63615	1.64196	1.66725	1.66904	1.77609	
Cd_7	441.6				1.59174		1.60285		1.64162	1.64704		1.67292		
$H_\gamma(G^1)$	434.0	1.58651	1.58710	1.59355	1.59268	1.59920	1.60367	1.62320	1.64319		1.67561	1.67436	1.78800	1.94493
Cd_8	398.8				1.59852		1.60870		1.65333	1.65792		1.68104		
Cd_9	361.2	1.59951	1.60022	1.61388	1.60726	1.61691	1.61622	1.63683	1.66933	1.67269	1.70536	1.69146	1.83263	
Cd	353.6				1.60937		1.61800		1.67346			1.69400		
Cd_{10}	346.7	1.60326	1.60399	1.62008	1.61148	1.62228	1.61978	1.64077	1.67753	1.68018	1.71485	1.69648	1.84731	
Cd_{11}	340.4	1.60510	1.60583	1.62320	1.61356	1.62492	1.62148	1.64271	1.68160	1.68390	1.71968	1.69892	1.85487	
Cd	334.5				1.61559		1.62356		1.68685	1.68838		1.70135		
Cd_{12}	328.4				1.61922		1.62622		1.69265	1.69454		1.70408		
Cd	326.4				1.62069				1.69356			1.70562		
Cd	326.1	1.60973	1.61045	1.63134		1.63166		1.64754			1.73245			
Cd	323.6				1.62159									
Cd	322.1													
Cd	321.0													
Cd	320.2				1.62256									
Cd	318.5				1.62311									
Cd	315.7				1.62462									
Cd_{13}	313.3	1.61446	1.61525	1.64024	1.62678	1.63908		1.65254						
Cd_{14}	308.1	1.61664	1.61744	1.64453		1.64258								
Cd	306.5													
Cd	298.0	1.62122	1.62213	1.65397										
Cd	288.0	1.62642	1.62742											
Cd	283.7	1.62893	1.62997											
Cd	276.3													

Index number 108(54)			
Wave length μ	n	Wave length μμ	n
4.12	1.6688	1.216	1.7208
3.83	1.6758	936	1.7276
3.56	1.6821	769.93	1.735000
3.24	1.6885	656.33	1.743488
2.98	1.6934	589.32	1.751094
2.71	1.6980	534.96	1.759751
2.40	1.7029	486.16	1.770658
2.02	1.7086	434.09	1.787782
1.625	1.7144	404.44	1.801758

TABLE 15.—EFFECT OF CHANGE IN TEMPERATURE ON THE ABSOLUTE REFRACTIVE INDEX OF GLASS

Ind. No.	Type	Mean temp.	Change in refractive index, $10^5\Delta n/\Delta t$ $\Delta t = \pm 50°$				
			C	D	F	G′	Lit.
14	513/637	52.8	+0.119	+0.137	+0.178	+0.213	(51)
23	517/602	59.3	−0.129	−0.105	−0.060	−0.010	(51)
45	545/503	59.2	+0.267	+0.299	+0.356	+0.410	(51)
60	571/430	58.0	+0.226	+0.250	+0.307	+0.360	(52)
		149.6	+0.324	+0.362	+0.456	+0.548	
		251.5	+0.509	+0.568	+0.666	+0.768	
		351.5	+0.577	+0.639	+0.751	+0.870	
		436.5	−1.861	−1.720	−1.504	−1.329	
61	572/504	56.5	+0.014	+0.045	+0.107	+0.150	(52)
		157.1	0.094	0.111	0.179	0.246	
		261.5	0.144	0.167	0.249	0.355	
		357.0	0.217	0.249	0.350	0.461	
63	573/576	61.2	0.024	0.035	0.092	0.099	(52)
		154.0	0.096	0.113	0.152	0.186	
		257.0	0.156	0.174	0.223	0.258	
		358.0	0.221	0.247	0.297	0.340	
84	610/574	55.9	0.394	0.410	0.504	0.528	(52)
		148.0	0.419	0.444	0.543	0.517	
		251.0	0.455	0.489	0.603	0.629	
		356.5	0.509	0.555	0.648	0.682	

TABLE 15.—EFFECT OF CHANGE IN TEMPERATURE ON THE ABSOLUTE REFRACTIVE INDEX OF GLASS.—(*Continued*)

Ind. No.	Type	Mean temp.	Change in refractive index, $10^5\Delta n/\Delta t$ $\Delta t = \pm 50°$				
			C	D	F	G′	Lit.
91	613/369	55.1	0.244	0.281	0.389	0.503	(51)
109	755/275	57.7	0.703	0.778	1.058	1.294	(52)
		126.0	0.916	1.051	1.302	1.668	
		176.5	0.960	1.092	1.430	1.714	
		231.0	1.127	1.237	1.632	1.993	
		280.5	1.277	1.396	1.790	2.140	
		325.0	1.382	1.544	1.960	2.405	
		379.0	1.758	1.904	2.263	2.893	
112	890/226	60.5	1.119	1.278	1.752	2.161	(52)
		125.5	1.275	1.442	1.959	2.477	
		177.5	1.379	1.594	2.098	2.617	
		250.5	1.577	1.783	2.396	2.992	
		330.0	1.808	2.027	2.753		
114	963/197	62.6	1.218	1.472	2.110	2.800	(52)
		156.2	1.579	1.809	2.536		
		233.0	1.928	2.251	3.212		
		281.0	1.591	1.911	2.918		
134	507/604	60	−0.066	−0.074	−0.033	−0.003	(51)
141	516/703	58.1	−0.202	−0.190	−0.168	−0.142	(51)
145	562/665	60.3	−0.314	−0.305	−0.246	−0.237	(51)

TABLE 16.—EFFECT OF PRESSURE ON OPTICAL PROPERTIES

The birefringence produced by a thrust F is measured in terms of the difference in index for white light of the two rays: $n_y - n_z = BF$, in which $B = \frac{n}{2R}\left(\frac{q}{v} - \frac{p}{v}\right)$, in which R = rigidity, $\frac{q}{v}$ and $\frac{p}{v}$, optical coefficients. The effect of uniform pressure, P', can be calculated from the equation $\frac{n_x - n}{n} = \frac{P'}{E}(1 - 2\sigma)\left(\frac{2p}{v} + \frac{q}{v}\right)$, in which E and σ are Young's modulus and Poisson's ratio. Unit of $F = 10^{-13}$ barye.

Ind. No.	Type	F	p/v	q/v	Lit.
19	516/620	−2.79			(1)
36	523/590	−2.52			(1)
41	537/512	−2.66			(30)
45	545/503	−3.70	0.289	0.182	(50)
60	571/430	−2.87	0.306	0.213	(50)
65	573/420	−3.13			(1)
67	574/570	−2.75			(1)
82	606/440	−3.03			(1)
83	608/570	−2.10			(1)
95	616/370	−3.06			(1)
96	621/361	−2.77			(30)
100	645/341	−2.56	0.335	0.264	(50)
103	655/330	−2.61			(1)
105	680/317	−2.17			(30)
107	717/295	−1.70			(30)
108	751/276	−1.30	0.354	0.319	(50)
110	756/270	−1.19			(1)
114	963/197	+1.88	0.427	0.466	(50)
134	507/614	−4.23	0.274	0.166	(50)

TABLE 17a.—TRANSMISSION FACTOR

$A = I/I_0$ (*v.* vol. I, p. 34); ultraviolet region; wave length, λ, in $\mu\mu$; In. = Index number of glass

In. λ	12	23	39	52	71	81	84	98	99	105
Glass thickness, 1 mm (36)										
384					0.995	0.986	0.989	0.983	0.985	0.947
361	0.995	0.995	0.994		.984	.962	.958	.952	.959	.83
347	.988	.991	.983	0.988	.959	.925	.88	.92	.89	.64
330	.957	.974	.938	.959	.89	.75	.76	.71	.74	.33
309	.78	.70		.69	.65					
Glass thickness, 10 mm (36)										
434					0.969					
425	0.993	0.982	0.970	0.978	.961	0.963	0.965	0.952	0.961	0.905
415	.982		.968	.973	.965					
406			.964		.974					
396	.986	.981	.980	.987	.971	.931	.941	.917	.944	.76
384	.972	.975	.955	.968	.948	.865	.894	.84	.86	.58
361	.950	.949	.942	.952	.849	.68	.65	.61	.66	.16
347	.88	.91	.85	.88	.66	.46	.28	.41	.30	.01
330	.65	.77	.53	.66	.32	.06	.07	.03	.05	0
309	.08	.03	0	.02	.01	0	0	0	0	0
Glass thickness, 100 mm (36)										
480	0.95	0.97	0.93	0.96		0.94		0.94	0.94	0.89
468	0.94	0.93	0.91	0.94		0.86		0.87	0.95	0.83
448	0.93	0.92	0.81	0.89		0.79		0.79	0.83	0.63
434					0.73					
425	0.94	0.83	0.74	0.80	0.67	0.68	0.70	0.61	0.67	0.67
415	0.84		0.72	0.76	0.70					
406			0.70		0.77					
396	0.87	0.82	0.82	0.88	0.74	0.49	0.54	0.42	0.56	0.06
384	0.75	0.78	0.63	0.72	0.59	0.23	0.33	0.18	0.22	0
361	0.60	0.60	0.55	0.61	0.19	0.02	0.13	0.01	0.01	
347	0.92	0.38	0.19	0.29	0.02	0	0	0	0	
330	0.01	0.07	0	0.02	0					

Ind. No. 1, pyrex, 1 mm thick (12)

λ	396	384	361	347	330	309	280
A	1.00	0.97	0.93	0.85	0.70	0.50	0.05

TABLE 17b.—FACTOR (1-A)

Absorption for 1 cm path for the visible spectrum (49)

Ind. No.	Type	Wave length in $\mu\mu$					
		357	388	415	442	500	640
12	510/640	4.7	2.5	1.2		0.7	0.5
23	518/602	3.4	2.5	1.8	1.4	0.5	0.3
38	523/513	49	30	12	3.6	0.7	0.7
59	568/530	9	6	2.7		1.6	
75	583/464	18	8.6	2.5	2.1	0.9	0.5
84	611/572	35	9.8	5.2	3.4	2.5	1.6
96	620/362	28	9.6	4.1		0.0	0.0
100	649/338	41	28	6.9		0.9	0.5

TABLE 17c.—ABSORPTION CONSTANT, $k, (I = I_0e^{-kd})$ FOR THE INFRA-RED SPECTRAL RANGE (53)

Ind. No.	Wave length in μ										
	0.7	0.95	1.1	1.4	1.7	2.0	2.3	2.5	2.7	2.9	3.1
25	0.01	0.04	0.05	0.01	0.01	0.09	0.20	0.34	0.51	0.73	1.24
31	0.02		0.01	0.01	0.02	0.06	0.11	0.23	0.29	0.79	1.15
68	0.02		0.03		0.05	0.07	0.11	0.17	0.34	0.75	1.31
70	0.00		0.01		0.02	0.05	0.08	0.18	0.25	0.62	1.09
102	0.00		0.02		0.01	0.02	0.02	0.03	0.11	0.41	0.69
108	0.00		0.00		0.00		0.00	0.01	0.08	0.30	0.63
112	0.00		0.02		0.01		0.01		0.06	0.25	0.51
135	0.00	0.01	0.06	0.10	0.16	0.21	0.37	0.85	1.25	1.73	
144		0.02	0.05	0.10	0.18	0.40	0.71	0.14	1.69		

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(For a key to the periodicals see end of volume)

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CHEMICAL DURABILITY OF GLASSES

W. E. S. TURNER

INTRODUCTION

In the measurement of the durability of glasses, results may be duplicated with an accuracy of 5 to 10% only. In a series of glasses of similar composition, the results with the more durable glasses may be reproduced with an accuracy of 5%; the less durable, up to about 10%.

INTRODUCTION

Les résultats ne peuvent être reproduits, dans les mesures de durabilité des verres, qu'avec une précision de 5 à 10% seulement. Dans les séries de verres de composition similaire, les résultats concernant les verres les plus durables peuvent être reproduits avec une précision de 5%; ceux relatifs aux verres les moins durables, jusqu'à environ 10%.

EINLEITUNG

Die Messungsergebnisse über die Dauerhaftigkeit der Gläser lassen sich nur mit einer Genauigkeit von 5 bis 10% angeben. In einer Reihe von Gläsern ähnlicher Zusammensetzung können die Ergebnisse mit dauerhafteren Gläsern auf 5%, mit weniger dauerhaften bis gegen 10% Genauigkeit angegeben werden.

INTRODUZIONE

I risultati ottenuti nelle misure di resistenza chimica dei vetri, sono riproducibili con una approssimazione del 5–10% soltanto. In una serie di vetri di composizione simile, i valori riferentisi ai vetri più resistenti sono riproducibili con l'approssimazione del 5%, e quelli riguardanti i vetri meno resistenti con una approssimazione del 10%.

EFFECT OF COMPOSITION

TABLE 1.—FUSED-QUARTZ GLASS

Milligrams loss in wt. sustained in each test by a 76 cm³ quartz flask, with 89 cm² surface exposed, when subjected in succession to the following reagents under the conditions shown (35); *cf.* (53).

Reagent, time and temperature			Loss mg
H_2O, 18°–100°	Many	Days at 18°	0.0
10% NH_3	2		0.8
10% NaOH	2		0.4
30% NaOH	2		0.0*
30% KOH	4		1.2†
2*N* NaOH	3	Hours at 100°	48
2*N* Na_2CO_3	3		12
2*N* KOH	3		31
2*N* NaOH	3		33
2*N* Na_2CO_3	3		8
2*N* KOH	3		64
2*N* NaOH	3		
N NaOH	14	Hours at 18°	2
N NaOH	14		1.8
N Na_2CO_3	14		0.6
Satd. $Ba(OH)_2$	14		0
Satd. Na_2SO_4	14		0
N H_3PO_4	14		0
10% NH_3	14		0
25% NH_3	60		0
25% NH_3, Fresh flask. Up to 60° with 4 renewals of reagent during experiment, 6 hrs			2.6

* No adsorption of NaOH.

† Adsorbed KOH difficult to remove by washing.

Remarks: $Ba(OH)_2$, 6 mo. at 18°, small crystals of Ba silicate formed. H_3PO_4 at 400°, extensive corrosion with formation of silicyl phosphate. *Dilute acids* in general, and conc. H_2SO_4, 18–100°, no action. Aqueous *methylene blue, congo red,* and *rhodamine;* ethereal *iodoeosin;* and alcoholic *aniline blue;* all slightly adsorbed but removable by hot solvents.

TABLE 2.—CaO · SiO₂ WOLLASTONITE

Milligrams oxides extracted from 2 g by acids (17, 30, 33, 38).

Oxide \ Acid	30 min at 18°	2*N* Acetic	0.1*N* HCl	2*N* HCl	2 hrs at 50°–60°	2*N* HCl	10*N* HCl
mg CaO		0.010	0.017	0.11		0.70	0.76
mg SiO_2		0.000	0.004	0.040		0.26	0.020

3- (or 4-) Oxide Glasses

TABLE 3

Grams H_2SO_4 equivalent to the alkali extracted by water at 80° acting for 1 hr on glass powder, size <160 mesh/in. (38, 41, 42, 43)

1. Molecular composition: $100SiO_2 + 40R_2O + xRO$									
x	$40Na_2O + xCaO$	$40K_2O + xCaO$	$20Na_2O + 20K_2O + xCaO$	$40Na_2O + xPbO$	$40K_2O + xPbO$	$20Na_2O + 20K_2O + xPbO$	$40Na_2O + xBaO$	$40K_2O + xBaO$	$20Na_2O + 20K_2O + xPbO$
5	18.4	28.3	30.2	31.6		31.2	37.7	34.0	34.0
10	9.0	27.6	15.3	9.3		19.0	4.54	31.2	21.6
15	4.3	20.4	4.42	4.2		18.2	4.44	27.8	7.6
20	3.7	8.6	3.26	3.4	23.0	6.6	4.25	24.6	6.2
30	2.3	5.1	2.08	1.68	19.0	3.2	1.85	17.4	3.8
40	1.06	2.2	1.05	1.04	8.9	1.50	1.08	9.5	2.8

TABLE 3.—(*Continued*)

2. Molecular composition: $100SiO_2 + 20R_2O + xRO$

x	$20Na_2O + xCaO$	$20K_2O + xCaO$	$10Na_2O + 10K_2O + xCaO$	$20Na_2O + xPbO$	$20K_2O + xPbO$	$10Na_2O + 10K_2O + xPbO$	$20Na_2O + xBaO$	$20K_2O + xBaO$	$10Na_2O + 10K_2O + xPbO$
5	3.03	5.4	1.99		9.6	3.32		10.4	2.44
10	1.34	1.44	0.94	0.69	3.7	1.15	1.20	2.01	1.50
15	0.66	0.96	0.66	0.51	1.61	0.68	1.07	1.76	1.21
20	0.40	0.60	0.40	0.37	0.60	0.37	0.87	1.08	1.03
30	0.34	0.36	0.26	0.140	0.26	0.16	0.55	0.74	0.87
40	0.25	0.30	0.24	0.091	0.15	0.12	0.50	0.64	0.68

TABLE 4

Grams oxide extracted by water at 100° acting for 5 hr on 100 g glass powder, containing 7300 to 7624 particles per cm^3 (30, 32).

Molecular composition: $6SiO_2 + (2 - x)R_2O + xRO$

Comp. $6SiO_2$ + / Oxide extracted	$2Na_2O$	$2K_2O$	$1.75Na_2O + 0.25CaO$	$1.75K_2O + 0.25CaO$	$1.5Na_2O + 0.5CaO$	$1.5K_2O + 0.5CaO$	$1.25Na_2O + 0.75CaO$	$1.25K_2O + 0.75CaO$	$Na_2O + CaO$	$K_2O + CaO$
R_2O.........	4.4	12.6	1.07	8.84	0.18	0.83	0.06	0.14	0.02	0.03
SiO_2.........	11.3	22.6	1.60	15.82	0.04	0.34	0.03	0.03	0.02	0.02
Total........	15.7	35.2	2.67	24.66	0.22	1.17	0.09	0.17	0.04	0.05

TABLE 5

Grams of oxides extracted at 100° in 5 hr by the action of 60 cm^3 H_2O on powdered glass, 4000 particles per cm^3 (21, 22, 58).

Molecular composition: $xSiO_2 + yR_2O + zRO + wR_2O_3$

Composition. Wt. %					Grams oxide extracted			
SiO_2	Na_2O	RO		$Al_2O_3 + Fe_2O_3$	SiO_2	Na_2O	RO	Total
73.7	22.5			4.0	4.25	1.47		5.80
69.6	22.0	5.1	SrO	3.5	1.84	0.716	0.0191	2.60
70.0	17.7	9.9		2.7	0.061	0.098	trace	0.159
68.0	14.8	15.7		1.7	0.024	0.035	trace	0.058
66.7	11.8	19.6		1.9	0.0134	0.018	trace	0.031
69.6	19.3	7.6	BaO	3.8	2.74	0.97	0.0515	3.82
67.5	16.2	14.2		2.4	0.236	0.168	trace	0.415
62.2	9.6	25.6		2.9	0.026	0.109	trace	0.134

TABLE 6

Per cent Na_2O extracted by boiling water in 1 hr acting on powdered glass, 20–30 mesh (I. M. M. sieves, *v.* p. 329) (11, 12, 44, 47, 48, 49).

Molecular composition: $100SiO_2 + (33.3 - x)Na_2O + xRO$ (R_2O_3 or RO_2)

R_aO_b / x	CaO	MgO	Al_2O_3	TiO_2	ZrO_2	ZnO	BaO
0.5							
1.0					4.4		
2.0	8.20			1.54	1.8	7.18	17.60
4.0	2.35	1.39	0.59	0.27	0.38	1.57	5.50
6.0	1.00	0.76	0.24	0.13	0.19	0.30	1.90

TABLE 6.—(*Continued*)

R_aO_b / x	CaO	MgO	Al_2O_3	TiO_2	ZrO_2	ZnO	BaO
8.0	0.50	0.29	0.09	0.07		0.18	0.68
10	0.25	0.13	0.03	0.045		0.12	0.22
12	0.10	0.07		0.03		0.06	0.12
14	0.05	0.048		0.02		0.04	0.06
16	0.04	0.028		0.012		0.02	0.04
18	0.02	0.020		0.010			
20				0.008			

TABLE 7

Per cent loss in weight in 1 hr in boiling 20.24 % HCl, 2*N* NaOH and 2*N* Na_2CO_3 acting on powdered glass 20–30 mesh (I. M. M. sieves) (12).

Molecular composition: $100SiO_2 + (33.3 - x)Na_2O + xRO$

	x	2	4	6	8	10	12	14	16	18	20
HCl	CaO		8.2	4.2	2.6	1.7	1.2	1.0	1.0		
	MgO		1.4	0.7	0.4	0.3	0.2	0.2	0.1		
	Al_2O_3		0.9	0.4	0.2	0.2					
	TiO_2	2.0	1.0	0.5	0.3	0.2	0.2	0.2	0.1	0.1	0.1
	ZrO_2	1.8	0.6	0.4							
	ZnO	1.8	0.9	0.5	0.3	0.2	0.2	0.1	0.1		
	BaO	9.6	2.0	1.0	0.5	0.3	0.2	0.2	0.2		
NaOH	CaO		2.6	2.3	2.1	2.0	1.7	1.5	1.2		
	MgO		3.1	2.8	2.5	2.7	2.1	2.1	2.1		
	Al_2O_3		2.8	2.5	2.5	2.6					
	TiO_2		6.0			3.6	3.2	2.9	2.6	2.4	2.3
	ZrO_2	1.3	0.8	0.7							
	ZnO	3.7	3.2	2.8	2.4	2.2	2.1	1.9	1.7		
	BaO	5.6	3.8	3.0	2.5	2.3	2.2	1.9	1.7		
Na_2CO_3	CaO		6.8	2.8	2.4	2.0	1.9	1.5	1.3		
	MgO			4.1	3.2	2.5	2.1	2.0	1.9		
	Al_2O_3		1.0	0.6	0.4	0.4					
	TiO_2	11.3	2.4	1.6	1.1	0.9	0.8	0.7	0.7	0.6	0.5
	ZrO_2	2.0	0.9	0.6							
	ZnO	11.2	2.5	0.5	0.4	0.3	0.2	0.2	0.2		
	BaO	38.0	7.0	4.9	4.0	3.5	3.2	2.6	2.2		

TABLE 8

Grams H_2SO_4 equivalent to alkali extracted by water at 80° acting for 1 hr on 100 g glass powdered to pass 160 mesh sieve.

1. Composition: $(70 - x)\%\ SiO_2 + x\%\ RO + y\%\ R_2O$ (39, 42)

x	RO	$25Na_2O$	$25K_2O$	$12.5Na_2O + 12.5K_2O$	$20Na_2O$	$20K_2O$	$10Na_2O + 10K_2O$
5	CaO	5.32	4.50				
	PbO	34.2	17.5				
	BaO	34.5	21.1	28.2			
10	CaO				1.64	0.75	0.67
	PbO				9.23	11.4	11.5
	BaO	28.8	18.6	22.9	13.3	9.64	7.40
15	CaO	1.98	1.00		1.12	0.60	0.49
	PbO	23.1	17.7		9.81	6.65	3.92
	BaO	22.6	15.8		10.4	7.11	4.87
20	CaO				0.72	0.51	0.40
	PbO				7.89	7.78	3.52
	BaO				8.93	3.47	2.99
25	CaO						
	PbO						
	BaO	14.0	12.7				

TABLE 8.—(*Continued*)

x	RO	$25Na_2O$	$25K_2O$	$12.5Na_2O + 12.5K_2O$	$20Na_2O$	$20K_2O$	$10Na_2O + 10K_2O$
30	CaO						
	PbO				4.88	4.61	3.17
	BaO				2.99	1.77	1.45
40	CaO						
	PbO				4.05	6.65	2.79
	BaO						
50	CaO						
	PbO				4.61	9.16	3.92
	BaO						

x	RO	$15Na_2O$	$15K_2O$	$7.5Na_2O + 7.5K_2O$	$10Na_2O$	$10K_2O$	$5Na_2O + 5K_2O$
15	CaO	0.44	0.240	0.22			
	PbO	2.91	1.696				
	BaO	2.68	1.371	1.28			
20	CaO	0.57	0.277		0.29	0.173	0.156
	PbO	2.54	1.610				
	BaO	2.09	0.998				
25	CaO						
	PbO	2.12	.848				
	BaO	1.66					
30	CaO						
	PbO				.45	.208	
	BaO				.68	.575	.337
35	CaO						
	PbO	1.40	.798				
	BaO	1.37					
40	CaO						
	PbO				.30	.163	
	BaO				.69	.563	.536
45	CaO						
	PbO	1.40	.845				
	BaO						
50	CaO						
	PbO				.24	.157	
	BaO						

TABLE 8.—(*Continued*)

2. Composition: $y\% \ SiO_2 + z\% \ PbO + (a - x)\% \ Na_2O + x\% \ K_2O$ (19, 40)

a	y	z \ x	0.0	2.5	5	7	7.5	10	14	15	17.5	20
20	60	20	7.9		4.9			3.5	1.68	2.08	3.8	7.8
20	50	30	4.8		3.6			2.31	1.50	1.63	3.00	4.5
10	60	30	0.43	0.32	0.19	0.122	0.136	0.28				
10	50	40	0.30	0.21	0.123	0.069	0.128	0.175				

TABLE 9

Per cent Na_2O extracted by boiling H_2O and % loss in weight by action of boiling 20.24% HCl, $2N$ NaOH and $2N$ Na_2CO_3 solns. resp. Time 1 hr. 20–30 mesh powder. The final glasses contained 0.08–0.2% CaO and 0.05–0.14% Fe_2O_3 (12, 49, 50).

Batch	Analytical %				% Na_2O by H_2O	% loss in wt. by		
	SiO_2	B_2O_3	Na_2O	Al_2O_3		HCl	NaOH	Na_2CO_3
$(80 - x)\% \ SiO_2 + x\% \ B_2O_3 + 20\% \ Na_2O$	79.8		19.5	0.69	2.11	1.40	2.92	6.35
	74.2	4.5	19.8	0.93	0.16	0.33	3.16	2.73
	71.6	8.3	18.8	1.00	0.06	0.31	3.10	2.64
	68.3	11.4	19.0	1.09	0.04	0.30	3.46	3.16
	64.7	14.5	20.0	0.71	0.07	1.02	4.54	3.70
	61.3	18.8	18.9	0.74	0.14	7.36	5.65	3.84
	50.0	28.8	20.4	0.78	2.25	39.4	17.2	17.1
	35.2	40.0	23.7	0.84	11.6	38.9	69.7	45.6
	32.2	43.7	23.1	0.82	14.7	39.1	94.6	56.1
$(90 - x)\% \ SiO_2 + x\% \ B_2O_3 + 10\% \ Na_2O$	74.9	12.5	11.3	0.92	0.004	0.09	3.11	1.40
	70.8	18.7	9.8	0.79	0.07	0.67	4.73	3.10
	67.2	21.8	10.1	0.88	0.36	2.73	7.01	4.29
	62.0	25.8	11.2	0.84	0.89	32.7	22.1	15.2
	57.9	31.3	9.6	0.98	2.42	41.0	62.1	38.6
	52.1	36.2	10.3	0.89	5.50	49.0		54.3
	46.3	42.3	10.4	0.80	7.46	49.3		64.4
	41.3	46.1	11.5	0.80				72.8

MULTI-OXIDE GLASSES. APPARATUS GLASS

In the tables of durability data for these glasses, the glasses are identified by means of the Index Numbers (I. N.) given in Table 10. Additional literature (1, 6, 10, 14, 18, 20, 23, 24, 25, 31, 32, 34, 35, 36, 54, 55, 57).

TABLE 10.—COMPOSITION IN MOLECULES PER 100 MOLECULES SiO_2

I. N.	Origin	B_2O_3	As_2O_5	Sb_2O_3	$Al_2O_3+Fe_2O_3$	CaO	MgO	ZnO	PbO	Na_2O	K_2O	MnO	Lit.
C/1		14.37			4.09					14.79		0.06	(18)
C/2					2.84	10.31		5.07		13.06		0.35	(18)
C/3					0.23	14.68				9.70	4.87		(18)
C/4					0.46	13.28				8.47	5.49		(18)
C/5					0.30	13.95				8.07	5.15	0.22	(18)
C/6					0.23	11.37				10.54	5.85		(18)
C/7					0.39	10.84				6.32	10.03		(18)
C/8					0.23	10.77				12.48	3.53		(18)
C/9					0.30	10.68				12.67	3.80		(18)
C/10		2.55			2.18	8.82		7.65		20.09			(18)
C/11					2.42	16.99				19.62	0.54	0.48	(18)
C/12					0.15	7.87				1.22	11.31	0.11	(18)
C/13					1.05	16.14				17.12	1.57		(18)
C/14					0.32	9.83				11.77	8.35	tr.	(18)
C/15					2.74	11.19				19.26	6.20	0.29	(18)
C/16									14.09		14.13		(18)
C/17					2.03	8.57				17.77	4.84	0.46	(18)
C/18					0.39	11.48				7.20	9.87		(15)
C/19					1.44	21.92			0.85	16.78	0.64		(15)
C/20			0.1			BaO 2.91			16.87	0.89	8.87	0.02	(15)

TABLE 10.—COMPOSITION IN MOLECULES PER 100 MOLECULES SiO_2.—(*Continued*)

I. N.	Origin	B_2O_3	As_2O_5	Sb_2O_3	$Al_2O_3+Fe_2O_3$		CaO	MgO	ZnO	PbO	Na_2O	K_2O	MnO	Lit.
C/21					2.39		10.12				17.13	6.11	0.45	(15)
C/22					0.47		11.52				15.35	4.63		(14)
C/23					0.75		14.34				14.47	7.91		
C/24					2.54		11.69				17.66	6.78		
C/25					3.04		10.62				24.18	2.20		
C/26	Jena 1914............	13.3			5.7		0.13	0.29	13.5		11.00	tr.	tr.	(4)
C/27	Jena 1914............	14.55			3.99		0.89		12.86		11.95			(26, 27)
					Al_2O_3	Fe_2O_3								
C/28	Jena 1920............	5.33			6.8		1.28		BaO 2.33		6.3	0.47		(26, 27)
C/29	British 1916*.........	2.6			8.3		12.40	0.20			20.20	4.00		(4)
C/30	British 1916*.........	9.4			5.6	0.05	0.64	tr.	10.3		17.40	0.33		(4)
C/31	Duroglass 1916*.......	5.9			5.9	0.04	7.00	0.8	4.0		16.80	2.50		(4)
C/32	Moncrieff 1916*.......	9.0			5.8	0.07	0.80	0.3	9.7		14.6	1.0		(4)
C/33	Wood Bros. 1916*.....	10.1			9.0	0.06	9.6	0.5			15.0	1.6		(4)
C/34	Poulenc Frères 1916...	4.9			0.85	0.07	8.9	tr.	7.9		9.0	5.5		(4)
C/35	French 1916..........				0.75	0.05	11.8	1.1			23.6	0.6		(4)
C/36	Swedish 1916.........	2.5			0.9	0.08	7.8	0.3	3.2		20.3	1.2		(4)
C/37	Italian 1916..........	2.0			0.3	0.07	10.9	tr.			17.2	3.0		(4)
C/38	U. S. A. Nonsol 1917..	9.5		0.13	2.25	0.11	1.25	7.5	8.05		17.0	0.28	tr.	(7)
C/39	U. S. A. Insolo 1917...	4.95		0.3	0.8	0.18	2.6	13.45	4.05		15.5	0.64	tr.	(7)
C/40	U. S. A. Fry 1917.....	10.0	0.07		2.5	0.11	4.15	5.55	3.85		14.1	1.25	tr.	(7)
C/41	U. S. A. Pyrex 1917...	12.6	0.23		1.45	0.07	0.3	0.5			4.6	0.5	tr.	(7)
C/42	U. S. A. Insol 1917....	2.9		0.2	0.57	0.12	5.0	10.05	8.95		14.3	2.9	tr.	(7)
C/43	Macbeth-Evans 1919..	9.03	0.02	0.11	1.30	0.18	0.96	5.47	5.50		14.65	0.27	tr.	(7)
C/44	Greiner & Friedrich Resistance "R"......	4.8		0.47	2.75	0.08	0.33	7.4	9.15		17.05	1.35		(7)
C/45	Köln-Ehrenfeld.......	5.45	0.82	0.4	2.25	0.12	2.85	5.9	10.9		10.8	1.7	tr.	(7)
C/46	Kavalier 1917.........		tr.		0.18	0.05	12.4	0.3			9.35	6.65	tr.	(7)
C/47	German (unmarked)...				0.21	0.07	8.95	0.57			14.3	4.75		(7)
C/48	Hungarian (Zsolna)....				0.23	0.07	12.6	tr.			9.0	6.4	tr.	(7)
C/49	Japanese 1917........				1.9	0.07	5.3	0.22			22.6	1.2		(7)
C/50	Murano 1922.........	13.63			5.61		1.62		11.17		8.79			(26, 27)
C/51	Murano 1923 No. 1....	10.28			4.71		8.57				5.16			(26, 27)
C/52	Murano 1923 No. 2....	10.99			3.62		3.30				5.21			(26, 27)
C/53	Murano 1923 No. 3....	11.81			2.94						5.56			(26, 27)

* Most of the glasses of these makes have been modified and improved since 1916.

TABLE 11.—ACTION OF WATER ON FLASKS

The values given are thousandths mg alkali extracted and mg loss in weight, each for 100 cm² surface. The autoclave data at 190° and at 183° respectively are not comparable with one another.

I. N. (17, 28)	Alkali extracted 10^{-3} mg		Auto-clave mg loss 4 hr 190°	I. N. (17, 28)	Alkali extracted 10^{-3} mg		Auto-clave mg loss 4 hr 190°
	8 da 20°	3 hr 80°			8 da 20°	3 hr 80°	
C/1	2.5	2.7	23.7	C/9	17.8	66	67.0
C/2	2.1	6.3		C/10	16.6	65	34.0
C/3	10.7	28.4		C/11	27.0	98	
C/4	8.9	28.2	17.2	C/12			63.0
C/5	13.1	26.8		C/13			37.0
C/6	14.0	56		C/14	32.0	217	
C/7	14.5	45	51.3	C/15	77.0	654	126
C/8	14.9	50		C/16	74.0	356	
C/46	12.5	24.6	(7)	C/48	13.6	29.3	(7)

TABLE 11.—ACTION OF WATER ON FLASKS.—(*Continued*)

I. N. (4)	Alkali extracted 10^{-3} mg		Milligrams loss in weight				
			3 hr steam Treatments			2 hr evap. 100°	Auto-clave 3 hr 183°
	8 da 20°	3 hr 80°	1st	2nd	3rd		
C/26	1.6	1.9	0.30	0.15	0.05	0.6	26.0
C/29	3.7	7.0	0.30	0.10	0.08	0.9	22.0
C/30	3.1	5.6	0.28	0.15	nil	0.6	23.7
C/31	2.6	6.2	0.25	0.12	0.08	1.05	26.8
C/32	2.3	4.7	0.22	0.04	nil	0.45	20.7
C/33	2.5	4.9	0.25	nil	nil	0.67	18.5
C/34	3.3	6.3	0.24	0.40	0.16	0.52	20.5
C/35	25.7	43.2	4.00	2.23	2.12	8.6	221_0
C/36	12.3	24.7	2.13	1.85	1.24	2.1	875.0
C/37	21.7	35.4	2.30	1.75	1.43	4.7	104_0

TABLE 11.—ACTION OF WATER ON FLASKS.—(*Continued*)

I. N.	mg loss in weight		I. N.	mg loss in weight	
	2 hr evap. 100°	Autoclave 3 hr 183°		2 hr evap. 100°	Autoclave 3 hr 183°
C/38	0.8	31.5	C/44	1.05	55.4
C/39	1.05	139	C/45	1.0	48.5
C/40	0.95	48.7	C/46	2.6	614
C/41	0.67	10.0	C/47	0.4	318_3
C/42	1.0	79.6	C/48		
C/43	0.3	46.2	C/49	5.4	
Lit.	(7, 24, 29)				

TABLE 12.—ACTION OF ACIDS ON FLASKS

Mean loss in wt. (mg per 100 cm² surface) from 3 successive treatments with each reagent. Reagents: A, HCl vapor for 3 hr (4). B, 20.24% HCl evap. for 1.5 hr (4, 7). C, 2*N* H_2SO_4 for 6 hr at 100° (17). D, concd. H_2SO_4 heated to fuming for 4 hr (51). E, 1.2 sp. gr. HNO_3 evap. for 1.5 hr (28, 29, 51). (*Cf.* Tables 15, 16, 18, and 20.)

R \ I. N. C/	26	29	30	31	32	33	34	35	36	37
A	1.59	1.01	0.52	0.36	0.63	2.60	0.37	0.71	0.39	0.73
B	10.6	5.0	3.2	2.4	2.7	11.1	1.7	2.7	1.9	1.8
C	1.2	0.8	0.9	1.3	0.8	0.8	0.8	1.9	1.9	1.3
D				1.0		0.2		1.0		
E					1.0	1.8	1.6			

R \ I. N. C/	38	39	40	41	42	43	44	45	46	47
B	1.0	1.0	1.1	0.5	1.1	0.5	0.9	1.4	0.7	0.2

TABLE 13.—ACTION OF ALKALIES ON FLASKS

Loss in wt., mg/100 cm² surface.

Reagents: A, 2*N* NaOH for 3 hr at 100° (17). B, 0.1*N* NaOH for 3 hr at 100° (17). C, 2*N* NH_4OH evap. for 65–70 min (17). D, 2*N* Na_2CO_3, 3 hr at 100° (17). E, 2*N* $(NH_4)_2S$ 3 hr at 100° (4, 7, 50). F, Na_2HPO_4 3 hr at 100° (28, 29, 50).

From No. 26 onwards in the case of the sodium hydroxide, ammonia and sodium carbonate tests the values quoted are the mean of three successive treatments.

R \ I. N. C/	1	2	3	4	6	7	8	9	10	11	15	16
A	67.3	39.7	35.4	37.5	39.8	37.7	38.5	42.4	46.5	31.3	46.0	58.0
D	23.5	17.6		59.5	76.9	79.2	73.0	79.4	23.0	40.7	45.0	51.0

R \ I. N. C/	26	29	30	31	32	33	34	35	36	37
A	129.2	92.2	97.4	79.8	94.6	104	78.6	157	114	121
B	21.4	20.0	20.7	18.0	20.6	17.5	15.3	45.6	30.2	37.1
C	3.2	4.5	2.7	3.0	2.9	2.6	2.4	7.2	4.9	5.6
D	30.7	30.1	27.7	24.7	26.0	27.7	36.0	200	87.8	121
E					1.0		1.2	1.1		
F, 0.5*N*						2.8	2.0	7.3		
F, 0.25*N*						1.6	1.2	5.3		

R \ I. N. C/	38	39	40	41	42	43	44	45	46	47
A	95.7	98.0	93.6	118	79.8	82.3	79.1	81.0	96.4	91.2
B	17.7	21.4	18.8	30.7	15.5	18.6	21.8	13.7	28.1	32.8
D	29.2	48.5	36.0	51.1	32.3	29.1	26.0	25.3	141	132

TABLE 14

Action of Na_2CO_3 and K_2CO_3 solutions for 3 hr at 100° and of water and NaOH for 50 days at room temperature. Loss in wt., mg/100 cm² (14).

I. N.	Na_2CO_3 g/l		K_2CO_3 g/l	NaOH g/l				H_2O†	
	13.2	132	172	10*	10†	100*	100†	*a*	*b*
C/22	46.4	75.8	48.1	3.9	4.6	5.2	5.7	6.6	6.0
C/23	49.5	83.3	52.8	4.5	5.1	6.3	6.2	16.5	12.6
C/24	26.3	45.2	21.2	5.1	6.4	6.0	6.7	23	22.5
C/25	24.8	41.2	20.0	5.5	5.0	6.6			

* Successive treatments of same flask.

† *I.e.*, alkali extracted by water in 50 days from (*a*) new flasks, (*b*) flasks pretreated with the 100 g/l NaOH for 100 days.

TABLE 15.—THE EFFECT OF BORIC OXIDE

Mg loss in wt. by 500 cm³ flasks. Reagent: (1), *N* HCl boiling for; A, 0.5 hr; B, 2 hr; C, 0.1*N* HCl autoclave 3 hr. (2), 0.01*N* NaOH boiling for: D, 0.5 hr, E, 2 hr, F, 0.1*N* NaOH autoclave 3 hr at 120° (25, 26).

I. N. \ R	A	B	C	D	E	F	I.N. \ R	A	B	C	D	E	F
C/27				3.2	10.0	81	C/41	0.30	2.0	2.0	6.0	19.5	229
C/28	0.35	2.0	2.1	4.5	11.0	123	C/51	0.34	2.6	2.3	4.3	10.5	94
*	0.33	2.5	2.2	4.5	10.7	108	C/52	0.33	2.5	2.2	4.5	10.7	108
C/50	0.50	3.1	2.5	2.5	9.0	81	C/53	0.31	2.0	2.0	6.0	19.1	200

* Murano 1923, white badge.

TABLE 16

Per cent loss in weight in 1 hr by boiling water, 20.24% HCl, and 2*N* NaOH, respectively, acting on 20–30 mesh powdered glass (46, 52).

Wt. % composition: $(75.8 - x)SiO_2 + xB_2O_3 + 8.6CaO + 6.9Na_2O + 7.9K_2O + 0.66R_2O_3$

x	H_2O	HCl	NaOH	*x*	H_2O	HCl	NaOH
0	0.060	0.056	1.50	12.5	0.085	1.45	2.32
0.5	0.060	0.056	1.45	15.0	0.105	7.40	2.70
1.0	0.060	0.056	1.45	20.0	0.170	29.8	3.95
2.5	0.060	0.056	1.46	25.0	0.485	47.2	5.65
5.0	0.060	0.060	1.55	30.0	1.150	54.80	8.00
7.5	0.062	0.090	1.75	35.0	2.175	59.4	13.5
10	0.068	0.300	2.00	40.0		62.6	25.5

TABLE 17.—ACTION OF NEUTRAL SALT SOLUTIONS
mg/100 cm² loss in wt. in 3 hr at 100°

	Na_2SO_4, 178 g/l (14)				5% NH_4Cl, mean, 3 successive treatments (4)								
I.N.C/	22	23	24	25	26	29	30*	31*	32	33	34*	36	37
mg	1.8	3.1	1.6	2.3	0.25	0.28	0.28	0.23	0.40	0.28	0.16	0.29	0.39

* No loss on 3rd treatment.

TABLE 18.—THE INFLUENCE OF REAGENT CONCENTRATION
mg/100 cm² loss in wt. (14, 15)

6 hr at 100°		Glass index No.			6 hr at 100°		Glass index No.		
Reagent	Equiv./l	C/8	14	15	Reagent	Equiv./l	C/8	14	15
H_2SO_4	0.001	0.2	1.1	1.7	HCl	0.001			1.5
	0.1	0.1	1.0	1.5		0.1	0.2	0.9	1.6
						1	0.3	1.1	1.9
	1	0.2	1.2	1.7		2	0.3		1.8
	5	0.2	1.0			4			1.7
	10	0.3	0.9	1.7	$C_2H_4O_2$	0.1	0.2	0.8	1.6
	25	0.1	0.2	0.5	Acetic	1	0.2	0.8	1.7
(Sp. gr.	= 1.84)	0.1	0.1	0.2	acid	5	0.1		1.4

TABLE 18.—THE INFLUENCE OF REAGENT CONCENTRATION.—(*Continued*)

mg/100 cm^2 loss in wt. (14, 15)

6 hr at 100°		Glass index No.			6 hr at 100°		Glass index No.		
Reagent	Equiv./l	C/8	14	15	Reagent	Equiv./l	C/16	19	20
HNO_3	0.1	0.2	1.2	1.7	HCl	1	1.2	0.3	1.4
	1	0.2	0.7	1.8		5	1.3		
	5	0.1	1.0	1.5	$C_2H_4O_2$	1	0.9		
	10	0.4	1.2	1.5					
	16.5	0.2		1.0	H_2SO_4	1	1.2		

KOH g/l	Gls. C/25	14	140	210	280	420	490	Data for $6SiO_2 + (2 - x)R_2O + xCaO$ in same paper (14)
mg loss, 3 hr 100°		17.5	28.0	28.3	27.2	23.6	24.6	

	KOH g/l		NH_4OH g/l (or wt. %)			
	140	490	4.3	43	10%	25%
I. N.	3 hr at 100°		50 days at room temperature			
C/22	21.7	20.8*		3.5		0.9
C/23	23.3	21.1*	3.6	3.5	3.2	1.0
C/24	26.9	21.6	3.4	3.5	3.6	1.0
C/25	28.5	24.1*	3.2	3.5	4.1	0.9

* Mean of 2 determinations.

TABLE 19.—INFLUENCE OF REPEATED ACTION AND TIME

Continued action of H_2O at 20° on glass No. C/21 (16)

Time of treatment	mmg ($=10^{-6}$ g) Na_2O per 100 cm^2 dissolved from glass					
	1. In original condition	2. After 42 da in H_2O vapor at 30°	3. After 42 da in moist CO_2 at 30°	4. After 12 mo in air of room	5. After 12 mo in outdoor air	4 followed by 3
1 min	36	65	59	48	66	109
1 day	63	62	10	50	45	13
2 days	19		7	17	18	6
3 days	14	17	6	15	15	7
5 days	14	14		12	12	6
7 days	11	9		9	8	
10 days	8	8		8	8	7

TABLE 20

mg/100 cm^2 loss in wt. by successive treatments (8)

No. of treatments	2 hr evap. H_2O at 100°			1.5 hr evap. 20.24% HCl			3 hr at 100°					
							2*N* NaOH			2*N* Na_2CO_3		
	C/31	33	35	26	31	35	31	33	35	32	33	35
1	0.6	1.2	12.2	7.0	2.1	3.75	68	86	160	25.7	26.2	85
2	0.7	1.65	8.7	9.1	2.9	2.25	75	97	143	21.7	26.1	121
3	0.75	1.8	5.6	8.8	2.4	1.5	68	97	124	20.0	30.1	135
4	0.9	1.7	5.2	9.0	2.1	1.35	83	86	131	22.6	27.0	135
5	0.2	0.08	2.4	8.8	2.0	0.9	75	111	132	22.8	28.3	157
6	0.3	0.3	2.3	10.2	2.2	1.05	78	99	120	24.8	29.8	137
7	1.05	1.5	3.4	8.5	2.0	1.3	77	97	130	22.6	25.3	130
8	0.9	1.4	2.6	9.6	2.2	1.1	74	117	137	23.2	27.3	181
9	0.15	0.9	2.8	9.9	2.3	1.2	67	110	121	22.6	25.7	154
10	0.08	0.8	4.4	10.9	2.2	1.3	75	100	153	21.8	27.7	163
11				10.4	2.2	1.2				21.9	24.5	138
12				8.8	2.0	0.9				21.8	25.2	145
13				11.0	1.75	0.7				21.6	27.3	133
14					2.25	0.6				20.3	23.5	149
15					2.0	0.9				20.4	23.7	141

TABLE 20.—(*Continued*)

mg/100 cm^2 loss in wt. by successive treatments (8)

20.24% HCl evaporating for 1.5 hr										
No. of treatments..	16	17	18	19	20	21	22	23	24	25
Index No. C/31....	2.1	2.1	1.35	1.75	1.8	1.75	2.7	1.8	1.8	2.0
Index No. C/35....	1.1	1.05	0.3	0.15	0.3	0.3	0.9	0.45	0.6	0.45

TABLE 21.—THE INFLUENCE OF TEMPERATURE

Amount extracted per 100 cm^2 surface

Alkali extracted (14)							mg matter extracted (9)				
By H_2O			Na_2CO_3, 132 g/l		K_2CO_3, 172 g/l		H_2O for 24 hr 250 cm^3 flask				
Index No.	3 days room temp.	1 hr 80°	50 days room temp.	3 hr 100°	50 days room temp.	3 hr 100°	Index No.				
C/	10^{-6} g		10^{-3} g				C/	80°	90°	95°	100°
22	6.3	63	4.4	75.8	2.0	48.1	33		1.4	2.4	5.0
23	16.5	210	4.6	83.3	2.1	52.8	32		1.0	2.0	4.0
24	23	337	2.2	45.2	0.8	21.2	47		1.0	2.4	5.4
25	40	607	2.0	41.2	0.9	20.0	38	4.8	7.5	14.2	55.4

mg loss in wt. of 500 cm^3 flasks by 20.24% HCl for 12 hr (9)

I. N. C/	90°	95°	99.9°	102°	104.8°
26	6.2	7.8	9.8	10.8	13.2
31	1.6	2.1	2.7	3.4	4.6
33	5.4	7.2	9.3	10.4	12.9

mg loss in wt. of 500 cm^3 flasks in 3 hr (5)

Index No. C/	By 2*N* NaOH					Index No. C/	By 2*N* Na_2CO_3				
	40°	60°	80°	90°	100°		40°	60°	80°	90°	100°
31	1.7	4.1	18.9	31.7	74.2	32		2.6	10.2	16.8	32.9
33	1.5	4.3	19.2	36.5	88.9	33		3.2	10.6	18.1	34.8
36			24.1	45.5	154	48	2.1	5.9	25.9	49.2	115

TABLE 22.—INFLUENCE OF CONCENTRATION, TIME AND TEMPERATURE

mg/100 cm^2 loss in wt. by action of commercially pure NaOH (C. P. NaOH somewhat less corrosive) (14)

NaOH g/l	Time	Temp. °C	Index No. C/			
			22	23	24	25
1	*3 hours	100			18.3	
10	50 days	18	3.9	4.5	5.1	5.5
10	*3 hours	100	27.6	32.8	35.2	34.5
100	50 days	18	5.2	6.3	6.1	6.6
100	*3 hours	100	54.0	58.3	60.6	62.9
450	50 days	18	1.8	1.7	2.0	3.7
	*3 hours	100	46.6	52.5	52.7	52.8

* Not clearly stated in text, but assumed from reference from earlier page.

OPTICAL GLASSES

TABLE 23

Hundredths-milligrams of iodoeosin per 100 cm² surface (2, 45)

Glass index No.	Type	n_D	Fractured surfaces					Polished surfaces			
			Fresh	7 da in moist air at 18°	Fractured under the soln.	Steamed 1 hr at 2 atm.	Grade	Fresh	7 da in moist air at 18°	Heated 4 hr 150°	Steamed 1 hr at 2 atm.
O/1	Fluor crown	1.4942	3	2	23		h^1	2	2	3	
2	Borosil. crown	1.5108	11	7	10	108	h^2	2	3	4	63
3	Borosil. crown	1.5135	8	3	18	106	h^1	3	3	4	65
4	Borosil. crown	1.5171	17	8	17	112	h^2	2	2	3	72
5	Hard crown	1.5173	16	7	8	181	h^2	4	6	9	155
6	Soft crown	1.5225	19	69	33		h^5	8	26	23	
7	Light Ba crown	1.5408	14	5	16	150	h^1	3	2	3	108
8	Medium Ba crown	1.5736	8	3	12	94	h^1	4	4	3	94
9	Dense Ba crown	1.6129	21	8	22	115	h^2	4	3	3	84
10	Dense Ba crown	1.6111	19	6	21	71	h^2	3	3	3	47
11	Dense Ba crown	1.6052	15	3	19	65	h^1	4	2	4	45
12	Telescope flint	1.5177	10	6	11	137	h^2	5	2	4	122
13	Light Ba flint	1.5655	10	3	13	55	h^1	4	4	3	37
14	Light Ba flint	1.5804	14	8	16	130	h^2	5	3	4	126
15	Light Ba flint	1.5282	10	2	11	164	h^1	4	2	3	140
16	Ba flint	1.6051	16	2	19	56	h^1	3	2	3	55
17	Extra light flint	1.5516	12	8	14	108	h^2	3	4	4	99
18	Light flint	1.5741	8	4	10	106	h^1	2	2	3	100
19	Light flint	1.5677	11	6	12	95	h^2	3	2	2	89
20	Dense flint	1.6174	24	6	20	86	h^2	3	2	2	85
21	Dense flint	1.6229	21	2	19	85	h^1	3	2	3	80
22	Extra dense flint	1.6521	26	1	20	69	h^1	2	1	1	58
23	Borosil. crown	1.5089	12	8			h^2				
24	Hard crown	1.5186	19	9			h^2				
25	Zinc crown	1.5160	11	5			h^1				
26	Light Ba crown	1.5040	22	3			h^1				
27	Medium Ba crown	1.5724	11	4			h^1				
28	Dense Ba crown	1.6087	24	9			h^2				
29	Dense Ba crown	1.6118	13	6			h^2				
30	Dense Ba crown	1.6129	14	5			h^1				
31	Light Ba flint	1.5515	12	2			h^1				
32	Dense Ba flint	1.6256	18	2			h^1				
33	Dense Ba flint	1.6683	19	2			h^1				
34	Extra light flint	1.5280	11	6			h^2				
35	Light flint	1.5789	17	2			h^1				
36	Dense flint	1.6039	19	6			h^2				
37	Dense flint	1.6221	20	4			h^1				
38	Extra dense flint	1.6475	20	2			h^1				
39	Densest extra large flint	1.7072	14	1			h^1				
40	Fluor crown	1.4933	4	2	4		h^1	2	3	3	
41	Borosil. crown	1.5100	17	8	17	107	h^2	3	4	4	87
42	Silicate crown	1.5144	28	20	34		h^3	4	17	18	
43	Ordinary sil. crown	1.5175	20	30	23		h^4				
44	Soft sil. crown	1.5151	41	58	48		h^5	5	25	24	
45	Light Ba flint	1.5646	15	5	16	102	h^1	3	2	2	86
46	Ordinary light flint	1.5800	14	7	16	104	h^2	3	2	3	81
47	Heavy flint	1.6190	23	2	19	80	h^1	2	2	2	71

TABLE 24.—DURABILITY BY AUTOCLAVE TREATMENT

Dimming test (appearance after weathering polished surface in air saturated with water vapor at 80° for 30 hr) and moisture retained by powdered glass. Grading by apparent effect of autoclave treatment: Grade 1 = least apparent effect. Grade 5 = greatest apparent effect. Dimming test: Three grades, 1, 2, 3. Symbols 1+ and 2− = rather worse than 1 and rather better than 2 resp. (2, 13, 45).

Glass ind. No.	Water for 4 hr at 4 atm.			Grade by dimming test	mg H_2O retained per 100 g glass powder, 90–100 mesh	
	Loss in wt. mg/100 cm²	Iodo-eosin value of water extract	Grade by appearance		Dried in vacuo	Heated to 120°C
O/1	127	182	5			
2	16.6	25.8	3	2	33	0
3	14.8	43.8	1			
4	10.9	41.3	1			
5	16.9	38.6	1	2−	135	87
6		1875	5	3−	230	151
7	21.7	38.0	3	1	9	0
8	10.5	31.4	3	1+	26	7
9	14.0	31.0	1	1+	26	7
10	11.5	19.7	4	2−	27	13
11	9.8	30.8	4			
12	8.6	21.9	4	2−	71	36
13	9.2	20.9	4	1+	28	12
14	8.5	18.9	4	2−	53	17
15	5.8	30.0	2			
16	6.1	11.5	3			
17	2.7	15.5	2			
18	3.7	10.4	2			
19	3.2	8.5	1	1	43	27
20	4.7	4.2	2	1+	28	16
21	3.2	3.4	2			
22	4.8	6.3	2			
23	27.2	73.2	2			
24	17.3	61.7	2			
25	13.7	31.7	4			
26	18.8	48.0	4			
27	11.0	31.7	3			
28	8.4	24.9	3			
29	9.2	20.7	3			
30	9.0	28.9	1			
31	5.3	18.5	2			
32	2.6	3.5	3			
33	2.8	4.3	3			
34	3.5	19.6	4			
35	2.4	7.7	1			
36	3.8	6.1	2			
37	2.7	2.7	1			
38	4.0	5.2	2			
39	1.3	1.6	1			
40	513	545	5			
41	21.6	63.6	3			
42	18.2	68.5	4			
43	12.9	63.4	4			
45	10.9	25.8	4			
46	3.3	9.4	3			
47	4.5	9.1	3			

LITERATURE

(For a key to the periodicals see end of volume)

(1) Baillie and Wilson, *54*, **41**: 45T; 22. (2) von Bichowsky, *38*, **3**: 296; 20. (3) Cauwood, Clarke, Muirhead and Turner, *105*, **3**: 228; 19. (4) Cauwood, English and Turner, *105*, **1**: 153; 17. (5) Cauwood and Turner, *105*, **1**: 144; 17. (6) Cauwood and Turner, *105*, **2**: 32; 18. (7) Cauwood and Turner, *105*, **2**: 219; 18. (8) Cauwood and Turner, *105*, **2**: 235; 18. (9) Cauwood and Turner, *105*, **2**: 260; 18.

(10) Committee Report, *Journal of the Institute of Chemistry of Great Britain and Ireland*, **3**: 202; 20. (11) Dimbleby, Muirhead and Turner, *105*, **6**: 101; 22. (12) Dimbleby and Turner, *O*. (13) Elsdon, Roberts and Jones, *105*, **3**: 52; 19. (14) Foerster, *25*, **25**: 2494; 92. (15) Foerster, *91*, **33**: 299; 94. (16) Foerster, *91*, **33**: 322; 94. (17) Foerster, *91*, **33**: 381; 94. (18) Foerster, *243*, **13**: 457; 93 (19) Hodkin and Turner, *105*, **4**: 120; 20.

(20) Kato, *379*, **367**; 138; 23. (21) Keppeler, *Beiträge zur Metallurgie*, Goldschmidt-Festschrift (Dresden), 40; 21. (22) Keppeler, *105*, **8**: 256; 24. (23) Kohlrausch, *25*, **24**: 3560; 91. (24) Kohlrausch, *25*, **26**: 2998; 93. (25) Mauri, *216*, **5**: 495; 23. (26) Mauri, *216*, **6**: 429; 24. (27) Mauri, *216*, **7**: 452; 25. (28) Migliacci, *216*, **15**: 87; 25. (29) Muirhead and Turner, *105*, **3**: 129; 19.
(30) Mylius and Foerster, *25*, **22**: 1092; 89. (31) Mylius and Foerster, *25*, **25**: 97; 92. (32) Mylius and Foerster, *91*, **31**: 241; 92. (33) Mylius and Foerster, *243*, **9**: 117; 89. (34) Mylius and Foerster, *243*, **11**: 311; 91. (35) Mylius and Meusser, *243*, **44**: 221; 05. (36) Nicolardot, *34*, **163**: 355; 16. (37) Nicolardot, *378*, **9**: 233, 469; 23. (38) Peddle, *105*, **4**: 14, 36, 55, 67, 93, 307, 317, 327, 351; 20. (39) Peddle, *105*, **4**: 97, 352; 20.
(40) Peddle, *105*, **5**: 195; 21. (41) Peddle, *105*, **5**: 95, 209, 218, 226, 247; 21 (42) Peddle, *105*, **5**: 247, 264; 21. (43) Peddle, *85*, **23**: 103; 21. (44) Rand, *81*, **17**: 236; 15. (45) Haigh, Report R.11, *British Scientific Instrument Research Association*, 1921. (46) Schaller, *92*, **22**: 2369; 09. (47) Sheen and Turner, *38*, **8**: 187; 24. (48) Turner, *38*, **3**: 379; 20. (49) Turner, *356*, **71**: 401; 23.
(50) Turner, *38*, **7**: 313; 24. (51) Turner and Wilson, *105*, **6**: 17; 22. (52) Turner and Winks, *0*. (53) Vilbrandt, *45*, **17**: 835; 25. (54) Walker, *1*, **27**: 865; 05. (55) Walker and Smither, *45*, **9**: 1090; 17. (56) Weber, *92*, **4**: 662; 91. (57) Weber and Sauer, *25*, **25**: 70, 1814; 92. (58) Williams and Cox, *81*, **18**: 315; 16.

VITREOUS ENAMELS FOR METALS

Ralph R. Danielson and H. G. Wolfram

COMPOSITIONS

1. Molecular Compositions

Type \ Component	Na_2O	K_2O	CaO	ZnO
Jewelry (28)	0.3 –0.6	KNaO	0	0
Cast Fe (3)	0.54	0.16	0.10	0.05
Cast Fe (15)	0.70–0.74	0.06–0.11	0–0.19	0–0.2

Type \ Component	PbO	Al_2O_3	As_2O_3	Sb_2O_3
Jewelry (28)	0.4–0.7	0	0.05–0.15	0
Cast Fe (3)	0.15	0.16	F	0.075
Cast Fe (15)	0	0.12–0.15	0.6 –0.86	0–0.13

Type \ Component	B_2O_3	SiO_2	SnO_2	P_2O_5
Jewelry (28)	0–0.2	1.3 –1.8	0	0
Cast Fe (3)	0.20	1.80	0	0
Cast Fe (15)	0.68–1.14	0.64–0.77	0–0.34	0–0.43

2. Weight Per Cent

A = Jewelry enamels.
B = Single coat gray ware enamels.
C = Dry process white cover enamels for cast iron.
D = Single coat white enamel. Wet process for cast iron.
E = White cover enamels. Wet process for cast iron.
F = White cover enamels for sheet iron and steel.
G = Ground coats for sheet iron and steel.

Enamel \ Component	Quartz	Feldspar	Borax	H_3BO_3	Na_2CO_3	$NaNO_3$	K_2CO_3	KNO_3	Cryolite	CaF_2	Lit.
A	14.4			19.2		9.9		23.2			(30)
A	31.2	1.2			1.7	2.4	2.1	2.9			(8)
B		50.2	30.5		3.1	3.1			3.7	4.2	(1)
B	10.0	40.0	30.5		6.5	5.5				1.5	(6)

2. Weight Per Cent.—(*Continued*)

Enamel \ Component	Quartz	Feldspar	Borax	H_3BO_3	Na_2CO_3	$NaNO_3$	$BaCO_3$	KNO_3	Cryolite	CaF_2	Lit.
C		33.1	18.7		2.6	2.6	4.4		2.6	4.4	(26)
C		33.4	19.5	17.9		2.4			9.8		(26)
D	12.8	18.9	25.6						9.4	2.7	(24)
D		36.0	31.8		5.5	3.7	$CaCO_3$		3.2		(9)
E	10.2	32.3	20.8		3.3	5.3			4.3	4.7	(9)
F	17.0	31.0	27.0		3.5	3.5			12.0	5.0	(6)
F	22.0	31.0	21.0		3.5	3.5			17.0		(6)
G	20.5	27.0	30.0		9.8	5.0				6.0	(6)
G	21.0	26.0	34.6		7.4	4.0	2.2			3.5	(19)
G	29.0	22.0	30.0		5.0	4.6				6.0	(6)

Enamel \ Component	Bone ash	Pb_3O_4	ZnO	SnO_2	As_2O_3	Sb_2O_3	MnO_2	Ni_2O_3	Co_2O_3	Lit.
A		33.3								(30)
A		53.8			4.7					(8)
B	3.1					2.1				(1)
B	4.5					1.5				(6)
C		14.6	9.1	7.9						(26)
C			10.2	6.8						(26)
D		30.6								(24)
D		18.2				1.6				(9)
E		14.0	5.1							(9)
F						1.0				(6)
F						2.0				(6)
G							1.2		0.5	(6)
G							0.26	0.26	0.26	(19)
G							2.0	1.0	0.4	(6)

(20) Kato, *379*, **367**; 138; 23. (21) Keppeler, *Beiträge zur Metallurgie*, Goldschmidt-Festschrift (Dresden), 40; 21. (22) Keppeler, *105*, **8**: 256; 24. (23) Kohlrausch, *25*, **24**: 3560; 91. (24) Kohlrausch, *25*, **26**: 2998; 93. (25) Mauri, *216*, **5**: 495; 23. (26) Mauri, *216*, **6**: 429; 24. (27) Mauri, *216*, **7**: 452; 25. (28) Migliacci, *216*, **15**: 87; 25. (29) Muirhead and Turner, *105*, **3**: 129; 19.

(30) Mylius and Foerster, *25*, **22**: 1092; 89. (31) Mylius and Foerster, *25*, **25**: 97; 92. (32) Mylius and Foerster, *91*, **31**: 241; 92. (33) Mylius and Foerster, *243*, **9**: 117; 89. (34) Mylius and Foerster, *243*, **11**: 311; 91. (35) Mylius and Meusser, *243*, **44**: 221; 05. (36) Nicolardot, *34*, **163**: 355; 16. (37) Nicolardot, *378*, **9**: 233, 469; 23. (38) Peddle, *105*, **4**: 14, 36, 55, 67, 93, 307, 317, 327, 351; 20. (39) Peddle, *105*, **4**: 97, 352; 20.

(40) Peddle, *105*, **5**: 195; 21. (41) Peddle, *105*, **5**: 95, 209, 218, 226, 247; 21 (42) Peddle, *105*, **5**: 247, 264; 21. (43) Peddle, *85*, **23**: 103; 21. (44) Rand, *81*, **17**: 236; 15. (45) Haigh, Report R.11, *British Scientific Instrument Research Association*, 1921. (46) Schaller, *92*, **22**: 2369; 09. (47) Sheen and Turner, *38*, **8**: 187; 24. (48) Turner, *38*, **3**: 379; 20. (49) Turner, *356*, **71**: 401; 23.

(50) Turner, *38*, **7**: 313; 24. (51) Turner and Wilson, *105*, **6**: 17; 22. (52) Turner and Winks, *0*. (53) Vilbrandt, *45*, **17**: 835; 25. (54) Walker, *1*, **27**: 865; 05. (55) Walker and Smither, *45*, **9**: 1090; 17. (56) Weber, *92*, **4**: 662; 91. (57) Weber and Sauer, *25*, **25**: 70, 1814; 92. (58) Williams and Cox, *81*, **18**: 315; 16.

VITREOUS ENAMELS FOR METALS

Ralph R. Danielson and H. G. Wolfram

COMPOSITIONS

1. Molecular Compositions

Type \ Component	Na_2O	K_2O	CaO	ZnO
Jewelry (28)	0.3 –0.6	KNaO	0	0
Cast Fe (3)	0.54	0.16	0.10	0.05
Cast Fe (15)	0.70–0.74	0.06–0.11	0–0.19	0–0.2

Type \ Component	PbO	Al_2O_3	As_2O_3	Sb_2O_3
Jewelry (28)	0.4–0.7	0	0.05–0.15	0
Cast Fe (3)	0.15	0.16	F	0.075
Cast Fe (15)	0	0.12–0.15	0.6 –0.86	0–0.13

Type \ Component	B_2O_3	SiO_2	SnO_2	P_2O_5
Jewelry (28)	0–0.2	1.3 –1.8	0	0
Cast Fe (3)	0.20	1.80	0	0
Cast Fe (15)	0.68–1.14	0.64–0.77	0–0.34	0–0.43

2. Weight Per Cent

A = Jewelry enamels.
B = Single coat gray ware enamels.
C = Dry process white cover enamels for cast iron.
D = Single coat white enamel. Wet process for cast iron.
E = White cover enamels. Wet process for cast iron.
F = White cover enamels for sheet iron and steel.
G = Ground coats for sheet iron and steel.

Enamel \ Component	Quartz	Feldspar	Borax	H_3BO_3	Na_2CO_3	$NaNO_3$	K_2CO_3	KNO_3	Cryolite	CaF_2	Lit.
A	14.4			19.2		9.9		23.2			(30)
A	31.2	1.2			1.7	2.4	2.1	2.9			(8)
B		50.2	30.5		3.1	3.1			3.7	4.2	(1)
B	10.0	40.0	30.5		6.5	5.5				1.5	(6)

2. Weight Per Cent.—(*Continued*)

Enamel \ Component	Quartz	Feldspar	Borax	H_3BO_3	Na_2CO_3	$NaNO_3$	$BaCO_3$	KNO_3	Cryolite	CaF_2	Lit.
C		33.1	18.7		2.6	2.6	4.4		2.6	4.4	(26)
C		33.4	19.5	17.9		2.4			9.8		(26)
D	12.8	18.9	25.6						9.4	2.7	(24)
D		36.0	31.8		5.5	3.7	$CaCO_3$		3.2		(9)
E	10.2	32.3	20.8		3.3	5.3			4.3	4.7	(9)
F	17.0	31.0	27.0		3.5	3.5			12.0	5.0	(6)
F	22.0	31.0	21.0		3.5	3.5			17.0		(6)
G	20.5	27.0	30.0		9.8	5.0				6.0	(6)
G	21.0	26.0	34.6		7.4	4.0	2.2			3.5	(19)
G	29.0	22.0	30.0		5.0	4.6				6.0	(6)

Enamel \ Component	Bone ash	Pb_3O_4	ZnO	SnO_2	As_2O_3	Sb_2O_3	MnO_2	Ni_2O_3	Co_2O_3	Lit.
A		33.3								(30)
A		53.8			4.7					(8)
B	3.1					2.1				(1)
B	4.5					1.5				(6)
C		14.6	9.1	7.9						(26)
C			10.2	6.8						(26)
D		30.6								(24)
D		18.2				1.6				(9)
E		14.0	5.1							(9)
F						1.0				(6)
F						2.0				(6)
G							1.2		0.5	(6)
G							0.26	0.26	0.26	(19)
G							2.0	1.0	0.4	(6)

SPECIFIC GRAVITY

Ground coat for sheet steel 2.54. White cover enamel for sheet steel 2.66. High lead-tin oxide enamel for cast iron 2.93. Leadless antimony enamel for cast iron 3.32. High lead oxide enamel for jewelry 3.79 (31).

STRENGTH

Ultimate Compressive Strength (Def. 4)

Commercial ground coat for sheet steel, 95 500 lb./in.^{2}. Commercial white cover for sheet steel, 91 740 lb./in.^{2}. Cylindrical test pieces ½ in. diam. × 1 in. long (11).

Cross Bending Strength

See (12, 20).

Impact Resistance

See (11, 17, 29).

HARDNESS

See (2).

THERMAL EXPANSION OF VITREOUS ENAMELS

The coefficient of cubical expansion, $\frac{10^7 dV}{V\,dt}$, can be approximately calculated from the wt. % composition of the melted enamel and the moduli given below.

MODULI

AlF_3	Al_2O_3	As_2O_5	BaO	B_2O_3	BeO	CaO	CaF_2	CeO_2	CoO	Cr_2O_3	Cryo-lite	CuO	FeO
4.4	5.0*	2.0	3.0	0.1*	4.7	5.0* 4.9†	2.5	4.2	4.4	5.1	7.4	2.2	4.0

K_2O	MgO	MnO	NaF	Na_2O	NiO_2	PbO	Sb_2O_5	SiO_2	SnO_2	ThO_2	TiO_2	ZrO_2	ZnO
8.5*	0.1* 1.3_5†	2.2	7.4	10* 13†	4.0	4.2	3.6	0.8* 0.15†	2.0	6.3	4.1	2.1	1.8

* Values from Winkleman and Schott (32).
† Values from English and Turner (13).
All others from Mayer and Havas (18).

The calculation is illustrated in the following example and in the table of Expansion of Enamels.

Composition	Wt.		Moduli		
Silica	25.30	×	0.8	=	20.2
Alumina	7.20	×	5.0	=	36.0
Potassium oxide	6.60	×	8.5	=	56.1
Sodium oxide	8.94	×	10.0	=	89.4
Boric oxide	12.77	×	0.1	=	1.3
Barium oxide	6.21	×	3.0	=	18.6
Zinc oxide	14.00	×	1.8	=	25.2
Calcium oxide	1.68	×	5.0	=	8.4
Calcium fluoride	7.30	×	2.5	=	18.3
Antimony oxide	10.00	×	3.6	=	36.0
	100.00				309.5

The calc. cubical coefficient of expansion for this enamel is therefore 309.5 × 10^{-7} per °C.

Danielson and Souder (10) have shown, however, that values so calculated are only approximate. The following are typical:

Types of enamel	Coeff. of linear expansion × 10^6. Observed values				$\frac{10^6}{l}\frac{\Delta l}{\Delta t}$
	20° to 200°C	20° to 400°C	20° to 450°C	20° to 500°C	Calculated values
Single coat gray ware	9.8	11.6		13.4	11.0
Ground coat for sheet steel	9.4	10.3	11.5		

The determinations made by Mayer and Havas were over the range 0–100°C while those made by Danielson and Souder were carried to the softening points of the enamels, *i.e.*, about 450° to 500°C. It will be noted that the coefficient rapidly increases with increase in temperature as shown by Fig. 1 (10).

The results of these various studies indicate that the factors given by Mayer and Havas place the oxides in approximately their correct order as regards their relative effect on the expansivity of enamels and may thus serve as a valuable guide in the technical control of enamel mixtures.

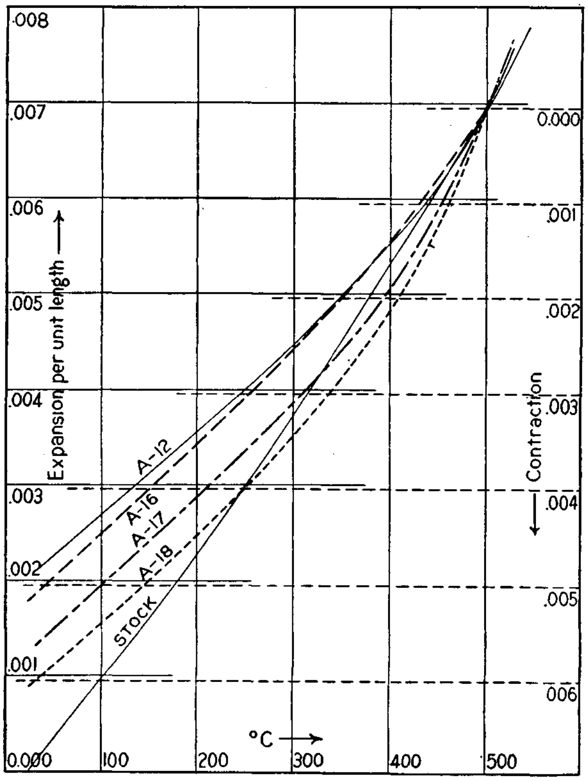

FIG. 1.—Expansion of some typical gray ware enamels and enameling steel.

From the observations of the various investigators it may generally be assumed that the average coefficients of expansion of commercial enamels and enameling metals will be within the following limits:

Type of enamel	$\frac{10^7\,dV}{V\,dt}$
Ground coat for sheet steel	260 to 320
White cover enamel for sheet steel	320 to 400
White enamel for cast iron	290 to 330
White enamel for jewelry	300 to 350
Cast iron	310
Sheet iron and steel	381 to 438

For table of expansion of various enamels *v.* p. 116.

HEAT TRANSFER BY ENAMELED METALS

Observations on a large number of commercial steel enameled units led to the following over-all coefficients of heat transfer under the conditions named (22).

Operating conditions	Over-all coefficient joule m^{-2} hr^{-1} (°C)
Steam, to cold water	1674 to 2929
Hot water, to cold water	1464
Steam, to boiling water	2929
Steam, to thick fruit product	669
Hot water, to cold water or brine	837 to 2510
Hot oil, to cold oil	271 to 586
Hot oil, to boiling water	628 to 837
Steam, to water in tubular heaters	2092 to 3347
Condensing steam to water in tubular condenser jacket	2929

Velocities of liquids over heating surfaces as affected by agitation, differences in mobility, and specific heat were involved in the above experiments.

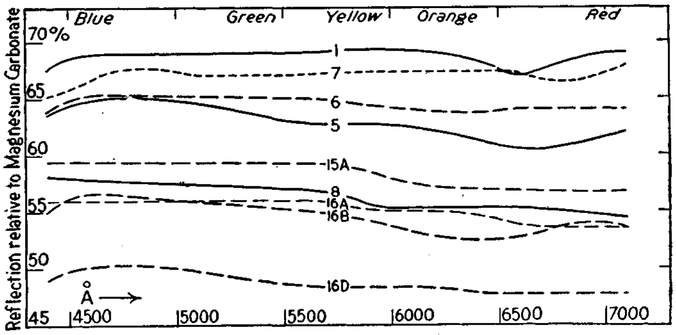

FIG. 2.—Opacifiers for enamels. No. 1. Tin oxide, 7 %. No. 7. Sodium antimonate, 11 %. No. 6. Sodium antimonate, 9 %. No. 5. Sodium antimonate, 7 %. No. 15*A*. Feldspar calcined, 9 %. No. 16*A*. Zinc aluminate calcined, 9 %. No. 8. Zinc aluminate calcined, 7 %. No. 16*B*. Zinc aluminate, 9 %. No. 16*D*. Zinc aluminate, 9 %.

The data on enameled cast-iron units are more limited. Over-all coefficients of heat transfer are given ranging from 1088 to 1464.

The thickness of the enamel coating rather than the thickness of the metal, seems to be the determining factor in the over-all coefficient.

THERMAL EMISSIVITY OF WHITE VITREOUS ENAMELED SURFACES

Very nearly the same as that of white-lead paint (4).

REFLECTIVITY OF SHEET STEEL ENAMELS

A typical white tin oxide enamel for sheet steel has an average reflectivity of 69%, relative to magnesium carbonate (7).

The same frit with other opacifying agents replacing tin oxide has reflectivities varying between 48 and 66% as shown in Figs. 2 and 3 (7).

See (27) for the effect of fineness of grinding on the opacity of enamels.

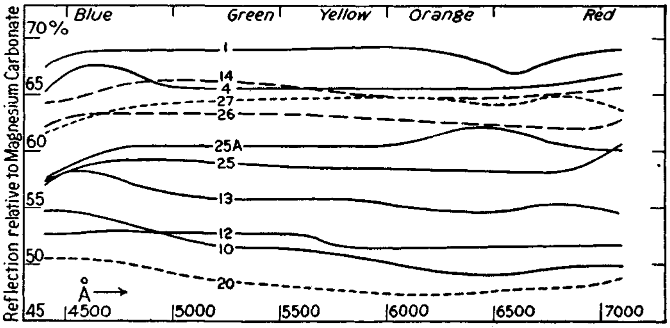

FIG. 3.—Opacifiers for enamels. No. 1. Tin oxide, 7 %. No. 4. Zirconium oxide, 7 %. No. 14. Zirconium oxide, 9 %. No. 10. Zirconium product, 7 %. No. 13. Commercial substitute, 7 %. No. 26. Zirconium silicate B, 9 %. No. 25. Zirconium silicate B, 7 %. No. 25*A*. Zirconium silicate B calcined, 7 %. No. 12. Zirconium silicate A, 7 %. No. 20. Zirconium silicate A, 11 %. No. 27. Zirconium silicate B, 11 %.

EXPANSION OF ENAMELS OF VARIOUS COMPOSITIONS (18)

Percentage composition of enamels

Type of enamel	SiO_2	B_2O_3	Cryolite		CaF_2	CoO	MnO	Al_2O_3	CaO	K_2O	Na_2O	$10^6 \frac{dV}{V\,dt}$	
			AlF_3	NaF								Obs.	Calc.
Ground coat	51.00	15.79			5.44	0.25	0.71	7.86	1.51	2.60	14.84	28.8	27.6
	64.86	9.46			3.67	0.21	0.51	6.45	1.01	1.71	12.12	24.5	23.7
	54.69	12.47			4.68	0.31	0.45	8.83	1.26	2.54	14.77	28.9	27.9
Cover	55.91	6.96	3.95	6.03	1.73			10.30	0.54	1.73	12.85	32.7	32.1
	51.00	6.80	6.29	9.62				8.85	1.77	2.28	13.39	35.8	36.1
	51.40	8.31	3.87	5.77	2.14			11.58	1.30	0.97	14.66	34.6	33.8
	48.08	8.98	6.38	9.75				9.36	0.54	1.67	15.24	37.2	37.5
Cover, with various oxides							SnO_2						
	54.81	6.82	3.87	5.91	1.70		1.96	10.10	0.53	1.70	12.60	31.8	31.8
	53.76	6.69	3.80	5.80	1.66		3.85	9.90	0.52	1.66	12.36	30.9	31.6
							TiO_2						
	54.81	6.82	3.87	5.91	1.70		1.96	10.10	0.53	1.70	12.60	32.7	32.2
	53.76	6.69	3.80	5.80	1.66		3.85	9.90	0.52	1.66	12.36	31.1	32.4
							ZrO_2						
	54.81	6.82	3.87	5.91	1.70		1.96	10.10	0.53	1.70	12.60	31.2	31.8
	53.76	6.69	3.80	5.80	1.66		3.85	9.90	0.52	1.66	12.36	30.1	31.6
Dry process	33.92	5.01	As_2O_3 5.23	PbO 44.61	ZnO 3.34			0.22	0.41	0.75	6.51	30.1	30.7

ACID RESISTANCE OF VITREOUS ENAMELS

See (**20, 16, 21, 5, 23, 14, 11, 29**) for sheet steel enamels and (**25**) for cast iron enamels.

LITERATURE

(For a key to the periodicals see end of volume)

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STRUCTURAL CEMENTS, LIMES AND PLASTERS

P. H. BATES AND W. E. EMLEY

HYDRAULIC CEMENTS

P. H. BATES

Hydraulic cements have the property of hardening under water and are usually made by burning argillaceous limestones or mixtures of argillaceous and calcareous materials. They include: portland, rosendale, natural, grappier, Eisenportland, Erzportland, Hochofen, trass, tufa, pozzuolana, etc., and hydraulic limes.

The definition and classification of cements is largely a matter of usage, which varies from nation to nation. In the U. S. there is a well-recognized standard for portland cement alone (A. S. T. M., C9–21).

A very infrequently used standard for natural cement differentiates this from portland cement only by its not requiring grinding before calcination, and giving different numerical values for the other properties (A. S. T. M., C10–09).

Rosendale, grappier, and hydraulic limes are natural cements in that the raw material is not ground before calcination. The other classes of cement mentioned above are mixtures of portland cement with various amounts of different slags of natural or of artificial origin. Their use is not very extensive and in general is confined to a few countries.

In France one standard covers the several varieties of hydraulic limes and cements (3).

"Hydraulic limes and cements will be called quick-, medium-, slow-, or extremely slow-setting according as their time of initial set is less than 5 min, 5 to 30 min, 30 min to 6 hr or more than 6 hr respectively.

"Until the time when compression test results can be generalized, the classification by strength shall be made as follows according to minimum strength in tension at 7 and 28 days."

Designation (package to show this designation)	Minimum tensile strength			
	kg cm^{-2}		lb. in.$^{-2}$	
	7 da	28 da	7 da	28 da
1/3 kg	1	3	14.2	42.6
3/5 kg	3	5	42.6	71.0
6/10 kg	6	10	85.0	142.0
10/15 kg	10	15	142.0	213.0
15/20 kg	15	20	213.0	284.0
20/25 kg	20	25	284.0	355.0

The chemical composition of all cements, even of the same class, varies widely. The following table, taken from the file of the U. S. Bureau of Standards, gives the composition of some portland cements of the U. S., wt. %:

SiO_2.....	22.25	25.02	20.75	22.66	20.37	23.40	19.03	19.82	20.80
Al_2O_3....	6.63	6.08	7.79	5.58	3.64	6.97	8.75	7.62	6.94
Fe_2O_3....	2.26	.49	2.40	4.51	8.97	2.68	4.75	2.10	3.84
CaO.....	63.84	62.89	60.48	62.22	61.42	60.87	62.81	62.04	64.12
MgO.....	2.41	1.11	3.28	.62	.82	1.13	1.33	3.90	1.02
SO_3......	1.07	1.75	1.76	1.05	1.19	1.41	1.37	1.43	1.30
Na_2O....	.21		.16	.17	1.54		.07	.24	
K_2O.....	.32		.80	.19	.24		.16	.26	
Ig. loss...	1.14	2.03	2.76	2.86	2.07	2.78	1.56	2.72	1.26

In the following table are given the analyses of some other cements:

	Natural cements(10)			Hydraulic lime (3)	Erzportland(10)	Slag (CaS, 2.7 %) (10)	White (10)
SiO_2.......	20.85	24.07	23.81	22.89	20.37	30.19	22.66
Al_2O_3......	6.04	11.69	8.01	2.15	3.64	11.08	8.61
Fe_2O_3......	1.40	.35	4.18		8.97	1.64	.55
CaO.......	34.83	47.08	32.00	64.85	61.42	46.16	62.46
MgO......	22.25	1.51	18.45	1.47	.82	2.17	1.10
Na_2O......	.14	.25	.26		1.54	.29	.40
K_2O.......	1.60	.91	.44		.24	.64	.53
SO_3........	2.11	.10	2.53	.61	1.19	1.10	1.64
Ig. loss.....	11.12	1.79	8.26	8.03	2.07	4.00	2.06

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Fe_2O_3....	2.26	.49	2.40	4.51	8.97	2.68	4.75	2.10	3.84
CaO.....	63.84	62.89	60.48	62.22	61.42	60.87	62.81	62.04	64.12
MgO.....	2.41	1.11	3.28	.62	.82	1.13	1.33	3.90	1.02
SO_3......	1.07	1.75	1.76	1.05	1.19	1.41	1.37	1.43	1.30
Na_2O....	.21		.16	.17	1.54		.07	.24	
K_2O.....	.32		.80	.19	.24		.16	.26	
Ig. loss...	1.14	2.03	2.76	2.86	2.07	2.78	1.56	2.72	1.26

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Fe_2O_3......	1.40	.35	4.18		8.97	1.64	.55
CaO.......	34.83	47.08	32.00	64.85	61.42	46.16	62.46
MgO......	22.25	1.51	18.45	1.47	.82	2.17	1.10
Na_2O......	.14	.25	.26		1.54	.29	.40
K_2O.......	1.60	.91	.44		.24	.64	.53
SO_3........	2.11	.10	2.53	.61	1.19	1.10	1.64
Ig. loss.....	11.12	1.79	8.26	8.03	2.07	4.00	2.06

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Portland cement is a heterogeneous mixture of several compounds of silica, alumina and lime (being mostly $3CaO.SiO_2$,

$2CaO.SiO_2$, $3CaO.Al_2O_3$, glass and uncombined lime), produced by heating to incipient fusion finely ground mixtures of limestone, marl, or other calcareous compounds with certain argillaceous materials as clay, shale, slag, etc. The cement contains, in addition to the above, compounds or solid solutions of iron, magnesium, sodium, potassium, titanium, etc. The compounds present do not occur in fixed or definite quantities and as a consequence the properties of portland cement vary widely. Furthermore, as it is not stable towards water, moisture, or carbon dioxide in the presence of moisture, its properties are constantly changing (²).

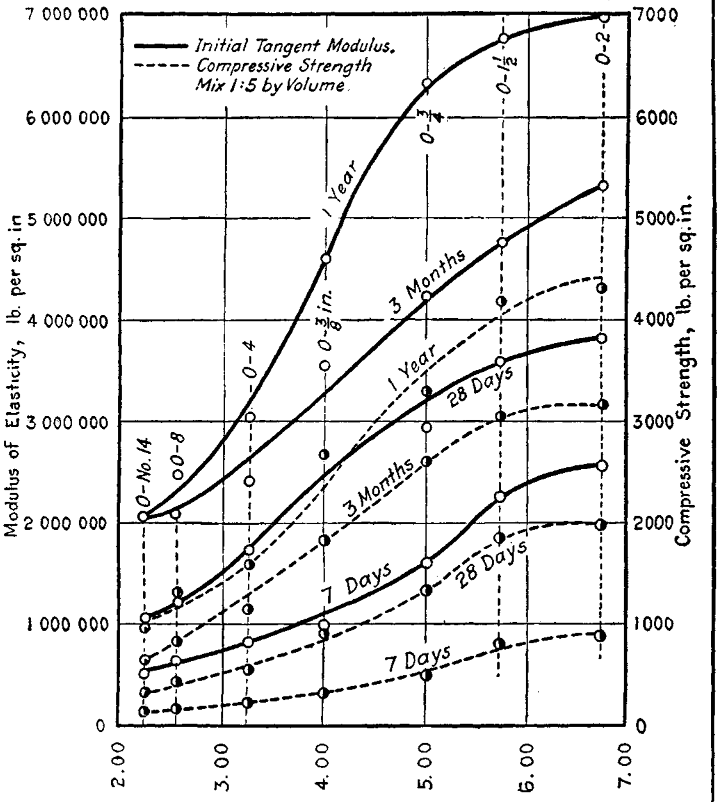

Fig. 1.—Effect of size of aggregate on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Sand and pebble aggregate. Relative consistency 1.10. Each value is the average of 24 tests from 6 times of mixing.

On mixing portland cement with water certain hydration reactions take place. The character and degree of these reactions depend upon the amount of water used and the presence of dissolved salts. The character and the degree of the reaction determine also the physical properties of the resulting material.

In view of the lack of the use of cement in the neat form (cement and water without the presence of any aggregate, either fine or coarse) no data will be presented referring to the properties when so used. All data will refer to concrete—large particles bonded with cement, or mortar—fine particles, all passing the ⅜ inch sieve, bonded with cement.

Strength of Concrete

The following equations have been suggested for calculating the compressive strength (Def. 4). Feret (²²) states that if values of the expression

$$\left(\frac{V_c}{1 - V_s - V_A}\right)^2$$

[where V_c = absolute volume of cement in unit volume of mortar,

V_s = abs. vol. of sand in unit vol. of mortar,

and V_A = abs. vol. of large aggregate in unit vol. of mortar] be graphed against the compressive strength (Def. 4) of any concrete made of any aggregate of the same consistency, aged under the same condition and for the same period, the points so obtained will lie close to a straight line passing through the origin.

According to Abrams (¹) the compressive strength, S, is expressed by the equation $S = A/B^x$

where x = the $\frac{\text{water}}{\text{cement}}$ vol. ratio in the mixture, and A and B are constants depending upon the quality of cement, age of concrete, curing conditions, etc.

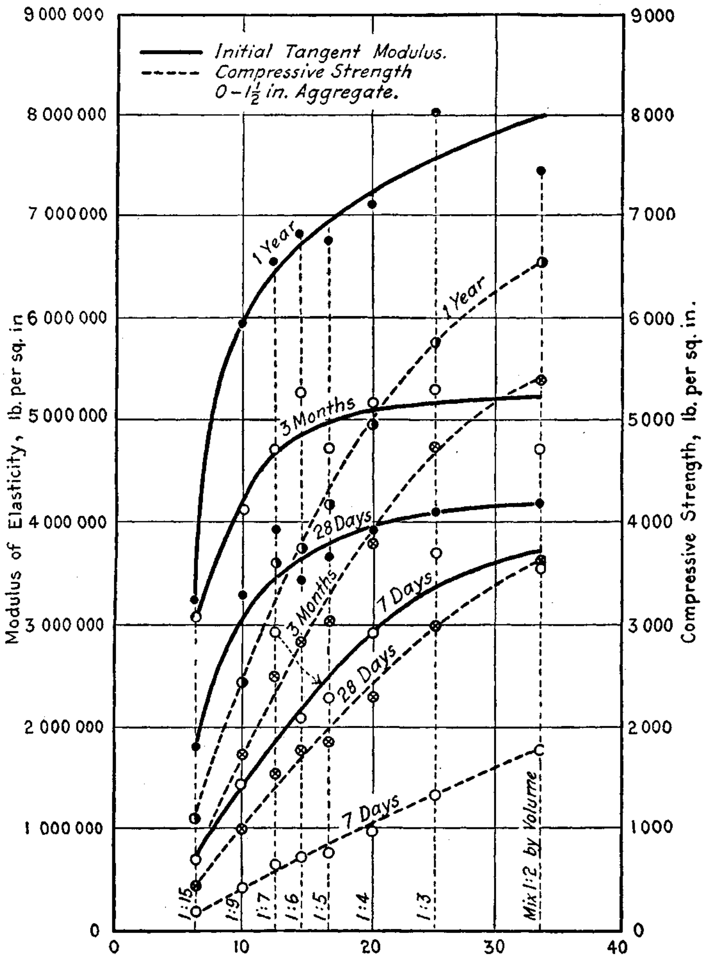

Fig. 2.—Effect of amount of cement on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Sand and pebble aggregate; graded 0-1½ in. Relative consistency 1.10. Each value is the average of 24 tests from 6 times of mixing.

Talbot (⁴⁰) finds $S = 32\ 000 \left(\frac{C}{V + C}\right)^{2.5}$ lb./in.²,

where C = vol. of cement in unit vol. mixture

and V = voids (air and water) in unit vol. mixture, when the "basic water" content is used. The "basic water" content is the amount of water per unit volume of the mortar that gives the minimum voids. The relation between strength and relative water content is not a straight line function. The strength of the concrete having a water content of 1.5 times that of the basic content would be reduced about one-third.

Modulus of Elasticity

Walker (42) gives $E = CS^m$
where E = modulus of elasticity,
C and m = constants depending upon the conditions of test,
and S = the compressive strength.

"Four different measures of modulus of elasticity of concrete are in more or less common use, as follows:

E_i = the initial tangent modulus;
E_t = tangent modulus at some load;
E_s = secant modulus at some load;
E_d = load modulus between two loads.

The initial tangent modulus for usual concrete mixtures may be represented by the equation $E_i = 33\ 000\ S^{5/8}$. For the tangent modulus at 25% of the compressive strength the equation becomes $E_t = 66\ 000\ S^{1/2}$."

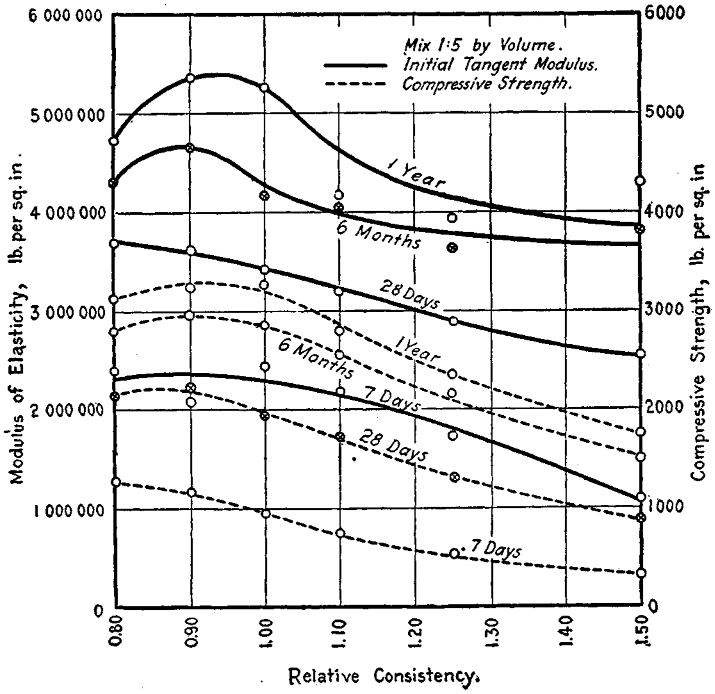

FIG. 3.—Effect of consistency of concrete on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Each value is the average of 15 tests from 3 sizes of sand and pebble aggregate.

Figures 1–4 illustrate the effect of the several variables mentioned above on the initial tangent modulus. In these graphs certain of the terms used have the same significance as indicated in the tables under "Strengths."

Poisson's Ratio (Def. 9)

Recorded values range from 0.08 to 0.18 (27, 39, 50).

Bulk Density

Varies from 0.68 to 0.90, according to grading and size of particles and is not affected by aging or slight changes in mixing temperature.

Thermal Expansion

Norton (34) found the following values for a "1:2:5 stone concrete." The concrete was permanently deformed by the heat treatment and did not return to its original length. The length on cooling was 75% of the maximum length obtained during heating.

Temperature range	$\frac{10^6 \Delta l}{l\, \Delta t}$
72°– 360°F	4.5 to 6.0
72°– 750°F	5.0 to 6.0
72°–1190°F	4.0 to 5.0
72°–1600°F	3.5 to 4.2

SPECIFIC HEAT (34)

Temperature range	g-cal g^{-1} deg.$^{-1}$C		
	1:2:5 stone	1:2:4 stone	1:2:4 cinder
72°– 312°F	0.156	0.154	
72°– 372°F	.192	.190	0.180
72°–1172°F	.201	.210	.206
72°–1472°F	.219	.214	.218

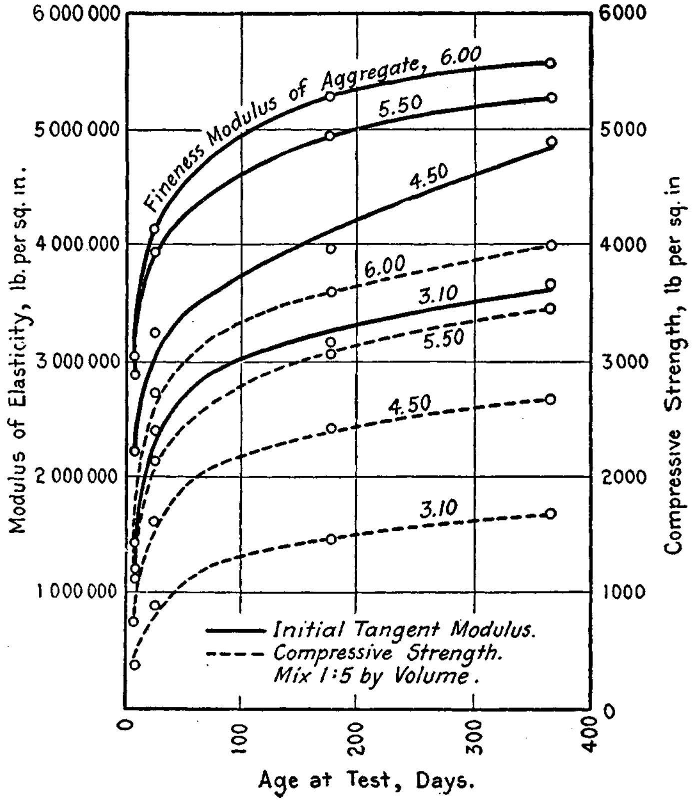

FIG. 4.—Effect of age of concrete on modulus of elasticity. Compression tests of 6 by 12-in. cylinders. Mix 1:5 by volume. Each value is the average of 30 to 35 tests from 6 or 7 consistencies.

Thermal Conductivity

1 g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$ = 1.24 BTU ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$

Upper temp., °C	Norton (34) Mix	k g-cal unit
35	stone 1-2-5*	0.00216
50	stone 1-2-4*	0.00113
50	cinder 1-2-4	0.00081
200	stone 1-2-4	0.0021
400	stone 1-2-4	0.0022
500	stone 1-2-4	0.0023
1000	stone 1-2-4	0.0027
1100	stone 1-2-4	0.0029

* Not tamped.

Mixture by volumes		50°C to 100°C 120°F to 212°F	100°C to 200°C 212°F to 390°F	200°C to 300°C 390°F to 570°F
Cement: aggregate	Cement: sand: gravel	g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$		
		k	k	k
"Neat"		0.00140	0.00163	0.00140
1–2	1–1.2–1.1	0.00326	0.00344	0.00318
1–3	1–1.9–1.7	0.00335	0.00379	0.00318
1–4	1–2.4–2.3	0.00413	0.00352	0.00328
1–5	1–3.1–3.0	0.00327	0.00323	0.00334
1–7	1–4.3–4.0	0.00400	0.00384	Carman and
1–9	1–5.6–5.1	0.00574	0.00352	Nelson (11)

Variation with Relative Water Content

Mixture	Relative water content, %	k 50°C to 100°C	 100°C to 200°C	 200°C to 300°C
1:2	100	0.00365	0.00322	0.00320
	110	0.00300	0.00332	0.00310
	120		0.00317	
1:3	100	0.00347	0.00365	0.00340
	110	0.00343	0.00391	
	120	0.00353	0.00345	0.00310
1:4	100		0.00357	
	110	0.00415	0.00373	0.00322
	120	0.00410	0.00316	
1:5	100		0.00353	
	110	0.00381	0.00380	0.00380
	120	0.00273	0.00305	0.00270
1:7	110	0.00402	0.00387	
	120		0.00300	
1:9	110	0.00573	0.00359	Carman and
	120		0.00273	Nelson (11)

Effect of Age (11)

Mixture	Relative water content %	Age days	k	Mixture	Relative water content %	Age days	k
1:2	110	28	0.00335	1:5	120	28	0.00330
		120	331			120	297
1:3	110	28	398	1:7	110	28	380
		120	365			120	380
1:4	110	28	376	1:9	110	28	340
		120	337			120	387

For additional data, *see* p. 122.

Thermal Diffusivity (11)

Diffusivity of Concrete, 100°–200°C

Relative water content, 110%

Mixture	Density g cm^{-3}	k	Specific heat cal g^{-1} °C^{-1}	Diffusivity cm^2 sec^{-1}
"Neat"	1.83	0.00147	0.278	0.00289
1–2	2.26	0.00344	0.216	0.00705
1–3	2.28	0.00379	0.218	0.00762
1–4	2.29	0.00352	0.218	0.00705
1–5	2.29	0.00323	0.217	0.00650
1–7	2.23	0.00384	0.227	0.00758
1–9	2.16	0.00352	0.223	0.00732

Setting Time

In the U. S., the standards of the Govt. and Amer. Eng. Stands. Com. require an initial set in not less than 1 hour, and a final set within 10 hours, as determined by a purely empirical test. In other countries cements may be made to meet various specification requirements as to setting (*cf.* p. 117). No method of measuring the set of mortars or concretes has been developed.

Time Rate of Change of Volume

These data have been obtained by linear measurements alone, and are as usual faulty, owing to lack of data that would accurately delimit the concrete under investigation. The change is among other variables a function of the size of specimen, amount of water used, and the humidity of the surrounding atmosphere. The values given indicate a contraction ranging from 0.018 to 0.08% for "reinforced concrete" (33).

Resistance to Weathering and Chemical Action

Mortars and concretes are attacked by acid. If dense and carbonated on the exterior they offer great resistance to weather and other chemical agents.

Tests of Portland Cement

Used in obtaining the data given in Tables 2, 3, 4, and 5.

The cement used in all tests consisted of a mixture of equal parts of four brands purchased in Chicago and gave satisfactory soundness tests (over boiling water).

Tests were made in accordance with the *Standard Specifications and Tests for Portland Cement*, A. S. T. M.

Miscellaneous tests

Fineness. Residue on No. 200 Tyler Sieve %	Normal consistency wt. %	Time of setting							
		Vicat needle				Gillmore needle			
		Initial		Final		Initial		Final	
		hr	min	hr	min	hr	min	hr	min
18.8	24.0	3	40	8	20	5	45	9	40
17.6	23.0	3	45	8	00	6	30	8	30

Mortar strength tests

1:3 Standard Sand Mortar.

Mixing water %	Tensile strength (Def. 4) of briquets, lb./in.^{2}					Compressive strength (Def. 4) 2 × 4 in. cylinders, lb./in.^{2}				
	7 da	28 da	3 mo	6 mo	1 yr	7 da	28 da	3 mo	6 mo	1 yr
10.5	235	365	425	380	405	1670	2570	3520	4250	3840
10.3	280	430	410	385	355	1720	2870	3710	4150	4370

Table 2.—Effect of Curing Condition of Concrete

Mix, 1:4 by volume. Relative consistency of concrete, 1.10; water-ratio, 0.82. Age at test, 28 days.

Aggregate: sand from Janesville, Wis., and pebbles from Elgin, Ill.; graded up to 1½ in. Each value is the average of 5 tests made on different days.

Ref. No.*	Days storage		Modulus of rupture of beams, lb./in.^{2}	Compressive strength of 6 × 12 in. cylinders, lb./in.^{2}	Modulus of rupture % compression
	Damp burlap	Dry air			
7, 8	28	0	550†	2580†	21.3
42	26	2	510	2630	19.4
43	21	7	450	2850	15.8
44	14	14	485	2920	16.6
45	7	21	470	3020	15.6
46	4	24	410	2330	17.6
47	0	28	370	2340	15.8
			Average 465	2670	17.5

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* See Table 1 for Ref. Nos.

† Average of 25 beam tests and 115 cylinder tests.

TABLE 1.—SIEVE ANALYSIS AND UNIT WEIGHT OF AGGREGATES

Used in obtaining the data given in Tables 2, 3, 4, and 5.

Square mesh wire cloth sieves, Tyler Series (*v.* p. 329), were used in making sieve analyses. Each sieve has a clear opening twice the width of the preceding one.

Ref. No.	Aggregate		Sieve analysis									Fineness modulus of aggregate*	Unit weight, lb./ft.^{3}
	Kind	Size / No.	Wt. % retained on each sieve										
			100	50	30	16	8	4	$\frac{3}{8}$	$\frac{3}{4}$	1½		
36	Janesville sand	0–No. 16	97	78	20	0						1.95	108
37		0–No. 8	98	80	28	11	0					2.17	111
38		0–No. 4	98	82	35	19	9	2	0			2.45	113
39	Janesville sand and Elgin pebbles	0–0.375 in.	99	90	63	54	49	45	0			4.00	123
40		0–0.75 in.	99	93	75	69	64	61	39	0		5.00	128
1–28, 41		0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	130
29		0–1.5 in.	98	84	43	30	20	14	8	3	0	3.00	118
30		0–1.5 in.	99	88	57	46	41	35	25	9	0	4.00	127
31		0–1.5 in.	99	90	64	56	51	46	33	11	0	4.50	131
32		0–1.5 in.	99	92	71	65	61	57	41	14	0	5.00	132
33		0–1.5 in.	99	93	75	70	66	62	45	15	0	5.25	133
34		0–1.5 in.	100	96	86	83	80	78	58	19	0	6.00	127
35		0–1.5 in.	100	97	89	86	85	84	63	21	0	6.25	124
42–53 59–64	Janesville sand and Elgin pebbles	0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	130
54	Janesville sand and crushed slag	0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	118
55	Janesville sand and crushed limestone	0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	129
56	Janesville sand and crushed granite	0–1.5 in.	99	95	80	76	74	71	52	18	0	5.65	121
57	Washed Elgin sand and Elgin pebbles	0–1.5 in.	99	95	86	80	72	67	49	17	0	5.65	127
58	Unwashed Elgin sand and Elgin pebbles	0–1.5 in.	100	98	91	86	81	73	50	18	0	5.97	130

* Sum of per cents in sieve analysis, divided by 100.

TABLE 3.—EFFECT OF QUANTITY OF CEMENT AND MIXING WATER

Aggregate: sand from Janesville, Wis., and pebbles from Elgin, Ill.; graded up to 1½ in. Fineness modulus, 5.65. Age at test, 28 da. Specimens tested damp. Each value for modulus of rupture is the average of 10 tests, and for compressive strength 20 tests, made on 10 different days.

Ref. No.	Mix by volume	Cement vol. % of concrete	Relative consistency	Water-ratio of concrete	Modulus of rupture of beams, lb./in.^{2} (7 in. deep, 10 in. wide, 38 in. long)			Compressive strength of 6 × 12 in. cylinders, lb./in.^{2}	Modulus of rupture, % compression
					Bottom*	Top*	Aver.		
Effect of quantity of cement									
1, 2	1:6	16.4	1.10	1.03	430	420	425	1820	23.4
3, 4	1:5	19.0	1.10	0.92	500	490	495	2140	23.1
5, 6	1:4.5	20.7	1.10	0.87	480	510	495	2130	23.2
7, 8	1:4	23.0	1.10	0.82	560	540	550†	2580†	21.3
9, 10	1:3.5	25.4	1.10	0.76	590	540	565	2980	19.0
11, 12	1:3	28.7	1.10	0.71	600	590	595	3480	17.1
13, 14	1:2.5	33.0	1.10	0.64	590	590	590	4110	14.3
15, 16	1:2	38.7	1.10	0.59	660	620	640	4390	14.6
				Average	550	540	545	2950	19.5
Effect of quantity of mixing water									
17, 18	1:4	23.8	0.90	0.68	590	560	575	3760	15.3
19, 20	1:4	23.5	0.95	0.72	580	600	590	3280	18.0
21, 22	1:4	23.4	1.00	0.75	580	560	570	3100	18.4
23, 24	1:4	23.2	1.05	0.78	570	550	560	2720	20.6
7, 8	1:4	23.0	1.10	0.82	560	540	550†	2580†	21.3
25, 26	1:4	22.5	1.25	0.92	460	540	500	1920	26.0
27, 28	1:4	22.3	1.50	1.08	400	500	450	1300	34.6
				Average	535	550	540	2660	22.0

* Part of concrete beam (as molded) which was exposed to tensile stress during loading.

† Average of 25 beam tests and 115 cylinder tests.

Table 4.—Effect of Size and Grading of Aggregate

Aggregates: sand from Janesville, Wis., and pebbles from Elgin, Ill. Aggregates of different size were obtained by separating sand and pebbles into various sizes and recombining as shown by sieve analyses in Table 2. Different gradings of aggregates were produced by mixing sand (0 to No. 4) and pebbles (No. 4 to 1½ in.) in different proportions.

Mix, 1:5 volume. Relative consistency, 1.10. Specimens tested damp. Each value is the average of 5 tests made on different days.

Ref. No.	Aggregate		Water-ratio of concrete	Modulus of rupture of beams, lb./in.²				Compressive strength 6 × 12 in. cylinder, lb./in.²				Modulus of rupture % compression			
	Size	Fineness Modulus		7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr
				Effect of size of aggregate											
36	0–16	1.95	1.29	95	160	255	340	270	620	1190	1600	35.2	25.8	21.5	21.2
37	0–8	2.17	1.25	95	195	320	370	360	850	1470	1860	26.4	23.0	21.8	19.9
38	0–4	2.45	1.20	125	250	370	425	430	1010	1620	2100	29.4	24.8	22.8	20.2
39	0–0.375	4.00	0.98	290	455	595	640	1040	2110	2930	4490	27.9	21.6	20.3	14.3
40	0–0.75	5.00	0.87	365	560	730	775	1290	2650	3650	4890	28.3	21.2	20.0	15.9
41	0–1.5	5.65	0.82	420	550*	810	880	1410	2580*	3590	5000	29.8	21.3	22.6	17.6
			Average...	230	360	510	570	800	1640	2410	3320	29.5	22.9	21.5	18.2
				Effect of grading of aggregate											
29	0–1.5	3.00	1.11	165	255	410	450	620	1290	1640	2330	26.6	19.8	25.0	19.3
30	0–1.5	4.00	0.98	230	390	505	570	950	2000	2550	3230	24.2	19.5	19.8	17.7
31	0–1.5	4.50	0.93	285	485	610	645	1090	2190	2750	3830	26.2	22.2	22.2	16.9
32	0–1.5	5.00	0.87	325	505	660	710	1160	2410	3580	4510	28.0	21.0	18.4	15.8
33	0–1.5	5.25	0.85	365	555	735	820	1320	2940	3810	5340	27.7	18.9	19.3	15.4
41	0–1.5	5.65	0.82	420	550*	810	880	1410	2580*	3590	5000	29.8	21.3	22.6	17.6
34	0–1.5	6.00	0.78	405	600	735	825	1300	2250	3310	4400	31.2	26.7	22.2	18.8
35	0–1.5	6.25	0.77	385	590	730	865	1140	1990	2840	4080	33.8	29.6	25.7	21.2
			Average...	320	490	650	720	1120	2210	3010	4090	28.4	22.4	21.9	17.8

* Average of 25 beam tests and 115 cylinder tests.

Table 5.—Effect of Kind of Aggregate

Mix, 1:4 by volume. Relative consistency, 1.10; water-ratio, 0.82.

Aggregate: sand, 0 to No. 4; and coarse aggregate, No. 4 to 1½ in.; all of same grading. Specimens tested damp. Age at test, 28 days. Each value is the average of 5 tests made on different days.

Ref. No.	Kind of aggregate		Modulus of rupture of beams, lb./in.²				Compressive strength 6 by 12 in. cylinder, lb./in.²				Modulus of rupture % compression			
	Sand	Coarse	7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr	7 da	28 da	3 mo	1 yr
7, 8	Janesville........	Elgin pebbles.....	420	550*	810	880	1410	2580*	3590	5000	29.8	21.3	22.6	17.6
54	Janesville........	Slag.............	450	585	765	760	1240	2300	3150	4530	36.3	25.4	24.3	16.8
55	Janesville........	Limestone........	440	595	790	830	1320	2350	3280	3970	33.4	25.3	24.1	20.9
56	Janesville........	Granite..........	375	540	665	725	1010	1980	2960	3760	37.1	27.3	22.4	19.3
57	Elgin washed.....	Elgin pebbles.....	405	595			1490	2640			27.2	22.5		
58	Elgin unwashed...	Elgin pebbles.....	425	610			1340	2520			31.7	24.2		
		Average........	420	580	760	800	1300	2390	3240	4320	32.6	24.3	23.4	18.8

* Average of 25 beam tests and 115 cylinder tests.

GYPSUM

(Plaster-of-Paris)

W. E. Emley

Raw Materials and Calcination.—Commercial gypsum should contain $\nless$ 64.5% $CaSO_4.2H_2O$ (A. S. T. M., C22–23T; C23–22). On calcination below 163°C, $CaSO_4.2H_2O$ (gypsum) = $CaSO_4.\frac{1}{2}H_2O + 1\frac{1}{2}H_2O$. Gentle calcination above 163°C, $CaSO_4.\frac{1}{2}H_2O$ = $CaSO_4$ (soluble anhydrite) $+ \frac{1}{2}H_2O$. At higher temperatures $CaSO_4$ (soluble anhydrite) = $CaSO_4$ (natural anhydrite (insol.)) ([29], [44]). For *dissociation pressures*, consult this item in the index of I. C. T. Commercial calcination and product *v.* ([8], [21], [38]).

Properties.—The properties of products made from calcined gypsum are dependent upon the nature of the calcined gypsum (purity, method of calcination, and fineness), upon the quantity of water used in placing it, and upon the kind and amount of other materials (accelerators, retarders, lime, clay, sand) added to it. These facts must be constantly borne in mind when interpreting the figures given below.

Setting Time.—A normal figure is 6 min for no impression by Vicat needle ([24]) (A. S. T. M., C26–33). Doubling the amount of water will give 29 min ([24]). Fine grinding after calcination may lower to 3 min ([49]). The setting reaction is not complete when the Vicat needle indicates that the material is set. Evolution of heat continues and the temp. continues to rise for many min ([18]). If the calcined gypsum is of such a nature that a max. temp. rise of 14°C is attained in 53 min this time can be decreased to 21 min (by 2% sodium chloride) or increased to more than 240 min (by 2% calcium acetate) ([43]).

The commercial accelerator generally recommended is finely ground raw or set gypsum. The accelerating effect of this material is so powerful that especial care must be taken to clean all vessels and tools before mixing a fresh batch of material. 0.5 to 0.6% of this material will decrease the time of set of gypsum plaster about 1 hr (48). Other soluble sulfates, such as are generally found in our water supplies, have similar effects.

Commercial retarder is a mixture made by cooking together soda, lime, and slaughter house refuse; 0.2% of this material will retard the time of set 2.5 to 3 hr (43). Carpenters' glue has a similar effect and is more readily obtainable.

Expansion on Setting.—Calcined gypsum will normally expand when it sets. Heavily retarded material may contract due to settling out of the solid. Calcined gypsum retarded to set in 2 hr and mixed with 35% water expanded 0.15% in length while setting. Increasing the water to 47% increased the expansion to 0.30%. Addition of sand seemed to have little effect.

After the gypsum has set and dried, wetting will cause expansion, drying, contraction. The magnitude of the movement is about 0.04% for the pure material. Addition of sand reduces this expansion, the reduction being proportional to the amount of sand, so that a specimen made of one part calcined gypsum to a little more than two parts of sand shows practically no movement, and leaner mixtures actually contract instead of expanding on being wetted (35).

Strength.—Calcined gypsum, if pure, properly calcined, of such fineness that it will all react, mixed with as little water as possible to bring it to a pouring consistency, molded in the form of a cylinder 2 in. diameter by 4 in. high, not retarded to such an extent that much water can evaporate prior to setting, and stored in a cool place until dry, will develop a compressive strength of at least 1000 lb./in.^{2} (A. S. T. M. C23–22); av. 1665, max. 2285 (21).

Naturally occurring impurities or added materials (except accelerators) will decrease the strength. The average figure for the compressive strength of a mixture of one part calcined gypsum to two parts sand by weight may be taken at 415 lb./in.^{2} (21); for a 1:3 mixture the figure is 335. Lime and clay reduce the strength at early ages, but this is gradually recovered (36). Portland cement reduces the strength in proportion to the cement added until the mixture reaches a minimum at 20% gypsum 80% cement, the strength of which is little more than half that of calcined gypsum (35).

Increased fineness up to 80% through a No. 100 U. S. Stand. sieve (*v.* p. 329), by making the calcined gypsum more reactive, causes increased strength. This size is 50% stronger than material only 40% of which passes a No. 100 sieve. Further increase in fineness is accompanied by a decrease in strength because more water is required to bring the mixture to a workable consistency (45).

The above figures are based on the max. consistency thickness which will allow pouring. Thicker consistencies will give greater strength, clear to the limit of workability of the mixture (9). Thinner consistencies will give lower strengths to zero, for calcined gypsum will not harden under water.

While there is a tendency for accelerators to increase the strength of calcined gypsum and for retarders to reduce it, the action of neither is marked unless retarder is present in sufficient amount to delay the set until the water required for setting has evaporated. Two per cent calcium acetate, for example, will retard calcined gypsum so far as to destroy completely its strength (43).

Castings made of calcined gypsum are strongest when completely dry. Moisture, or more particularly percolating water, seems to dissolve the bond between the crystals, resulting in permanent loss of strength or eventual disintegration. On account of the comparatively high dissociation pressure of gypsum at ordinary temperatures (100 mm Hg at 62°C) (41), it is dangerous to resort to artificial drying. The strength reaches very nearly its maximum as soon as the casting is dry, so that the age of a test specimen is of little importance (A. S. T. M. C26–23).

The ratio compressive strength/tensile strength = *ca.* 4.62 (21).

Thermal Conductivity and Fire Resistance.—(25). (*See also* p. 315.)

Heat of Dehydration.—*See* I. C. T. Section on Thermochemistry.

Porosity, Solubility and Weather Resistance.—Calcined gypsum will not harden under water. When hardened in air and immersed in running water, castings made of calcined gypsum will eventually disintegrate. Calcined gypsum should not be used in situations where it will be exposed to the weather unless special precautions are taken.

These characteristics are usually attributed to the fact that gypsum is "quite soluble," but it is now believed that they are dependent more upon porosity than solubility.

The solubility of gypsum in pure water varies from 0.18% at 0°C to a maximum of 0.21% at 40°C, but it is much more soluble in water containing certain common salts (23). Taking the weight of set gypsum at 77 lb./ft.^{3} (32) and the specific gravity of the solid material at 2.35, the pores must occupy 47.5% of the total volume. (This figure may vary within wide limits, depending upon the fineness of the calcined gypsum and the quantity of mixing water used.) Owing to the crystalline nature of the material, these pores are comparatively large and afford passages for circulation of water, thereby rendering material assistance in the solution of the gypsum.

It has been found that if calcined gypsum is heavily retarded so that it can be trowelled frequently while setting, the dense surface thus produced is quite effective in improving the weather resistance of the finished product (46).

LIME MORTAR AND MASONRY

W. E. Emley

Commercial limes and mortars are made by mixing properly calcined limestone with water, or water and sand. Their properties depend on many variables, lack of control of which render most of the published quantitative data valueless. For the available qualitative information, reference should be made to the literature cited.

Raw Materials

Nature of Raw Materials, Commercial Definitions and Specifications (12).—(A. S. T. M. C51–22T; C5–22T).

Density.—*v.* p. 53.

Porosity.—Limestone usually less than 1 vol. % (*v.* p. 53).

Dissociation Pressure and Rate of Dissociation.—The dissociation pressure reaches 1 atm at 898°C for $CaCO_3$ and 756.5°C for $MgCO_3$. For further data, *v.* "Dissociation pressure" in the index of I. C. T. Commercial calcination is *ca.* 6 hr at *ca.* 1400°C (6, 15).

Other Properties.—*See* the pure materials in the various tables of I. C. T. *See also* p. 47.

Hydrated Lime and Lime Putty

Manufacture.—When CaO is properly mixed with an excess of water sufficient to keep the temp. below 100°C "lime putty" is obtained. With less excess, the resultant product is dry "hydrated lime." With still less water, the temperature may rise above 375°C and an "oxyhydrate" is obtained (17, 26).

"Plasticity."—(20, 25, 26, 28).

Lime Mortars

Decrease in Volume on "Setting."—From 9% for non-plastic to 27% for plastic lime putty (28). This contraction is in practice reduced to *ca.* 5% by admixture of 80–90% of sand (5, 40).

Setting Time.—No agreement as to definition of term. The following laboratory test has been proposed (37):

Setting shall be assumed to be attained when an electrical resistance of 30 000 ohms is reached between two 5 mm brass plugs imbedded 8 mm in the plaster with their centers 10 cm apart.

Under this definition, neat lime putty will set in 40–50 hr, and this may be reduced 5–10 hr by admixture of sand (37).

Rate of Carbonation.—As ordinarily mixed and placed, lime mortar will carbonate from the surface inwards at *ca.* ⅛ in. per month (16). This is subject to change, within narrow limits, by variations of the factors enumerated above. A 2-in. cube exposed on 5 sides will carbonate completely in *ca.* 8 months; an 8-in. mortar joint exposed on one side will require more than 5 years.

Soundness.—(20, 31, 47).

Strength.—For purposes of intercomparison only, the following figures may be quoted as the strength of a mortar made of high calcium hydrate with three parts by weight of run-of-mine Ottawa sand and enough water to bring the mixture to "Standard" consistency (19) on the plunger viscometer, the mortar being molded in the form of 2-in. cubes for compression, the usual type of briquette for tension, and 12 × 1 × 1 in. bars for transverse and shear, and the specimens stored in the laboratory, with 5 sides exposed, for 90 days: Compressive, 403; Tensile, 69; Shearing, 82; Transverse, 146 lb./in.^{2}

Expansion after Setting.—No published data. Humidity and thermal coefficients at room temperature approximately equal to those of concrete. Thermal coefficient much greater at higher temperatures (9).

Strength of Masonry (7, 13).—Common brick masonry (1 to 4 pt. by vol. lime mortar) should withstand a compression of 125 lb./in.^{2} (14). *See also* p. 66.

Thermal Conductivity and Fire Resistance.—(25).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Abrams, *309*, No. **1**; 22. (2) *Ibid.*, No. **6**; 24. (3) Ancienne Soc. J. and A. Pavin de LaFarge, *Sales Circ.* (4) Anon, *66*, **23 II**: 432; 23. (5) Anon., *Nat. Lime Assoc., Bull.* No. **305A**. (6) Bleininger and Emley, *81*, **13**: 618; 11. (7) Bragg, *32*, No. **111**; 18. (8) Bur. Standards, *Circ. No.* **108**; 21. (9) *Ibid.*, No. **151**; 24.

(10) Bur. Standards, *O.* (11) Carman and Nelson, *86*, No. **122**: 29; 21. (12) Clarke, *156*, No. **695**: 557; 20. (13) Cleare, *Proc. Sand Lime Brick Assoc.*, **1920**: 57. (14) Dept. of Commerce, *Report of building code committee*, 1925. (15) Emley, *32*, No. **16**: 84; 13. (16) Emley, *81*, **16**: 117; 14. (17) Emley, *310*, **1914**: 254. (18) Emley, *81*, **19**: 573; 17. (19) Emley, *32*, No. **169**; 20.

(20) Emley and Berger, *38*, **6**: 1007; 23. (21) Emley and Faxon, *38*, **3**: 984; 20. (22) Feret, *311*, **6**, No. **3**: 63; 23. (23) Gale and Schaller, *156*, No. **580**: 302; 14. (24) Householder, *38*, **1**: 578; 18. (25) Hull, *32*, No. **130**; 19. (26) Hursh, *81*, **14**: 792; 12. (27) Johnson, *66*, **24 II**: 1024; 24. (28) Johnson, *O.* (29) Larsen, *66*, **23 I**: 236; 23.

(30) Lazell, *Hydrated Lime*, p. 39; 15. (31) Lazell, *310*, **1905**: 135. (32) Marani *in* Kidder-Nolan *Architects' Handbook*, 1918. (33) Matsumoto, *86*, No. **126**: 5; 21. (34) Norton, *122*, **35**: 1012; 13. (35) Porter, *66*, **23 I**: 244; 23. (36) Porter, *Rock Products*, **1924**: 47. (37) Stockett, *O.* (38) Stone, *30*, No. **155**; 17. (39) Talbot, *86*, No. **20**; 08.

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(50) Withey, *Univ. Wisconsin*, Bull. No. **466**; 11.

MAGNESIA CEMENTS AND CONCRETES

LEROY C. STEWART

BULK DENSITY (7)

Grams per cm^3: Stucco, 3.0 to 3.4. Flooring, 1.55 to 1.8. Special mixes with wood flour, cork dust, etc., 1.0 to 2.0.

ULTIMATE TENSILE STRENGTH (DEF. 4) AND MODULUS OF RUPTURE (DEF. 5) OF CEMENTS MADE WITH SPECIALLY CALCINED DOLOMITES

Wt. %: Calcined dolomite 31, ground flint 12.5, Ottowa sand 56.5. 1.179 sp. gr. $MgCl_2$ soln., kg/cm^2 (22).

Dolomite	Tensile strength			Modulus of rupture*		
	1 day	3 days	7 days	Not sprayed	Wet	Recovered
A			32.6	112.2	54.0	68.0
B	18.1	30.2	34.4	133.0	69.6	102.6

* Bars sprayed 24 hr at 14, 16 and 18 days' age. "Wet" bars broken at 19 days' age and "Recovered" at 21 days' age. "Not Sprayed" bars broken at 20 days' age.

ELASTIC PROPERTIES

Elastic limit (Def. 2), modulus of elasticity (Def. 10*a*) and ultimate compressive strength (Def. 4) of cement mortar and concrete.

1.23 sp. gr. $MgCl_2$ soln. used. Aged 80–85 days. Unit kg/cm^2 (1).

Magnesite-sand-rock by wt.	Elas. lim.	Mod. elas.	Compr. str.
1- 4-0	253	194 000	319
1- 6-0	150	192 000	240
1- 8-0	127	146 000	185
1-10-0	53-114	96 400	143
1- 2-4	234	269 000	359
1- 3-6	234	194 000	305

Under this definition, neat lime putty will set in 40–50 hr, and this may be reduced 5–10 hr by admixture of sand (37).

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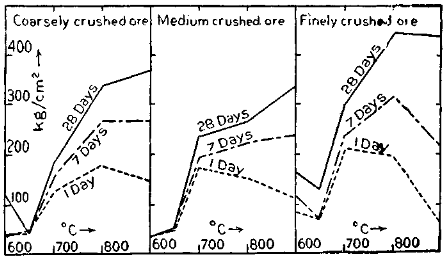


FIG. 1.—Ultimate compressive strength (Def. 4) of magnesium oxychloride flooring mixtures as affected by size and burning temperature of magnesite ore (3).

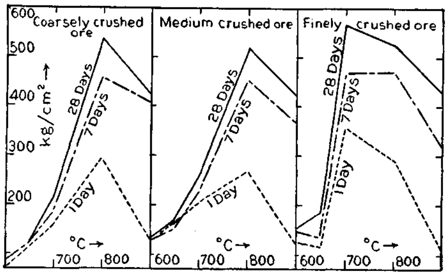


FIG. 2.—Ultimate compressive strength (Def. 4) of magnesium oxychloride mortar mixtures as affected by size and burning temperature of magnesite ore (3).

Graphs in Figs. 1 and 2 represent averages of three compositions, using $MgCl_2$ solution (sp. gr. 1.184) and Washington magnesite. Coarse ore passed 3.35 mm sieve, retained on 2.00 mm; medium passed 2.00 mm, retained on 0.585 mm; fine passed 0.249 mm opening.

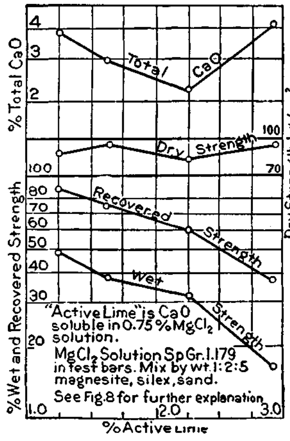


FIG. 9.—Effect of active lime in magnesite on magnesium oxychloride cement (21).

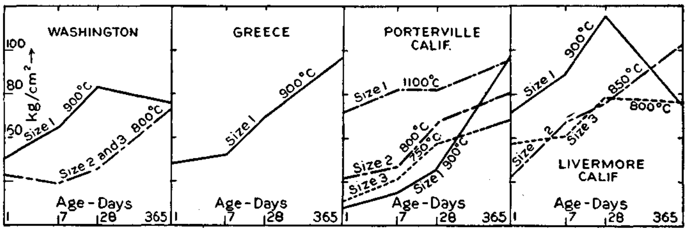


FIG. 3.—Modulus of rupture (Def. 5) of magnesium oxychloride flooring mixture as affected by source, size and burning temperature of magnesite ore (4).

Sizes of magnesite: 1, passing 2.54 cm, retained on 1.27 cm screen; 2, passing 1.27 cm, retained on 0.64 cm screen; 3, passing 0.64 cm, retained on 0.32 cm screen. Mix: 45 % MgO, 10 % wood flour, 5 % asbestos, 20 % silex, 5 % silocel, 5 % clay, 10 % pigment (all by weight); $MgCl_2$ soln., sp. gr. 1.179.

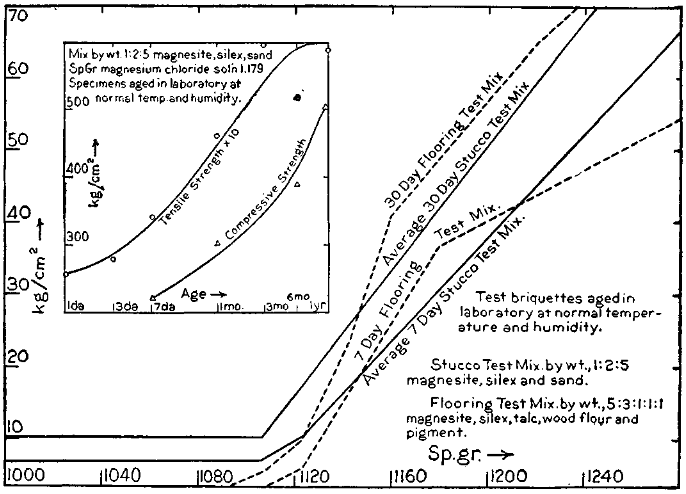


FIG. 5 (Insert).—Strength of magnesium oxychloride cements (7). Average for 12 commercial magnesites.

FIG. 6.—Effect of magnesium chloride solution strength on tensile strength of oxychloride cements (11).

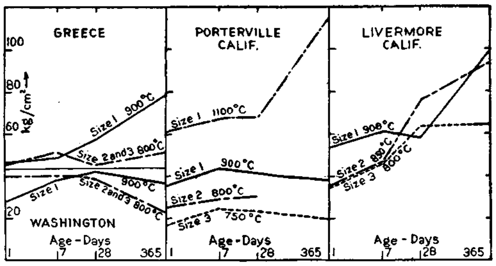


FIG. 4.—Modulus of rupture (Def. 5) of magnesium oxychloride stucco mixture as affected by source, size and burning temperature of magnesite ore (4).

Sizes as in Fig. 3. Mix: 10 % MgO, 20 % silex, 67 % mortar sand, 3 % asbestos (all by weight); $MgCl_2$ soln., sp. gr. 1.179.

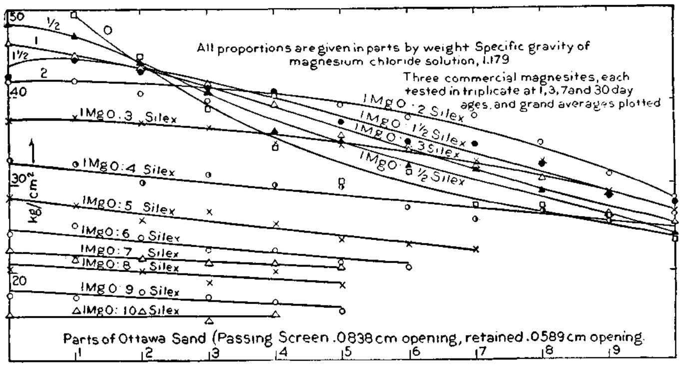


FIG. 7.—Tensile strength of oxychloride-silex-sand mixtures (8).

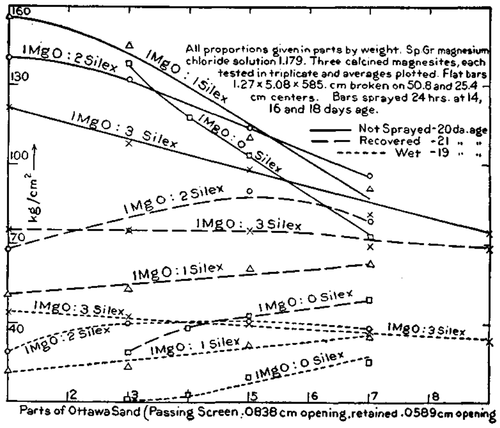


FIG. 8.—Water resistance of oxychloride-silex-sand mixtures. Modulus of rupture (10).

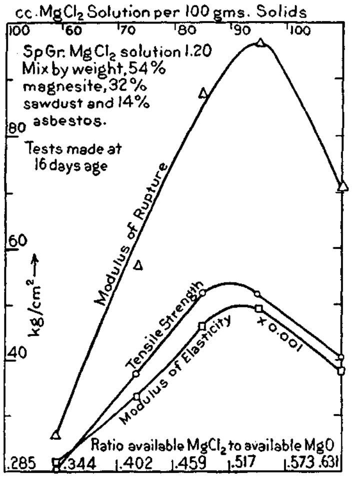


FIG. 10.—Effect of variation in amount of magnesium chloride solution on strength and elasticity of magnesium oxychloride flooring (19).

Modulus of elasticity $= Pl^3/4dbh^3$, where P = load applied at center, l = length of bar between supports, d = deflection of supports at center, b = width of bar and h = thickness of bar.

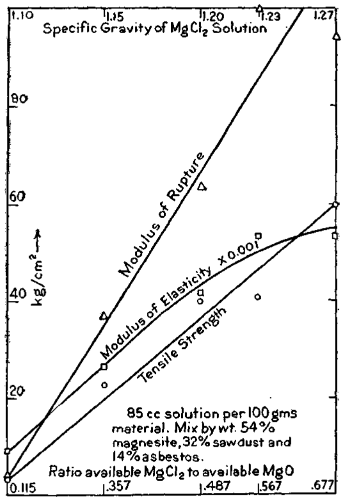


FIG. 11.—Effect of variation in density of magnesium chloride solution on strength and elasticity of magnesium oxychloride solution (19).

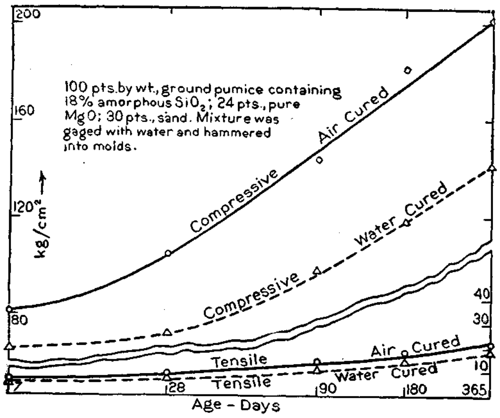


FIG. 15.—Tensile and compressive strengths of an hydraulic magnesian cement (24).

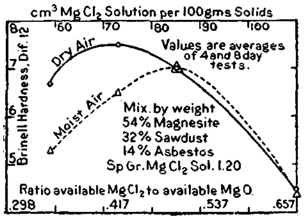


FIG. 12.—Effect of variation in amount of magnesium chloride solution on Brinell hardness of magnesium oxychloride flooring (19).

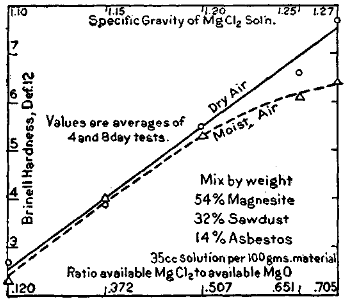


FIG. 13.—Effect of variation in density of magnesium chloride solution on Brinell hardness of magnesium oxychloride flooring (19).

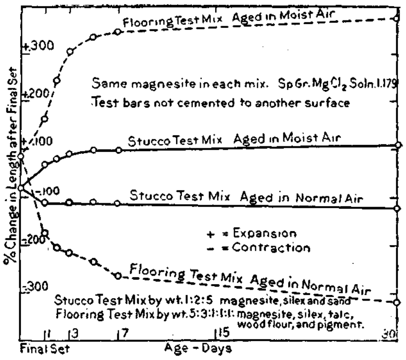


FIG. 16.—Volume change in magnesium oxychloride cements (7).

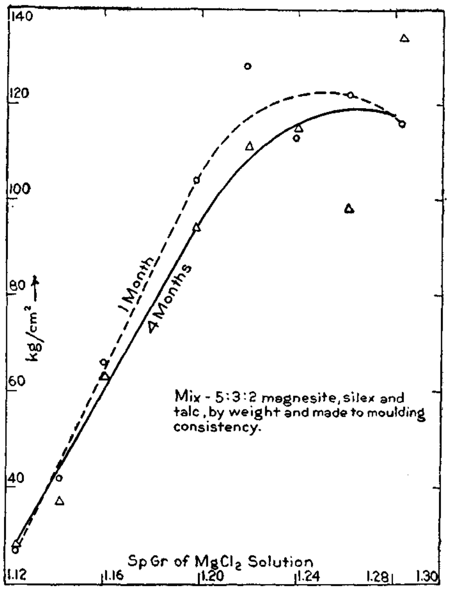


FIG. 14.—Tensile strength of high magnesite oxychloride mixtures as affected by density of magnesium chloride solution (7).

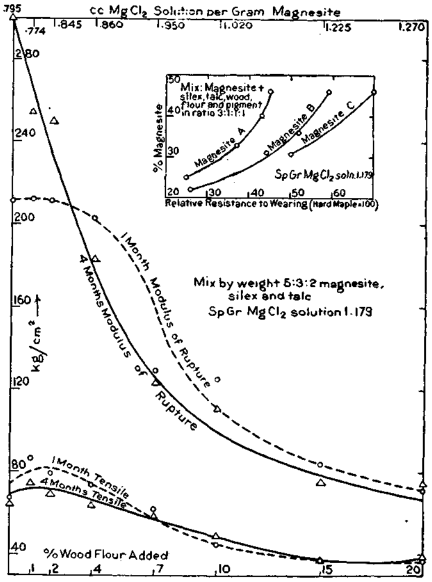


FIG. 17.—Effect of wood flour on strength of magnesium oxychloride cement mixture (7).

FIG. 18 (Insert).—Effect of % of magnesite on wearing resistance of magnesium oxychloride flooring (12).

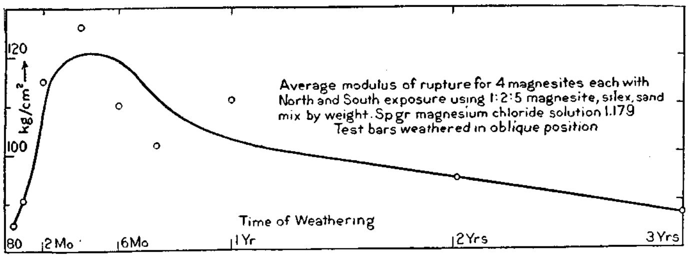


FIG. 19.—Permanency of magnesium oxychloride cement under exterior weathering (7).

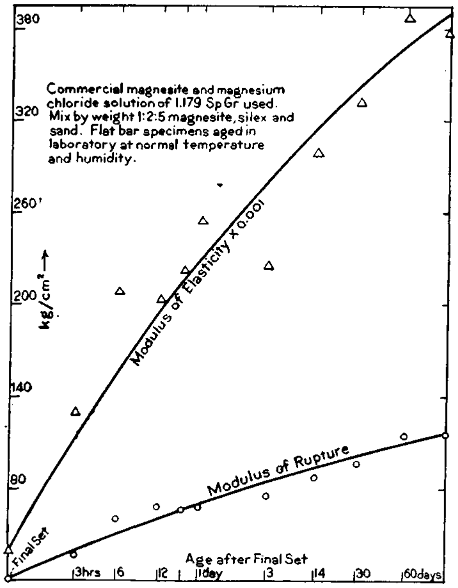


FIG. 20.—Transverse strength and elasticity of magnesium oxychloride cement at various ages (7).

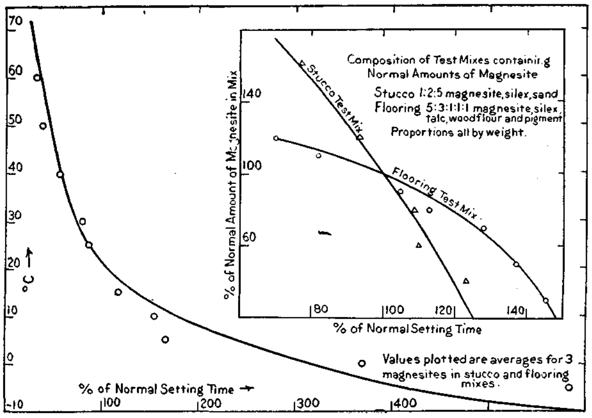


FIG. 21.—Effect of temperature on setting time of magnesium oxychloride cements (9).

FIG. 22 (Insert).—Effect of magnesite proportion on setting time of magnesium oxychloride cements (9).

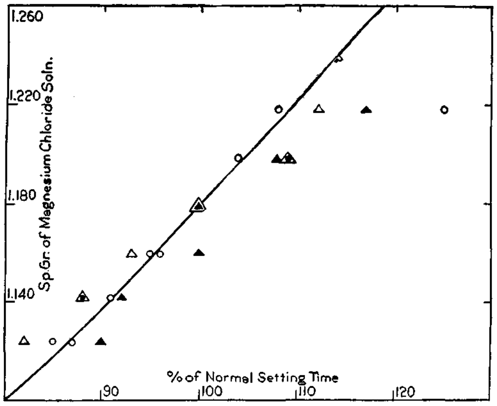


FIG. 23.—Effect of magnesium chloride solution strength on setting time of oxychloride cement (9).

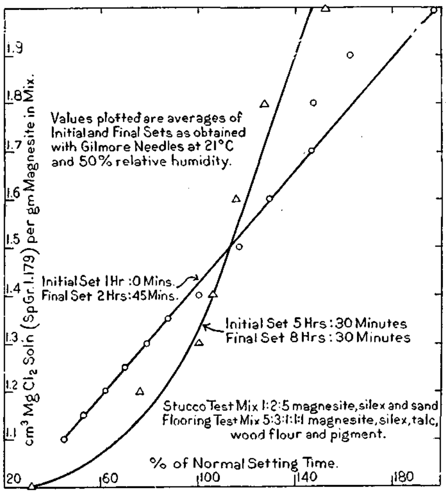
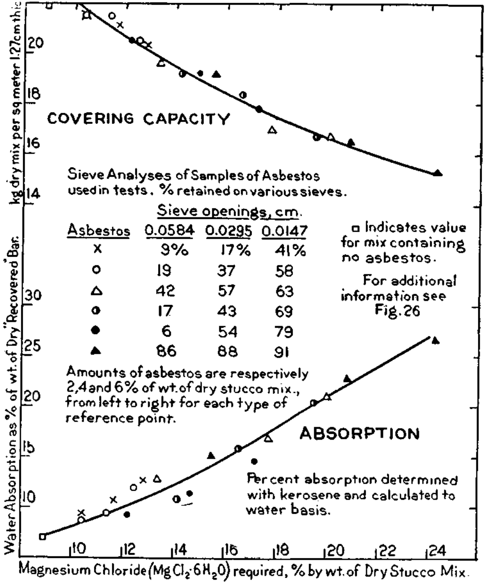


FIG. 24.—Effect of consistency on setting time of magnesium oxychloride cements (9).



Sieve Analyses of Samples of Asbestos used in tests. % retained on various sieves.

	Sieve openings, cm.		
Asbestos	0.0584	0.0295	0.0147
×	9%	17%	41%
○	19	37	58
△	42	57	63
◐	17	43	69
●	6	54	79
▲	86	88	91

Amounts of asbestos are respectively 2, 4 and 6% of wt. of dry stucco mix., from left to right for each type of reference point.

□ Indicates value for mix containing no asbestos.

For additional information see Fig. 26

Per cent absorption determined with kerosene and calculated to water basis.

FIG. 25.—Effect of kind and amount of asbestos on covering capacity and absorption of magnesium oxychloride stucco (7).

Coefficient of Static Friction of Commercial Magnesium Oxychloride Flooring (7)

	Coefficient of friction
Flooring on flooring	0.35–0.50
Leather on flooring	0.45–0.70
Wood (parallel to grain) on flooring	0.25–0.50

WEARING RESISTANCE

Effect of fiber variation on wearing resistance of magnesium oxychloride flooring (12).

Wt. %: Magnesite 46, silex 27, talc 9, fiber 9, pigment 9; 1.179 sp. gr. $MgCl_2$ soln. Wearing resistance of hard maple taken as 100 (12).

Fiber	Asbestos			White pine		Hard maple		Oak		Calif. red-wood		Cork		Hard yellow pine sawdust
	Long fiber	Medium fiber	Short fiber	Sawdust	Flour	Sawdust	Flour	Sawdust	Flour	Sawdust	Flour	Granulated	Flour	
Wear. resist.	61	55	47	50	42	40	31	45	41	43	38	56	50	43

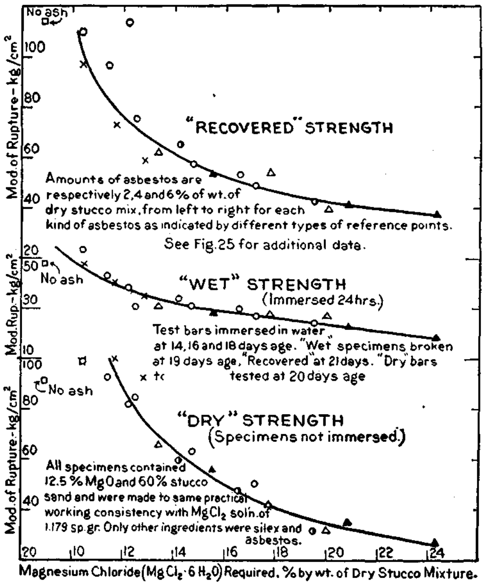


Fig. 26.—Effect of kind and amount of asbestos on water resistance of magnesium oxychloride stucco (7).

COEFFICIENT OF LINEAR THERMAL EXPANSION

Dry ingredients by weight	Sp. gr. $MgCl_2$ solution	$\frac{10^6}{l}\frac{l}{\Delta t}$	Δt°C	Lit.
1 magnesite : 4 sand	1.23	12.60	13–93	(1)
1 magnesite : 6 sand	1.23	11.4	13–93	(1)
54 magnesite : 32 sawdust : 14 asbestos	1.20	22.7	Room	(19)
1 magnesite : 2 silex : 5 sand	1.179	15.1	4–51	(18)

SPECIFIC HEAT AND THERMAL CONDUCTIVITY OF CEMENT MORTARS (1)

By wt. mag.-sand	Sp. gr. $MgCl_2$ soln.	c_p, cal g°C	k, cal cm^{-2} sec^{-1}(°C cm^{-1})$^{-1}$
1–4	1.23	0.19	0.0042
1–6	1.23	0.20	0.0045

(*See also* p. 314.)

HEAT EVOLVED DURING MIXING AND SETTING OF MAGNESIUM OXYCHLORIDE CEMENTS (7)

150 to 250 g-cal per gram of commercially calcined magnesite.

ELECTRICAL RESISTANCE OF CEMENT MORTARS

1.23 sp. gr. $MgCl_2$ solution. R for various ages in megohm-cm (1)

Magnesite-sand by wt.	2 days	2 mo. dry	2 mo. wet
1–4	0.025	200	0.0012
1–6	0.032	138	0.001

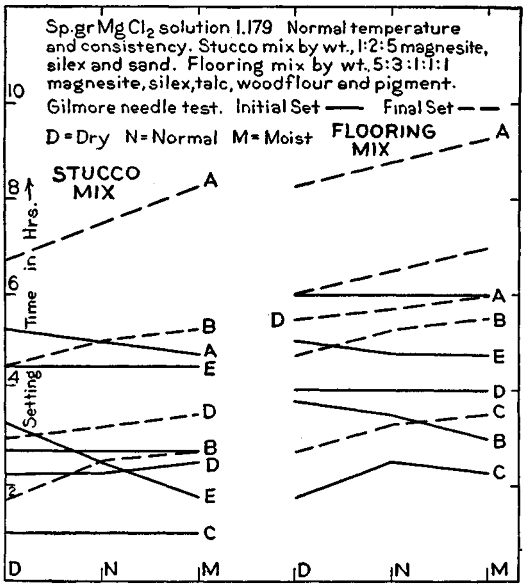


Fig. 27.—Effect of humidity on setting time of magnesium oxychloride cements (9).

SETTING TIME OF COMMERCIAL MAGNESITES IN VARIOUS MIXES (9)

Sp. gr. $MgCl_2$ soln. 1.179. Normal temperature, humidity and consistency. Stucco test mix by weight, 1:2:5 magnesite, silex and sand. Flooring test mix by weight, 5:3:1:1:1 magnesite, silex, talc, wood flour and pigment. Time of set determined with Gilmore needles.

For fourteen different samples of commercial magnesites, the initial set for neat mix varies from 0.5–6.25 hr, the final set from 1.5–16 hr; for stucco test mix, the initial set from 1–7.5 hr, final set, 2.75–11.5 hr; for flooring test mix, initial set, 1.5–8 hr, final set, 3–15 hr, depending on the nature of the magnesite.

Setting Time of Magnesium Oxychloride Cement Mixtures

Effect of source, size and burning temperature of magnesite ore (4). Flooring mix: Wt. %: MgO 45, wood flour 10, asbestos 5, silex 20, silocel 5, clay 5, pigment 10. Stucco mix: Wt. %: MgO 10, silex 20, mortar sand 67, asbestos 3. 1.179 sp. gr. $MgCl_2$ soln. Gilmore needles.

Magnesite		t°C	Flooring mix				Stucco mix			
			Initial		Final		Initial		Final	
Source	Size*		Hr	Min	Hr	Min	Hr	Min	Hr	Min
Washington	1	900	3	45	8+		2	05	6	55
Washington	2+3	800	1	20	3	50	2	00	3	40
Greece	1	900	1	15	3	00	1	25	3	15
Greece	2	800					0	50	2	25
Porterville, Calif.	1	1100	1	35	3	50	2	45	3	40
Porterville, Calif.	1	900	0	30	2	30	0	55	2	00
Porterville, Calif.	2	800	1	15	2	50	0	55	1	50
Porterville, Calif.	3	750	3	15	5	45	4	00	6	05
Livermore, Calif.	1	900	2	15	4	00	2	30	4	30
Livermore, Calif.	2	850	1	10	2	20	1	50	3	20
Livermore, Calif.	3	800	1	15	2	25	1	15	2	00

* Sizes of Magnesite: 1—passing 2.54 cm, retained on 1.27 cm screen; 2—passing 1.27 cm, retained on 0.64 cm screen; 3—passing 0.64 cm, retained on 0.32 cm screen.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Alvarez, *Univ. Calif., Pub. in Eng.*, *1*, No. **3**: 21; 15. (2) Andre, *34*, **94**: 444; 82. (3) Bates and Young, *38*, **4**: 570; 21. (4) Bates, Young and Rapp, *32*, No. **239**; 23. (5) Bender, *25*, **3**: 932; 71. *13*, **159**: 341; 71. (6) Davis, *135*, **25**: 258; 72. (7) Dow Chemical Co., *O.* (8) Dow Chem. Co., *$MgCl_2$ Service Bull.*, No. **1**; 22. (9) *Ibid.*, No. **2**; 22. (10) Dow Chem. Co., *$MgCl_2$ Service Bull.*, No. **4**; 22. (11) *Ibid.*, No. **5**; 21. (12) *Ibid.*, No. **6**; 21. (13) Hof, *136*, **33**: 693; 09. (14) Kallauner, *136*, **33**: 871; 09. **37**: 1045, 1275; 13. (15) Krause, *13*, **165**: 38; 73. (16) Krieger, *136*, **34**: 246; 10. **37**: 1274; 13. (17) Lahrman, *314*, **35**: 265; 11. (18) Olin and Peterson, *33*, **31**: 266; 24. (19) Roark, *Univ. Wisconsin, Eng. Expt. Sta.*, Bull. **879**; 17. (20) Robinson and Waggaman, *50*, **13**: 673; 09. (21) Seaton, Hill and Stewart, *33*, **25**: 270; 21. (22) Shaw and Bole, *38*, **6**: 311; 22. (23) Sorel, *34*, **65**: 102; 67. (24) Vournazos, *34*, **172**: 1578; 21. (25) Webber, *54*, **10**: 111; 91.

DENTAL CEMENTS

W. B. HOLMES

1. TYPICAL CHEMICAL COMPOSITIONS, WEIGHT %

ZINC OXIDE CEMENTS

Powder		Liquids	
ZnO	70–100	Sp. gr.	1.55–1.85
Bi_2O_3	0–6	P_2O_5	33–50
MgO	0–9	H_2O	45–67
Fe_2O_3	0–2	Al_2O_3	4–6
*Al_2O_3	0–7	Na_2O	0–3
*SiO_2	0–8		
*PO_4	0–2		

SILICEOUS CEMENTS

Powder		Liquids	
SiO_2	25–45	Sp. gr.	1.50–1.80
Al_2O_3	27–40	P_2O_5	35–45
CaO	4–13	H_2O	44–70
Na_2O	0–8	Al_2O_3	4–6
*BeO	0–16	ZnO	0–8
PO_4	4–24		
F	0–10		

COPPER CEMENTS

Powder		Liquids	
ZnO	0–90	Sp. gr.	1.50–1.70
CuO	0–90	P_2O_5	33–45
Cu_2O	0–30	H_2O	44–65
Cu_2I_2	0–5	Al_2O_3	4–6
Co_2O_3	0–8	ZnO	0–4
Fe_2O_3	0–20	FeO	0–4
$CuSiO_3$	0–1	NiO	0–1
$Cu_3(PO_4)_2$	0–5	CuO	0–1

*MgO.

2. CRUSHING STRENGTH(1)

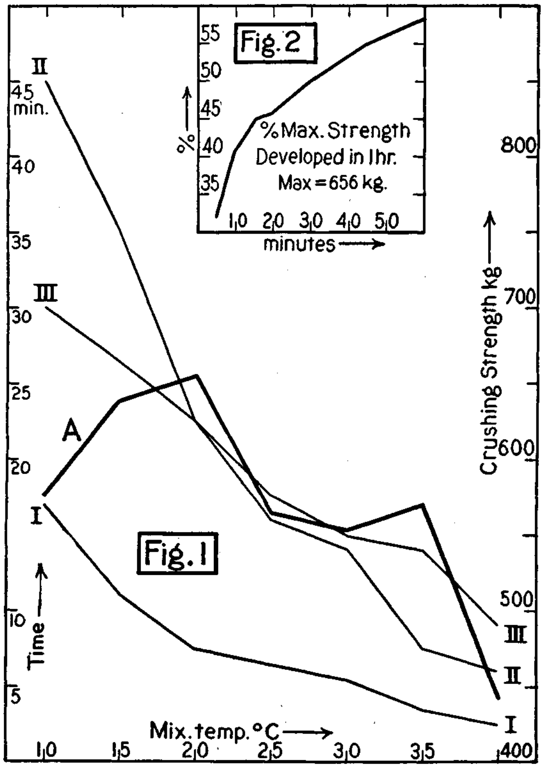
1. *Limits for Commercial Cements.*—Cement mixed at 20°C and then incubated at 37°C in oil. For the saliva tests the cylinders are incubated in oil for 15 min, then washed with petroleum ether and the incubation continued in saliva. Pressure applied to a cylinder (5 × 5 mm) at the rate of 453.6 kg/min.

Incubation: / Type and No. of samples tested	(1) In oil for 15 min	1 day	7 days	28 days
	Crushing strength. Unit = 100 kg			
Sil. (7)	1.5–2.8	3.3–5.6	4.1–6.3	4.0–6.5
ZnO (18)	0.4–3.5	0.9–4.8	0.7–5.6	1.0–5.6
Cu (15)	0.5–2.9	0.5–4.4	0.4–5.4	0.7–5.4

Incubation: / Type and No. of samples tested	(2) In saliva for 1 day	7 days	28 days
	Crushing strength. Unit = 100 kg		
Sil. (7)	1.0–5.6	1.1–5.9	1.2–6.6
ZnO (18)	0.9–4.4	1.1–4.9	1.0–4.4
Cu (15)	0.8–4.4	1.2–4.5	0.0–4.3

2. *Influence of Mixing Temperature.*—*See* Curve A, Fig. 1.

3. *Rate of Hardening of a "Synthetic Porcelain" Cement at 37°C as Measured by Its Crushing Strength.*—*See* Fig. 2, which gives the crushing strength in % of maximum strength, during the first hour.



3. SETTING TIME(1)

Time from mixing to failure of Gilmore needle to indent in 5 sec application. Seven siliceous cements, 5–12 min; 18 ZnO cements, 9–78 min; 15 Cu cements, 8–25 min; *t* = 20°C. For influence of mixing temperature *see* Fig. 1, Curve I, a siliceous cement and Curves II and III, ZnO cements.

Heat of Setting

No calorimetric data available. For temperature rise on setting *v.* (2).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Poetschke, *45*, **8**: 302; 16. (2) Poetschke, *45*, **15**: 339; 23.

LITERATURE

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W. B. Holmes

1. TYPICAL CHEMICAL COMPOSITIONS, WEIGHT %

Zinc Oxide Cements

Powder		Liquids	
ZnO	70–100	Sp. gr.	1.55– 1.85
Bi_2O_3	0– 6	P_2O_5	33 –50
MgO	0– 9	H_2O	45 –67
Fe_2O_3	0– 2	Al_2O_3	4 – 6
*Al_2O_3	0– 7	Na_2O	0 – 3
*SiO_2	0– 8		
*PO_4	0– 2		

Siliceous Cements

Powder		Liquids	
SiO_2	25–45	Sp. gr.	1.50– 1.80
Al_2O_3	27–40	P_2O_5	35 –45
CaO	4–13	H_2O	44 –70
Na_2O	0– 8	Al_2O_3	4 – 6
*BeO	0–16	ZnO	0 – 8
PO_4	4–24		
F	0–10		

Copper Cements

Powder		Liquids	
ZnO	0–90	Sp. gr.	1.50– 1.70
CuO	0–90	P_2O_5	33 –45
Cu_2O	0–30	H_2O	44 –65
Cu_2I_2	0– 5	Al_2O_3	4 – 6
Co_2O_3	0– 8	ZnO	0 – 4
Fe_2O_3	0–20	FeO	0 – 4
$CuSiO_3$	0– 1	NiO	0 – 1
$Cu_3(PO_4)_2$	0– 5	CuO	0 – 1

*MgO.

2. CRUSHING STRENGTH(1)

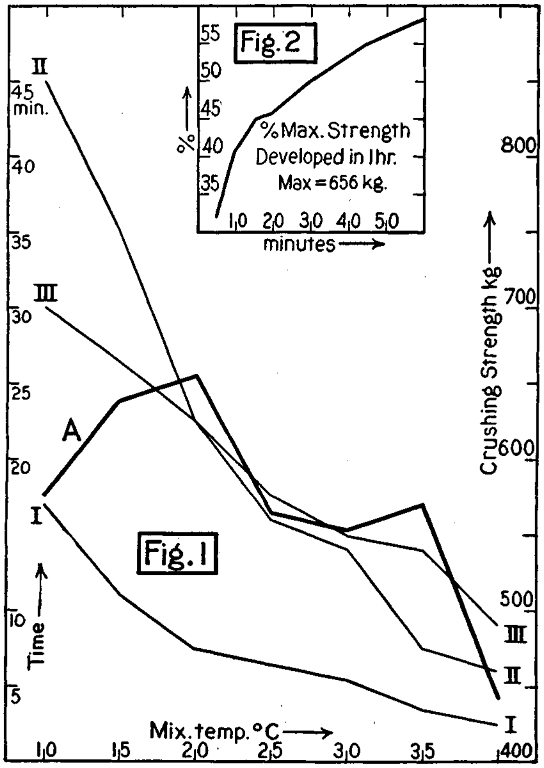
1. *Limits for Commercial Cements.*—Cement mixed at 20°C and then incubated at 37°C in oil. For the saliva tests the cylinders are incubated in oil for 15 min, then washed with petroleum ether and the incubation continued in saliva. Pressure applied to a cylinder (5 × 5 mm) at the rate of 453.6 kg/min.

Incubation: Type and No. of samples tested	(1) In oil for 15 min	1 day	7 days	28 days
	Crushing strength. Unit = 100 kg			
Sil. (7)	1.5–2.8	3.3–5.6	4.1–6.3	4.0–6.5
ZnO (18)	0.4–3.5	0.9–4.8	0.7–5.6	1.0–5.6
Cu (15)	0.5–2.9	0.5–4.4	0.4–5.4	0.7–5.4

Incubation: Type and No. of samples tested	(2) In saliva for 1 day	7 days	28 days
	Crushing strength. Unit = 100 kg		
Sil. (7)	1.0–5.6	1.1–5.9	1.2–6.6
ZnO (18)	0.9–4.4	1.1–4.9	1.0–4.4
Cu (15)	0.8–4.4	1.2–4.5	0.0–4.3

2. *Influence of Mixing Temperature.*—*See* Curve A, Fig. 1.

3. *Rate of Hardening of a "Synthetic Porcelain" Cement at 37°C as Measured by Its Crushing Strength.*—*See* Fig. 2, which gives the crushing strength in % of maximum strength, during the first hour.



3. SETTING TIME(1)

Time from mixing to failure of Gilmore needle to indent in 5 sec application. Seven siliceous cements, 5–12 min; 18 ZnO cements, 9–78 min; 15 Cu cements, 8–25 min; t = 20°C. For influence of mixing temperature *see* Fig. 1, Curve I, a siliceous cement and Curves II and III, ZnO cements.

Heat of Setting

No calorimetric data available. For temperature rise on setting *v.* (2).

LITERATURE

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SOLID FUELS

S. W. PARR

1. CLASSIFICATION

For the purpose of displaying typical values of their properties and compositions, solid fuels will be assigned to classes on the basis of two characteristics which will be called unit-heat-value (*UHV*) and unit-volatile-matter (*UVM*), respectively, and which are defined by the following equations ([17, 21]).

$$UHV = \frac{H - 5000S}{F}\ \text{BTU/lb.} = \frac{H - 2778S}{F}\ \text{g-cal/g}, \qquad (1)$$

where H is the total calorific value of the fuel (BTU/lb., g-cal/g, respectively); and

$$UVM = 100\left(\frac{V - (0.08 + 0.4S)}{F}\right)\%, \qquad (2)$$

where V = the volatile matter per unit mass of fuel.

In both equations the factor, $F = 1 - (W + 1.08A + 0.55S)$, where W, A and S are, respectively, the water, ash and sulfur content of the unit mass of fuel as determined by chemical analysis.

The numerical factors in equations (1) and (2) are such that the quantities UHV and UVM represent, respectively, the heating value and the volatile matter per unit mass of fuel-substance contained in the solid fuel; *see also* ([17, 21]).

By means of these two characteristics, every solid fuel can be represented as a point on a plane and the location of this point with respect to the areas which have been selected for delimiting the various classes of solid fuels, identifies the class to which the fuel belongs and its relative location in that class. This is illustrated by the diagram in Fig. 1. The circles represent the loci of certain selected samples, representative of each class, and whose compositions are shown in Table *A*. The crosses represent the loci of a series of coals corresponding to the composition averages of Tables 2–10.

Another method for classifying coals, based upon limits for carbon, hydrogen, oxygen plus nitrogen, and volatile matter has been proposed by Seyler ([27, 28, 29, 30]). The classes which he proposes are, however, in close agreement with those defined in Fig. 1 [*cf.* ([24])] and a comparison of the proposed nomenclatures is shown in the following table. All proposed nomenclatures are provisional, since no agreement has as yet been reached.

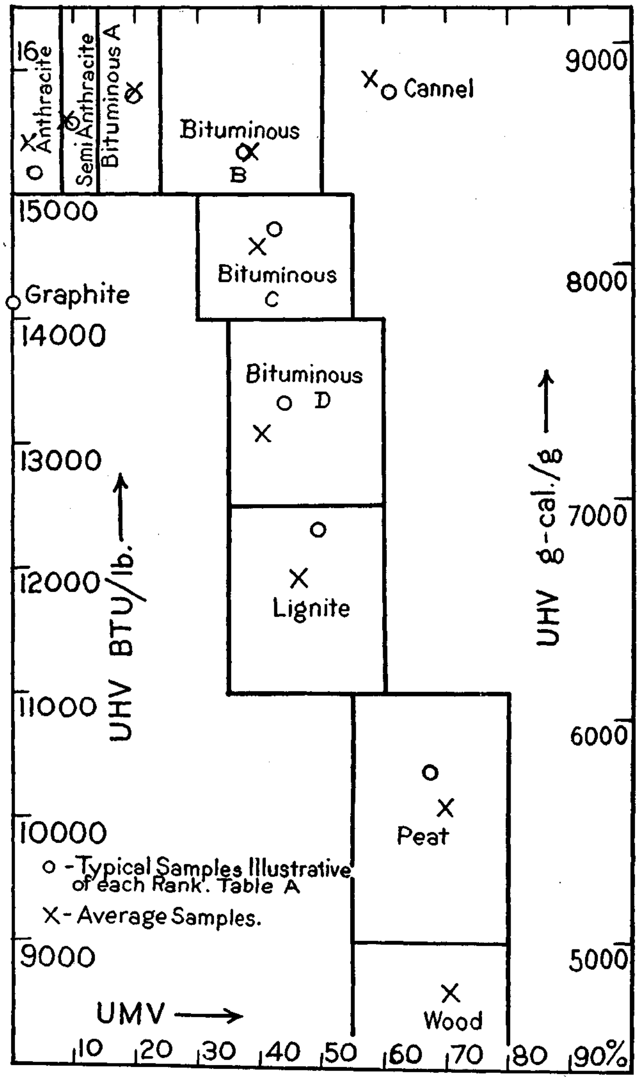

FIG. 1.—Classification of solid fuels.

TABLE *A*.—PERCENTAGE COMPOSITION OF TYPE SAMPLES OF SOLID FUELS

Type	State and county	Proximate				Ultimate					Air-dry loss	g-cal/g	BTU/lb	*UHV* BTU	*UVM*
		Volatiles	Fixed C	H_2O	Ash	S	H	C	N	O					
Anthracite	Schuylkill Co., Pa.	3.27	84.28	3.33	9.12	0.60	2.71	81.35	0.79	2.10	2.6	7 417	13 351	15 410	2.66
Semi-anthracite	Sullivan Co., Pa.	8.59	78.08	3.16	10.17	0.67	3.12	79.49	1.10	2.29	2.6	7 431	13 376	15 610	8.79
Bituminous A	McDowell Co., W. Va.	18.68	72.04	2.80	6.48	0.70	4.26	81.75	1.35	2.66	0.0	7 923	14 261	15 820	19.89
Bituminous B	Mingo Co., W. Va.	34.37	56.85	2.44	6.34	0.95	4.96	77.90	1.54	5.87	1.0	7 721	13 898	15 340	38.20
Bituminous C	Williamson Co., Ill.	32.92	48.30	9.94	8.84	1.28	4.24	66.18	1.46	8.06	4.4	6 508	11 714	14 590	39.71
Bituminous D	Moffat Co., Colo.	30.41	44.36	18.94	6.29	0.64	3.60	57.47	0.82	12.23	6.1	5 401	9 722	13 080	40.19
Lignite	El Paso Co., Colo.	24.44	27.27	34.40	13.89	0.14	2.64	35.94	0.66	12.33	26.4	3 364	6 055	11 930	46.20
Peat	Fond du Lac Co., Wis.	13.37	5.70	76.94	3.99	0.17	1.02	10.87	0.68	6.33	73.8	1 044	1 879	10 100	69.58
Wood	Air-dry	61.87	26.50	11.36	0.27		5.35	44.13	0.08	38.83		4 242	7 635	8 650	70.05
Cannel	Johnson Co., Ky.	50.64	36.70	2.20	10.46	0.99	6.33	72.01	1.17	6.84	1.3	7 638	13 748	15 920	57.55

TABLE *B*.—PERCENTAGE COMPOSITION OF TYPICAL WORLD COALS

Country and location	H_2O	Volatiles	Fixed C	Ash	S	BTU/lb.	g-cal/g	*UHV* BTU	*UVM*
England, Durham, Horden	1.50	34.68	59.15	3.80	0.87	13 330	7 420	14 140	36.20
England, Leicester, Nailstone	13.22	30.99	50.52	5.27	1.25	13 170	7 320	16 290	38.05
England, Yorkshire, Dearne Valley	8.44	37.01	51.19	2.00	1.36	13 397	7 440	15 020	40.90
Scotland, Ayrshire, Caprington	6.86	36.65	51.56	4.14	0.79	12 422	6 905	14 010	40.80
Scotland, Edinburgh, Newbattle	9.87	31.32	55.02	3.43	0.36	12 915	7 200	14 930	63.40
Scotland, Lanark, Coalburn	7.50	31.56	56.68	4.04	0.22	13 690	7 610	15 540	35.25
Wales, Cardiff	1.04	17.17	76.53	5.26	0.86	14 479	8 045	15 540	17.68
Wales, Neath	1.83	7.47	86.82	3.88	0.79	14 574	8 090	15 520	7.32
Wales, Port Talbot	2.41	11.65	70.49	15.45	1.01	13 124	7 310	16 260	12.48
Germany, Westphalia, Ruhr	0.30	6.00	87.60	6.10	0.90	14 080	7 822	15 100	5.90
Germany, Westphalia, Ruhr	0.80	12.40	79.50	7.30	1.40	13 940	7 745	15 300	12.42
Germany, Westphalia, Ruhr	2.60	29.20	64.20	4.00	0.80	13 760	7 644	14 810	30.80
Germany, Saar	1.73	33.16	57.54	7.57	0.94	13 896	7 720	15 450	35.90
Germany, Saxony	8.17	35.93	53.75	2.15	0.76	12 728	7 071	14 230	39.80
Germany, Saxony, brown coal	14.42	44.63	33.85	7.10	1.17	8 872	4 929	11 400	56.50
Bulgaria, Boronschtitza	0.72	36.05	56.43	5.30	3.01	12 690	7 050	13 650	37.50
Japan, Joban	12.24	40.61	36.11	11.04	1.02	9 759	5 423	12 900	52.20
Japan, Chihuko	4.21	42.92	45.71	7.33	0.68	12 965	7 205	14 780	48.10
S. Africa, Middleburg	2.57	29.16	57.68	10.59	0.42	12 392	6 885	14 425	32.45
S. Africa, Natal	1.28	23.70	67.06	7.96	1.24	13 720	7 622	15 271	25.01
Australia, New South Wales	1.89	41.35	50.51	6.25	1.01	12 760	7 090	14 000	41.50
Australia, New Zealand	0.70	16.68	77.67	4.95	0.30	14 915	8 286	15 890	17.20
Canada, Alberta, Crows Nest	2.10	23.10	58.60	16.20	0.50	12 400	6 888	15 420	26.95
Canada, New Brunswick, Minto	1.20	31.70	53.80	13.30	6.60	13 020	7 240	15 690	37.90
Canada, Nova Scotia, Sidney Field	3.70	35.00	54.20	7.02	2.79	13 150	7 306	14 910	37.40

TABLE 1.—CLASSIFICATION OF COALS

Type No.	Table No.	Type	Name	
		Parr	Common	Seyler
1	2	Anthracite	Anthracite	Anthracite
2	3	Semi-anthracite	Semi-anthracite	Carbonaceous
3	4	Bituminous A	Semi-bituminous or low volatile	Meta-bituminous (short flame)
4	5	Bituminous B	Bituminous (eastern field)	Ortho-bituminous (true bituminous)
5	6	Bituminous C	Bituminous (mid-continental field)	Para-bituminous (long flame)
6	7	Bituminous D	Lignite, black, or subbituminous	Lignitous
7	8	Lignite	Lignite, brown	Lignitous

TABLE 1.—CLASSIFICATION OF COALS.—(*Continued*)

Type No.	Table No.	Type	Name	
		Parr	Common	Seyler
8	9	Peat		
9		Wood		
10	10	Cannel		
11	11	Coke		
12		Semi-coke		
13		Briquettes		
14		Pulverized		

PERCENTAGE COMPOSITION OF U. S. COALS

TABLE 2.—TYPE 1, ANTHRACITE

State, county, and seam	H_2O	Vol.*	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Colo., Gunnison	2.70	3.32	88.15	5.83	0.80	14 099	7 840	15 510	2.79
Colo., Gunnison	4.86	6.96	81.87	6.31	0.81	13 468	7 475	15 300	6.98
N. Mex., Santa Fe	5.70	2.18	86.13	5.93	0.69	13 286	7 375	15 130	1.63
N. Mex., Santa Fe	7.55	7.25	75.88	9.32	0.76	12 101	6 725	14 720	7.55
Pa., Schuylkill	2.76	2.48	82.07	12.69	0.54	12 577	6 970	15 075	1.51
Pa., Schuylkill	2.80	1.16	88.21	7.83	0.89	13 298	7 380	15 010	0.24
Pa., Schuylkill	2.30	1.54	82.77	13.39	1.05	12 523	6 955	15 080	0.08
Pa., Schuylkill	3.33	3.27	84.28	9.12	0.60	13 351	7 415	15 410	2.66
Pa., Luzerne	1.31	5.68	85.87	7.14	0.42	13 777	7 645	15 150	5.44
Pa., Luzerne	2.19	5.67	86.24	5.90	0.57	13 828	7 680	15 120	5.77
Pa., Lackawanna	3.43	6.79	78.25	11.53	0.46	12 782	7 097	15 200	6.75
Utah, Washington, No. 6	8.21	4.41	58.02	29.36	2.28	8 908	4 948	14 920	2.05
Wash., Lewis, Primrose	7.40	4.80	52.00	35.80	0.74	8 200	4 555	15 530	1.20
Wash., Whatcom, Puget	4.40	7.40	76.00	12.23	0.96	12 590	6 998	15 360	7.37
Average	4.21	4.49	78.98	12.31	0.82	12 485	6 935	15 170	3.86

* Vol. = volatile matter.

TABLE 3.—TYPE 2, SEMI-ANTHRACITE

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Ark., Pope, Hartshorne	2.07	9.81	78.82	9.3	1.74	13 702	7 620	15 690	9.65
Col., Gunnison, Crested Butte	1.94	9.22	80.34	8.50	0.85	13 740	7 640	15 485	9.28
Pa., Sullivan	3.38	8.47	76.65	11.50	0.63	13 156	7 305	15 660	8.71
Pa., Sullivan	3.47	9.28	76.10	11.15	0.78	13 216	7 345	15 685	9.60
Pa., Sullivan	3.40	9.34	75.58	11.68	0.81	13 120	7 292	15 630	9.67
Pa., Sullivan	3.16	8.59	78.08	10.17	0.67	13 376	7 430	15 610	8.58
Utah, Washington, No. 4	7.02	10.30	60.61	22.07	4.06	10 408	5 787	15 290	10.35
Va., Montgomery, large	2.5	12.40	67.50	17.60	0.51	12 360	6 860	15 770	13.81
Wash., Lewis, Primrose	3.60	8.40	59.60	28.40	0.66	10 050	5 578	15 330	9.00
Average	3.39	9.53	72.58	14.48	1.19	12 570	6 980	15 580	9.83

TABLE 4.—TYPE 3, BITUMINOUS A

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Ark., Sebastian, Hartshorne	1.7	16.91	73.03	8.36	1.23	13 840	7 688	15 510	17.70
Md., Allegheny, Pittsburgh	2.43	19.02	71.19	7.36	1.04	14 087	7 822	15 730	20.12
Md., Garrett, Freeport	2.39	16.41	71.82	9.38	2.01	13 707	7 618	15 770	17.23
Okla., Haskell, Hartshorne	2.37	19.26	69.54	8.83	1.03	13 840	7 690	15 740	20.72
Pa., Cambria, Lower Freeport	2.87	21.44	69.23	6.46	1.52	14 177	7 875	15 690	22.74
Pa., Clearfield, Lower Kittanning	3.20	21.00	69.30	6.50	0.69	14 060	7 820	15 700	22.60
Pa., Somerset, Pittsburgh	3.04	19.59	70.33	7.04	0.74	14 175	8 045	15 920	21.10
Pa., Huntington, Fulton	1.65	17.48	72.26	8.61	1.55	14 076	7 825	15 850	18.31
Va., Tazewell, Pocahontas No. 3	2.85	21.25	71.43	4.47	0.59	14 620	8 128	15 830	22.40
W. Va., Fayette, Sewell	3.58	21.07	72.75	2.60	0.64	14 751	8 190	15 790	22.20
W. Va., McDowell, Pocahontas No. 4	2.87	14.91	78.39	3.83	0.81	14 809	8 235	15 920	14.33
W. Va., McDowell, Pocahontas No. 3	2.03	18.51	75.54	3.92	0.49	14 812	8 240	15 840	19.29
Average	2.58	18.90	72.06	6.45	1.02	14 246	7 915	15 795	19.87

TABLE 5.—TYPE 4, BITUMINOUS B

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Ala., St. Clair, Harkness	2.28	33.07	54.63	10.02	1.76	13 333	7 405	15 410	36.77
Ala., Tuscaloosa, Jagger	1.60	24.98	68.55	4.87	0.51	14 697	8 155	15 800	26.28
Ala., Jefferson, Pratt	1.05	31.70	62.15	6.15	1.38	14 377	7 980	15 610	33.45
Ky., Letcher, Elkhorn	2.91	36.33	57.53	3.23	0.53	14 170	7 875	15 160	38.44
Ky., Harlan, Harlan	2.80	37.00	55.90	4.30	1.10	13 950	7 748	15 120	39.42
Ky., Whitley, Jellico	5.02	36.08	54.47	4.43	0.92	13 608	7 555	15 110	39.40

TABLE 5.—TYPE 4, BITUMINOUS B.—(*Continued*)

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Ohio, Jefferson, Lower Freeport	3.50	37.98	51.08	7.44	3.09	13 286	7 377	15 140	41.78
Ohio, Tuscarawas, Lower Kittanning	4.49	40.55	47.43	7.53	2.93	12 958	7 200	14 960	45.25
Ohio, Belmont, Meigs Creek	4.34	38.95	45.50	11.21	3.65	12 402	6 895	14 990	49.85
Ohio, Guernsey, Pittsburgh	4.36	41.14	45.76	8.74	4.85	12 710	7 058	14 910	46.05
Pa., Washington, Washington	4.45	33.53	49.51	12.51	3.04	12 242	6 800	15 060	39.00
Pa., Westmoreland, Pittsburgh	2.73	30.34	57.80	9.13	1.33	13 613	7 556	15 610	33.47
Pa., Cambria, Upper Freeport	2.73	26.04	65.05	6.18	1.39	14 269	7 925	15 800	27.82
Pa., Jefferson, Lower Freeport	1.86	34.63	53.23	10.28	2.91	13 151	7 300	15 220	38.00
Va., Russell, Upper Banner	2.07	35.90	57.70	5.33	0.57	14 335	7 952	15 590	38.40
Va., Wise, Imboden	2.16	33.10	58.27	6.47	0.68	13 994	7 756	15 410	35.70
W. Va., Marion, Pittsburgh	1.75	36.77	55.14	6.34	0.90	14 107	7 845	15 490	39.50
W. Va., Randolph, Lower Kittanning	1.45	28.97	59.48	10.10	0.98	13 718	7 620	15 700	31.84
W. Va., Kanawha, Coalburg	3.44	35.20	53.08	8.28	0.70	13 304	7 396	15 220	39.50
W. Va., Kanawha, No. 2 gas	2.66	33.30	59.60	4.44	1.14	14 368	7 975	15 590	35.38
Average	2.85	34.27	55.59	7.35	1.71	13 630	7 580	15 330	37.40

TABLE 6.—TYPE 5, BITUMINOUS C

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Ill., Vermilion, No. 7	13.16	37.95	39.02	9.85	4.33	11 110	6 175	14 760	46.60
Ill., Williamson, No. 6	9.44	32.99	48.95	8.62	0.93	11 858	6 594	14 470	39.10
Ill., Saline, No. 5	5.56	34.41	51.31	8.72	2.87	12 643	7 038	14 990	39.04
Ill., Sangamon, No. 5	13.09	36.51	41.14	9.26	3.77	10 935	6 075	14 360	45.70
Ill., Bureau, No. 2	16.27	38.35	38.00	7.38	2.93	10 883	6 045	14 480	49.25
Ill., Mercer, No. 1	15.58	39.17	35.80	9.45	4.69	10 673	5 927	14 570	50.98
Ind., Sullivan, No. 6	14.86	31.65	46.14	7.35	2.16	11 324	6 300	14 620	39.78
Ind., Vigo, Minshall	13.10	36.83	41.73	8.34	2.60	11 484	6 378	14 860	49.20
Iowa, Lucas	15.39	30.49	41.49	12.63	3.19	10 242	5 690	14 560	40.70
Iowa, Marion	14.21	33.17	37.40	15.22	4.66	10 019	5 573	14 640	45.00
Ky., Webster, No. 12	5.58	35.04	51.32	8.06	1.59	12 755	7 095	14 950	39.68
Ky., Hopkins, No. 14	8.85	35.29	47.51	8.35	2.79	11 921	6 625	14 595	41.51
Ky., Union, No. 9	4.37	36.27	47.67	11.69	3.58	12 325	6 852	14 985	41.80
Kans., Cherokee, Cherokee	5.11	32.60	53.39	8.90	4.34	12 926	7 185	15 320	36.40
Kans., Osage, Osage	5.10	36.85	48.10	9.95	5.02	10 930	6 070	14 970	47.58
Mo., Henry, Jordan	10.10	34.83	41.76	13.31	4.32	11 158	6 200	14 950	43.78
Okla., Pittsburg, Lower Hartshorne	4.33	35.51	54.04	6.12	0.84	13 574	7 548	15 260	39.15
Okla., Okmulgee, Henryetta	8.87	34.82	47.68	8.63	1.62	12 096	6 720	14 880	41.45
Average	10.16	35.15	45.13	9.54	3.12	11 603	6 460	14 720	42.55

TABLE 7.—TYPE 6, BITUMINOUS D

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Colo., Boulder	19.14	33.44	42.07	5.35	0.27	10 017	5 570	13 380	43.90
Colo., El Paso	19.23	32.34	41.41	7.02	0.45	9 306	5 170	12 780	43.43
Colo., Moffat	22.10	31.61	41.95	4.34	0.72	9 297	5 165	12 710	42.50
Colo., Weld	22.20	39.23	33.12	5.45	0.33	9 578	5 320	13 310	53.90
Mont., Choutou	16.83	27.89	43.78	11.50	1.19	9 563	5 315	13 575	37.69
Mont., Musselshell, Homestead	18.14	27.22	50.49	4.15	0.88	10 420	5 795	13 540	33.20
Mont., Park, Maxey	16.33	30.12	40.05	13.50	0.41	9 247	5 130	13 400	40.51
N. Mex., McKinley	13.50	37.75	42.51	6.24	0.36	11 140	6 195	13 990	46.65
N. Mex., San Juan	19.01	32.43	43.15	5.41	0.92	10 193	5 670	13 575	42.30
Utah, Summit	17.08	36.94	41.24	4.74	1.53	10 179	5 663	13 140	46.72
Wash., King, No. 1	16.45	34.63	36.38	12.54	0.38	9 581	5 335	13 690	47.96
Wash., Lewis	20.50	33.50	33.70	12.31	1.28	8 690	4 820	13 170	48.80
Wash., Thurston	21.00	33.10	36.70	9.20	0.42	8 910	4 950	12 910	46.78
Wyo., Carbon	13.62	34.55	43.14	8.69	1.44	10 339	5 745	13 480	43.60
Wyo., Hot Springs, Gebo	17.87	31.26	43.48	7.39	0.66	10 062	5 594	13 780	41.75
Wyo., Sheridan	22.57	32.53	40.36	4.55	0.30	9 218	5 123	12 710	44.34
Wyo., Sweetwater	15.71	33.50	48.40	2.39	0.93	11 144	6 185	13 670	40.55
Average	18.31	33.06	41.29	7.34	0.73	9 818	5 450	13 330	43.80

TABLE 8.—TYPE 7, LIGNITE

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Ark., Ouachita, Lignite	39.50	25.35	22.57	12.58	0.53	5 877	3 262	12 550	51.75
Colo., Adams	35.00	27.39	30.23	7.38	0.31	6 982	3 880	12 230	46.90
Colo., Elbert, Laramie	33.10	25.60	25.60	15.66	0.44	6 150	3 420	12 300	48.60
Colo., El Paso	34.40	24.44	27.27	13.89	0.14	6 055	3 362	11 930	46.20
N. D., Adams, Haynes	32.65	30.57	28.49	8.29	1.53	7 357	4 080	12 640	50.80
N. D., Billings	43.51	25.23	24.87	6.39	1.04	5 814	3 230	11 700	49.40
N. D., Bowman	34.80	31.09	25.98	8.13	0.66	6 916	3 840	12 270	53.80
N. D., Morton	38.52	27.60	26.60	7.28	1.31	6 703	3 722	12 530	50.15
N. D., Stark	42.06	24.55	25.73	7.66	1.13	6 158	3 420	12 440	47.80
N. D., Ward	36.93	24.92	27.72	10.43	0.22	6 010	3 340	11 610	46.40
N. D., Williams	42.91	26.81	24.98	5.30	0.71	6 232	3 460	12 160	49.30
Tex., Milam	35.30	26.22	29.58	8.90	0.76	6 898	3 830	12 540	46.15
Tex., Wood	33.71	29.25	29.76	7.28	0.53	7 348	4 075	12 600	50.70
Average	37.11	26.85	26.87	9.17	0.72	6 500	3 640	12 300	49.20

TABLE 9.—TYPE 8, PEAT

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Conn., Fairfield	90.31	3.79	1.27	4.63	0.08	511	284	10 900	82.68
Conn., New London	85.66	8.52	4.54	1.28	0.10	1 382	769	9 900	67.40
Fla., Duval	73.10	14.00	8.05	4.85	1.06	2 309	1 282	10 695	61.80
Fla., Lake	82.12	11.75	5.72	0.41	0.05	1 886	1 047	10 820	67.20
Fla., Putnam	80.78	9.72	6.32	3.18	0.40	1 661	924	10 520	59.80
Me., Aroostook	86.18	8.27	3.98	1.57	0.10	1 294	719	10 680	67.00
Me., Knox	90.82	6.07	2.73	0.38	0.02	819	455	9 350	68.80
Me., Washington	85.22	8.86	4.72	1.20	0.07	1 444	802	10 710	64.90
Mich., Kalamazoo	66.91	19.04	9.29	4.76	0.09	3 024	1 670	10 825	66.66
N. Y., Oswego	54.66	29.15	12.44	3.75	0.17	4 104	2 278	9 950	69.77
Wis., Dane	71.33	16.01	6.75	5.91	0.12	2 187	1 216	9 820	69.61
Wis., Langlade	80.24	9.21	4.17	6.38	0.13	1 256	697	9 780	67.40
Wis., Marinette	76.36	10.78	4.66	8.20	0.16	1 498	832	9 930	68.30
Average	78.74	11.93	5.74	3.57	0.19	1 798	999	10 370	66.80

TABLE 10.—TYPE 10, CANNEL COAL

State, county, and seam	H_2O	Vol.	Fixed C	Ash	S	BTU/ lb.	g-cal/g	*UHV* BTU	*UVM*
Ind., Perry	1.47	49.08	26.35	23.10	1.50	10 850	6 030	14 810	64.0
Ky., Johnson, Cannel	2.36	48.40	38.75	10.49	1.20	13 770	7 645	16 010	54.9
Ky., Johnson, Lesley Cannel	1.7	50.7	38.2	9.3	1.02	14 250	7 915	16 190	56.5
Tenn., Campbell. Blue Gem	1.50	45.10	34.10	19.30	1.16	12 340	6 855	15 930	55.8
Tex., Webb, Cannel	3.98	48.87	34.91	12.24	1.96	12 227	6 790	14 830	57.65
Wash., Lewis, Cannel No. 3	7.88	61.57	15.11	15.44	0.29	11 920	6 630	15 810	79.26
W. Va., Boone, Chilton	0.52	50.92	35.82	12.74	1.10	13 830	7 680	16 200	57.95
W. Va., Boone, Cedar Grove	0.43	56.99	33.90	8.68	1.85	15 000	8 335	16 720	62.30
Average	2.48	51.45	32.14	13.91	1.26	13 023	7 230	15 820	60.85

TABLE 11.—ANALYSIS AND PHYSICAL PROPERTIES OF COKE AND WOOD CHARCOAL

Type	H_2O	Vol.	Fixed C	Ash	H	C	N	O	S	BTU/ lb.	% porosity	lb./ ft.^{3}
Jones and Laughlin	0.2	1.5	85.9	12.4	0.6	84.9	1.0	0.2	0.9	12 400	48.2	31
Continental No. 1	0.1	0.9	88.1	10.9	0.7	86.3	1.3	0.0	0.8	12 810	50.3	29
Leisenring No. 1	0.1	0.5	88.0	11.4	0.4	85.9	1.1	0.4	0.8	12 510	46.5	30.5
Wilkenson	0.2	0.5	80.3	19.0	0.4	78.9	1.4	0.0	0.5	11 690	54.1	27
Wood charcoal	3.2	20.0	72.8	4.0	3.7	78.7	0.4	13.1	0.1	12 920	63.2	17

CALORIFIC VALUE

The values characteristic of the different classes of solid fuels are evident from Fig. 1. The calorific value of a solid fuel of the fossil fuel type may be computed (1 to 2%) by means of the Du Long formula, $H = 8080C + 34\,500\left(H - \frac{O}{H}\right) + 2250S$, g-cal, where C = total carbon, $\left(H - \frac{O}{H}\right)$ = combustible hydrogen, and S = sulfur; *cf.* (34).

It may also be computed from equation (1) since the value of *UHV* is constant for a given mine or region and needs to be determined only once. For standard calorimetric methods, *v.* (5).

SULFUR CONTENT

For methods of differentiating between organic and inorganic *S*, *v.* (23). Distribution of the different forms, *v.* (19, 39, 40).

ASH FUSIBILITY

Methods (14, 26). Results for 2000 coals (26). Fusibility of coal ash by states and seams (41). Bibliography (7); *see also* (8, 25). Values range from 1040° to 1700°C.

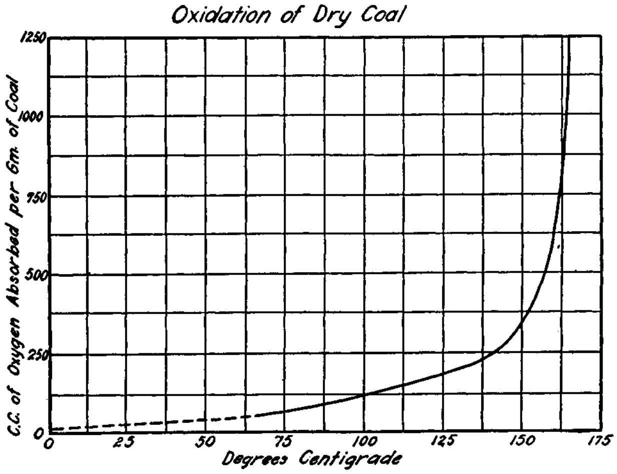

FIG. 2.—(*Courtesy Industrial and Engineering Chemistry.*)

DENSITY

True density, g/cm³; anthracite, 1.4–1.8; bituminous, 1.2–1.5; lignite, 1.1–1.4 (15). Coke, 1.45–2.0(35).

BULK DENSITY IN BIN OR PILE, ±10 TO 15% (9)

Anthracite

Size	lb./ft.³	kg/m³
Buckwheat	55	888
Pea	54	870
Chestnut	56	891
Range	56	899
Egg	56	891
Furnace	54	866
Bituminous		
Screenings	51–52	820–830
Lump	48	774
Sub-bituminous		
Lump	45–46	720–737

Additional literature: (3, 11, 12, 42).

POROSITY

Methods (3). Coal—no data. Coke—29–59% (3); *v.* Table 11.

SPECIFIC HEAT

0.26 to 0.37 g-cal/g (22).

SPONTANEOUS COMBUSTION, WEATHERING AND DETERIORATION

Absorption of oxygen by powdered bituminous coal: Fig. 2 (18). Effect of storage on calorific power: Fig. 3 (20).

COKING BEHAVIOR

See (6, 10, 13, 14, 16, 32, 33, 37).

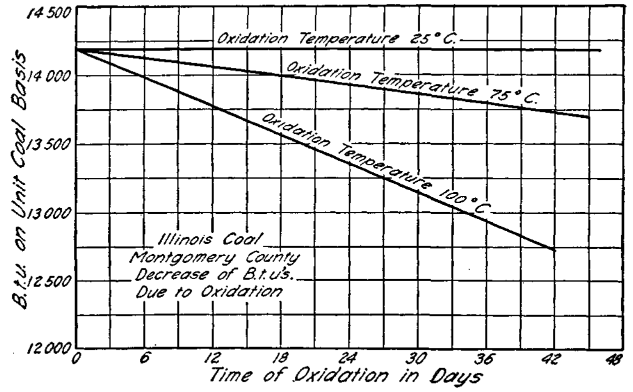

FIG. 3.—(*Courtesy Industrial and Engineering Chemistry.*)

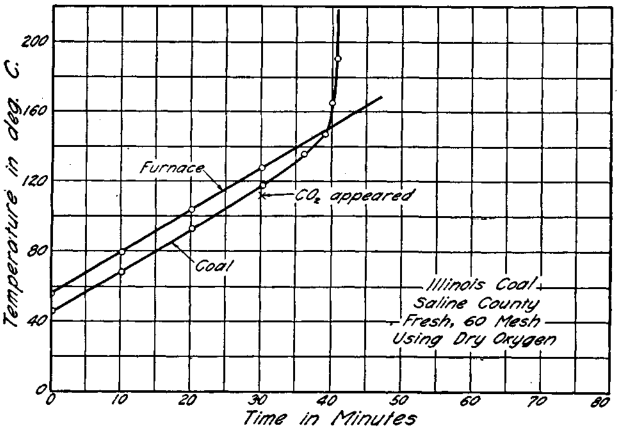

FIG. 4.—(*Courtesy Industrial and Engineering Chemistry.*)

IGNITION TEMPERATURES

The ignition temperature of a mass of coal is the temperature at which oxidation within the mass proceeds autogenously under the conditions of the experiment. Curves showing typical progress of heating within and without a 10 g sample of bituminous coal are shown in Figs. 4 and 5 (38). The following table (36) gives the ignition temperatures of various types of coal, using dry oxygen and 60 mesh "as-received" coal.

Type No.	CO_2 evolved at, °C	Ignition temp., °C
5	73	153
5	70	152
5	74	169
5	75	147
5	70	153
5	65	157
5	70	157
5	81	152
5	75	159
5	80	149
4	70	170
5	75	171
1	70	242
4	75	171
4	75	194
4	78	213
4	85	185

COMBUSTIBILITY OF COKE

A combustibility test is designed to show "the speed at which the carbon molecules in the coke combine with oxygen under given conditions" and is especially important in determining the value of a blast furnace coke. For method and results, *v.* (31).

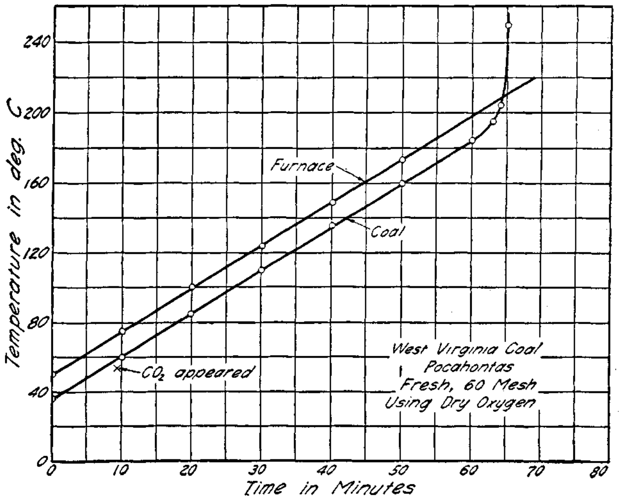

FIG. 5.—(*Courtesy Industrial and Engineering Chemistry.*)

LITERATURE

(For a key to the periodicals see end of volume)

(1) A. S. T. M., *66*, **22 I**: 815; 22. (2) A. S. T. M., *66*, **22 I**: 822; 22. (3) A. S. T. M., *66*, **23 I**: 766; 23. (4) A. S. T. M., *393*, 994; 1924. (5) A. S. T. M., *393*, 1007; 1924. (6) Dunn, *54*, **32**: 397; 13. (7) Fieldner, Hall and Field, *29*, No. **129**; 18. (8) Fieldner, Selvig and Parker, *45*, **14**: 695; 22. (9) Flagg, *32*, No. **184**; 18.

(10) Foxwell, *394*, **3**: 122; 24. (11) Hachita, *395*, **83**: 670; 07. (12) Hailstone, *396*, **151**: 566; 20. (13) Layng and Hathorne, *45*, **17**: 165; 25. (14) Lessing, *394*, **2**: 152, 186; 23. (15) Marks, *Mechanical Engineers' Handbook*, p. 455 (New York, McGraw-Hill Book Company, Inc., 1916. (16) Meurice, *394*, **2**: 305; 23. (17) Parr, *45*, **14**: 919; 22. (18) Parr, *45*, **17**: 120; 25. (19) Parr, *Univ. of Illinois, Univ. Studies, 1*, No. **7**: 33; 04.

(20) Parr and Milner, *45*, **17**: 115; 25. (21) Parr and Wheeler, *86*, No. **37**: 09. (22) Porter and Taylor, *45*, **5**: 289; 13. (23) Powell and Parr, *86*, No. **111**; 19. (24) Ralston, *30*, No. **93**; 15. (25) Rose, *33*, **25**: 141; 21. (26) Selvig and Fieldner, *29*, No. **209**; 22. (27) Seyler, *394*, **2**: 272; 23. (28) Seyler, *394*, **3**: 15; 24. (29) Seyler, *394*, **3**: 41; 24.

(30) Seyler, *394*, **3**: 79; 24. (31) Sherman and Blizard, U. S. Bureau of Mines, *O.* (32) Sinkinson, *4*, **117**: 839; 20. (33) Sinnatt and Grounds, *54*, **39**: 83; 20. (34) Somermeier, *Coal; Its Composition, Analysis, Utilization and Valuation*, p. 10 (New York, McGraw-Hill Book Company, Inc.), 1912. (35) Sperr, *80*, **64**: 640; 20. (36) Staley, Univ. of Illinois, *O.* (37) Weighell, *396*, **156**: 885; 21. (38) Wheeler, *394*, **3**: 366; 24. (39) Yancey and Fraser, *86*, No. **125**; 21.

(40) Yancey and Parr, *45*, **16**: 501; 24. (41) *Coal Catalog*, **1926**: 1078. (42) *Ibid.*, **1926**: 1116.

PETROLEUMS, PETROLEUM PRODUCTS AND COMMERCIAL OILS OF MINERAL ORIGIN

E. H. LESLIE AND J. C. GENIESSE

With acknowledgments to E. B. Badger and Sons Company of Boston for valued clerical assistance

COMBUSTIBILITY OF COKE

A combustibility test is designed to show "the speed at which the carbon molecules in the coke combine with oxygen under given conditions" and is especially important in determining the value of a blast furnace coke. For method and results, *v.* (31).

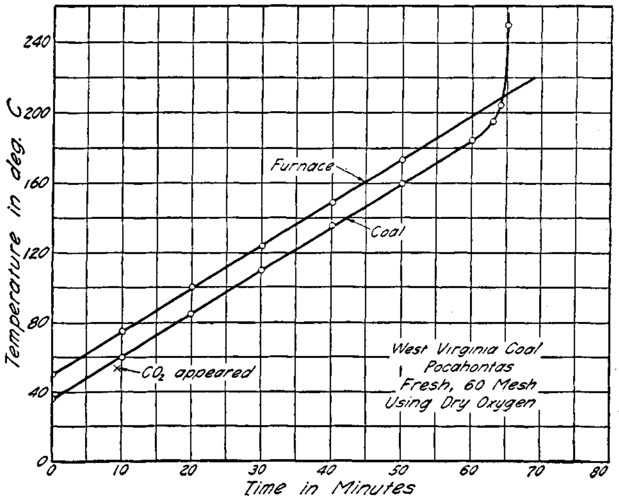

FIG. 5.—(*Courtesy Industrial and Engineering Chemistry.*)

LITERATURE

(For a key to the periodicals see end of volume)

(1) A. S. T. M., *66*, **22 I:** 815; 22. (2) A. S. T. M., *66*, **22 I:** 822; 22. (3) A. S. T. M., *66*, **23 I:** 766; 23. (4) A. S. T. M., *393*, 994; 1924. (5) A. S. T. M., *393*, 1007; 1924. (6) Dunn, *54*, **32:** 397; 13. (7) Fieldner, Hall and Field, *29*, No. **129;** 18. (8) Fieldner, Selvig and Parker, *45*, **14:** 695; 22. (9) Flagg, *32*, No. **184;** 18.

(10) Foxwell, *394*, **3:** 122; 24. (11) Hachita, *395*, **83:** 670; 07. (12) Hailstone, *396*, **151:** 566; 20. (13) Layng and Hathorne, *45*, **17:** 165; 25. (14) Lessing, *394*, **2:** 152, 186; 23. (15) Marks, *Mechanical Engineers' Handbook*, p. 455 (New York, McGraw-Hill Book Company, Inc., 1916. (16) Meurice, *394*, **2:** 305; 23. (17) Parr, *45*, **14:** 919; 22. (18) Parr, *45*, **17:** 120; 25. (19) Parr, *Univ. of Illinois, Univ. Studies, 1*, No. **7:** 33; 04.

(20) Parr and Milner, *45*, **17:** 115; 25. (21) Parr and Wheeler, *86*, No. **37:** 09. (22) Porter and Taylor, *45*, **5:** 289; 13. (23) Powell and Parr, *86*, No. **111;** 19. (24) Ralston, *30*, No. **93;** 15. (25) Rose, *33*, **25:** 141; 21. (26) Selvig and Fieldner, *29*, No. **209;** 22. (27) Seyler, *394*, **2:** 272; 23. (28) Seyler, *394*, **3:** 15; 24. (29) Seyler, *394*, **3:** 41; 24.

(30) Seyler, *394*, **3:** 79; 24. (31) Sherman and Blizard, U. S. Bureau of Mines, *O.* (32) Sinkinson, *4*, **117:** 839; 20. (33) Sinnatt and Grounds, *54*, **39:** 83; 20. (34) Somermeier, *Coal; Its Composition, Analysis, Utilization and Valuation*, p. 10 (New York, McGraw-Hill Book Company, Inc.), 1912. (35) Sperr, *80*, **64:** 640; 20. (36) Staley, Univ. of Illinois, *O.* (37) Weighell, *396*, **156:** 885; 21. (38) Wheeler, *394*, **3:** 366; 24. (39) Yancey and Fraser, *86*, No. **125;** 21.

(40) Yancey and Parr, *45*, **16:** 501; 24. (41) *Coal Catalog*, **1926:** 1078. (42) *Ibid.*, **1926:** 1116.

PETROLEUMS, PETROLEUM PRODUCTS AND COMMERCIAL OILS OF MINERAL ORIGIN

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COMPOSITION AND DENSITY OF CRUDE PETROLEUMS

North America

CANADA

Low boiling constituents are of the C_nH_{2n+2} series up to C_{10}. The C_nH_{2n} series starts at C_{11} and includes both straight-chain olefins and saturated naphthenes. The series poorer in hydrogen occur in the high boiling fractions. More aromatics present than in Pennsylvania or Ohio oils. Sulfur as thiophanes, $C_nH_{2n}S$ (**121, 127, 135, 136, 172**).

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Bothwell	0.857	0	84.3	13.4	2.3			(53.1)
Cherryvale			85.4	13.1			0.37	(53.1)
Great Manitoulin Is.	0.828	0	83.1	14.3	2.6			(53.1)
Humboldt			85.6	12.4			0.37	(53.1)
Humboldt			85.3	11.8			0.15	(53.1)
Oil Springs	0.844		83.6	13.4	0.18		0.6	(53.1)
Petrolia	0.862	20	83.9	13.4	0.16		1.01	(53.1)
Petrolia	0.870		84.5	13.5	2.0			(53.1)
Petrolia (169 m)	0.844	0	82.7	13.5	3.8			(53.1)

UNITED STATES

California.—Proportion of distillates below 225°C small to moderate and composed of methylenes similar in B. P. and sp. gr. to those in Russian oil, except for the compounds $C_{11}H_{22}$, $C_{12}H_{24}$ and $C_{13}H_{26}$. Proportion of aromatics large. Members of the C_nH_{2n+2} series absent (133). Organic bases mainly mixture of alkylated quinolines with small side chains (139). Oxygen usually as naphthenic acids with some phenolic compounds. Sulfur as $C_nH_{2n}S$.

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Adams Canyon	0.921	30			1.46		0.90	(113)
Bardsdale	0.892	20	84.2	12.2	1.25		1.5	(113)
Coalinga*	0.951	15	86.4	11.7	1.14		0.60	(53.1)
Kern River	0.967	15	86.4	11.3	0.74		0.89	(53.1)
McKittrick			86.1	11.5			0.87	(113)
McKittrick	0 960	15	86.5	11.4	0.58		0.74	(53.1)
Midway	0.958	15	86.6	11.6	0.74		0.82	(53.1)
Puente†	0.892	20	85.0	12.0	1.20		0.80	(113)
Summerland	0.985		86.3	11.7	1.25		0.84	(125)
Sunset	0.971	15	85.6	11.4	0.84		1.09	(53.1)
Torrey	0.884	20	86.0	12.5	1.15		0.5	(113)
Ventura			86.9	11.8	1.11			(113)
Ventura County	0.912		84.0	12.7	1.7	1.2	0.4	(15.1)
San Joaquin Valley	0.961	15.5	86.3	11.4	0.81		0.82	(7)
Fresno region	0.842	20	86.2	13.1			0.21	(53.1)

* Contains hexane, benzene, toluene, xylene and 7 hydrocarbons of the C_nH_{2n} series (123).

† Contains naphthenes C_7H_{14}, C_8H_{16}, $C_{10}H_{20}$, $C_{11}H_{22}$. Paraffins above M. P. 95° absent. A considerable proportion of aromatics in distillate. Large proportion of naphthene in 221°–222° distillate.

Kansas.—Mixture of paraffin- and naphthene-base crude (172).

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Chanute			84.7	14.6	0.45		0.61	(165)
Humbolt	0.912		85.6	12.4			0.37	(113)
Neodesha			84.0	13.1	0.81	0.04	0.88	(165)
Towanda			84.2	13.0	0.45		1.9	(165)

Ohio.—Paraffin-base predominates in the east. Heptylene and many alkyl sulfides have been isolated (129, 137).

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Baltimore	0.824	20	84.2	14.6	0.08		0.61	(53.1)
Findlay	0.836		84.6	13.6	0.11		0.72	(113)
Heilstone Oil Co.	0.830	20	85.8	13.8	0.023		0.63	(53.1)
Liberty (Wood)	0.843	20	85.1	13.3	0.056		0.76	(53.1)
Liberty (Hancock)	0.828	20	84.2	13.4	0.35		0.68	(53.1)
Liberty (Hancock)	0.835	20	84.0	13.1	0.047		0.71	(53.1)
Lima	0.851	20	85.0	13.1	0.024		0.81	(53.1)
Lima			85.0	13.8			0.60	(113)
Mahone*	0.904		86.4	13.3	0		0.01	(128)
Mecca			86.3	13.1	0.23			(53.1)
Montgomery	0.827	20	83.9	13.2	0.054		0.37	(53.1)
Ohio	0.887	0	84.2	13.1	2.7			(53.1)
Ohio (Wood)	0.819	20	84.3	13.5	0.21		0.56	(53.1)
Portage	0.815	20	84.4	13.4	0.13		0.68	(53.1)
St. Mary's	0.829	20	84.7	13.5	0.068		0.61	(53.1)
Trenton Limestone†			85.5	13.9				

* Does not contain C_nH_{2n} or C_nH_{2n+2} series. The C_nH_{2n-2} series from C_{11} to C_{15} present in small amounts. Main constituents $C_{16}H_{28}$, $C_{17}H_{30}$ and $C_{19}H_{34}$. No nitrogen and only 0.01 % sulfur.

† Similar to Pennsylvania but larger proportion of aromatics. 0.2 to 0.5 % nitrogen. The $x = 0$, -2 and -4 series (C_nH_{2n+x}) present and 13 hydrocarbons isolated (129, 120.1).

UNITED STATES.—(*Continued*)

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Oklahoma.—Mixed paraffin- and asphaltic-base oils.								
Field not given			85.7	13.1	0.30		0.40	(113)
Healdton			85.0	12.9			0.76	(113)
Oregon.—Trace of aromatics (53.1).								
	0.960	20	86.1	11.9	0.87		1.19	(53.1)
Pennsylvania.—Typical paraffin-base oils. C_nH_{2n+2} series up to C_{35}. C_nH_{2n} series from C_{21} to C_{26}. Light lubricant fraction mainly x = − 2 series with some aromatics (C_nH_{2n+x}); x = − 4 and −8 series, and also series up to −16 have been identified (124, 126, 130, 172).								
Allegheny	0.886	0	84.9	13.7	1.4			(53.1)
Oil City	0.810		85.8	14.0	0.06			(113)
Oil Creek	0.816	0	82.0	14.8	3.2			(53.1)
Pennsylvania			86.1	13.9			0.06	(113)
Pennsylvania			85.8	14.0				(124)
Pa. pipe line	0.862	15	85.5	14.2				(53.1)
Texas								
Beaumont*	0.91		85.7	11.0	2.61		0.7	(53.1)
Beaumont*	0.912		85.0	12.3	0.92		1.75	(173)
Utah								
			86.9	11.9	0.02		0.64	(53.1)
West Virginia.—Similar to Pennsylvania.								
Rogers Gulch	0.857	0	83.2	13.2	3.6			(53.1)
Mecook	0.897	0	83.6	12.9	3.5			(53.1)
White Oak	0.873	0	83.5	13.3	3.2			(53.1)
Burning Springs	0.841	0	84.3	14.1	1.6			(53.1)
Cumberland			85.2	13.4	0.54			(113)

* Sulfur as organic, H_2S, and free. Oil composed largely of bicylic polymethylenes with small amount unsaturated hydrocarbons and their sulfur derivatives. x = −2 and −4 series (C_nH_{2n+x}) present and also higher series up to −20 (130, 122, 131, 174).

MEXICO (31, 32)

Crude—no location given	0.929	15	84.2	11.4	0.8		3.6	
	0.940	15	83.8	11.3	1.1		3.8	
	0.970	15	83.0	11.0	1.7		4.3	

South America

Argentina	0.928	15	86.7	12.1	1.0		0.2	(31, 32)
Argentina	0.939	15	86.2	11.7	1.8		0.3	(31, 32)
Argentina (San Rafael)	0.993	15	87.0	10.8	0.9		1.3	(31, 32)
(El Quemado)	0.960	15					0.5	(119)
*Colombia**	0.948	20	85.62	11.91	0.54			(134)

* Mainly the C_nH_{2n} series with some aromatics.

Europe

FRANCE

Alsace								
Pechelbronn (tar product)	0.892	0	85.7	12.0	2.3			(169)

FRANCE.—(*Continued*)

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Pechelbronn (wet)	0.891	15	85.9	12.3	1.2		0.6	(31, 32)
Pechelbronn (dried)	0.906	15	86.4	12.1	0.8		0.7	(31, 32)
Pechelbronn (dry)	0.908	15	86.0	12.0	1.2		0.8	(31, 32)
Pechelbronn	0.912	0	86.9	11.8	1.3			(169)
Pechelbronn	0.908	0	85.6	9.6	4.75			(169)
Schwabweiler	0.829	0	79.5	13.6	6.9			(169)
Schwabweiler	0.861	0	86.2	13.3	0.5			(169)
Gabian	0.894	0	86.1	12.7		1.2		(169)

GERMANY

Hanover	0.941	15	86.5	11.6	0.7		1.2	(31, 32)
Odesse	0.892	0	80.4	12.7	6.9			(53.1)
Oberg	0.944	0	84.4	11.5	4.1			(53.1)
Wietze	0.955	0	86.2	11.4	2.4			(53.1)

ITALY

Pavia, Retorbido	0.979	0	86.4	12.2	1.4			(53.1)
Parma								
Neviano di Rossi	0.809	0	81.9	12.5	5.6			(53.1)
Marzolaro	0.938	0	84.9	11.4	3.7			(53.1)
Sala Braganze	0.786	0	84.0	13.4	1.8			(53.1)
Terra di Lavoro	0.970	21	83.6	10.8				(53.1)

POLAND

Galicia. C_nH_{2n} series present. No olefins but some aromatics.								
East Galicia	0.870	0	82.2	12.1	5.7			(109)
West Galicia	0.885	0	85.3	12.6	2.1			(53.1)
Boryslaw	0.845	15	84.4	14.3	1.34			(53.1)
Harklowa	0.903	15	84.4	14.4	1.25			(53.1)
Justa Nowice	0.863	15	85.3	14.4	0.20		0.11	(53.1)
Kosmacz	0.867	15	85.5	13.9	0.57			(53.1)
Mraznica	0.880	15	84.6	14.0	1.25		0.14	(53.1)
Schodniza			85.0	14.1	0.86		0.027	(53.1)
Urycz	0.886	15	84.9	14.1	0.84		0.16	(53.1)
Wankowa-Brelikow	0.854	15	85.3	14.4	0.11		0.19	(53.1)
Not definitely located	0.855	15	86.5	13.0	0.2		0.3	(31)
Not definitely located	0.871	15	86.8	12.6	0.3		0.3	(31)

RUMANIA [*cf.* (66)]

Source	Sp. gr. at t°C		% C	% H	% N	% O	% S	Lit.
Crude (location not given)	0.928	15	86.8	12.1	0.7		0.4	(31)
	0.940	15	87.2	11.3	1.1		0.4	(31)
	0.947	15	87.1	11.5		1.0	0.4	(31)
Apostolache	0.828	15	85.5	14.1			0.19	(53.1)
Baicoi	0.773	15	84.1	14.8			0.09	(53.1)
Berca	0.801	15	85.6	14.0				(53.1)

RUMANIA [*cf.* (66)].—(*Continued*)

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Bisoca	0.877	15	85.2	13.9				(53.1)
Bustenari	0.842	15	86.3	13.3			0.18	(53.1)
Campeni Parjol	0.773	15	85.3	14.2			0.03	(53.1)
Campina	0.848	15	86.0	13.3			0.13	(53.1)
Casin	0.800	15	85.1	13.8			0.14	(53.1)
Comanesti	0.839	15	85.2	14.2				(53.1)
Dofteana Pacuritza	0.847	15	86.1	13.0			0.21	(53.1)
Glodeni	0.833	15	85.6	13.9				(53.1)
Gura Ocnitzei	0.870	15	85.9	13.1				(53.1)
Lucacesti	0.873	15	85.9	13.3			0.28	(53.1)
Matitza-Maora	0.878	15	85.5	13.9			0.05	(53.1)
Mosoarele	0.836	15	85.5	13.4				(53.1)
Pacuretzi	0.811	15	85.9	13.3			0.08	(53.1)
Poiana-Verbilau	0.804	15	85.4	13.9			0.07	(53.1)
Recca	0.875	15	86.2	12.8			0.16	(53.1)
Sarata Monteoru	0.876	15	85.4	13.2			0.33	(53.1)
Solontzi	0.840	15	86.5	13.2			0.17	(53.1)
Stanesti	0.846	15	86.0	13.0			0.06	(53.1)
Tega	0.893	15	86.5	12.9				(53.1)
Tetzcani Antal	0.791	15	85.9	13.4			0.14	(53.1)
Tetzcani Sarbi	0.832	15	85.7	13.3				(53.1)
Tetzcani Vatra	0.792	15	85.2	14.0				(53.1)
Wallachei (Ploesti)	0.862	0	82.6	12.5	4.9			(53.1)
	0.901	0	83.0	12.2	4.8			(53.1)

RUSSIA

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Crude (no location given)	0.876	15	86.3	12.9	0.6		0.2	(31)
	0.902	15	86.1	12.8	0.9		0.2	(31)

Baku.—Low boiling distillate is of the C_nH_{2n} series. Aromatics 85–250°C. The high boiling distillate contains the x = −6, −8, −10, −12, and −20 series (C_nH_{2n+x}) and small amount naphthenic acids (130, 142).

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Baku	0.897		86.5	12.0		1.5		(53.1)
Baku	0.954		85.3	11.6		3.1		(53.1)
Benkendorff			86.6	13.4				(53.1)
Benkendorff			87.0	13.2				(53.1)
Benkendorff			86.9	13.2				(53.1)
Baku (av. analysis)			86.0	13.0		1.0		(53.1)
Balachany-Ssabuntschi	0.882		87.4	12.5		0.1		(53.1)
Binagady	0.913		85.5	12.0	2.4		0.41	(53.1)

Caucasian.—Almost entirely naphthene hydrocarbons. Small amounts of phenols, naphthenic acids and other aromatics (143).

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Caucasian			86.9	13.3			0.064	(143)
Caucasian	0.940	20	85.3	11.6		3.1		(169)
Caucasian	0.887	0	84.2	12.4		3.4		(169)
Fergana-Tschimeon	0.872		85.8	13.6			0.08	(53.1)
Grozni	0.850		86.0	13.0	0.07	0.74	0.14	(53.1)
Grozni	0.906		86.4	13.0	0.07	0.4	0.10	(53.1)
Transcaspian			86.9	12.2	0.80		0.16	(53.1)
Transcaspian	0.873		86.6	12.4	0.14	0.37		(53.1)
Tscheleken	0.874		86.4	12.4		0.38		(53.1)
Uchta	0.928		85.5	12.2	0.20	1.03	1.09	(53.1)
Uchta	0.897		85.3	12.5	0.14	1.21	0.88	(53.1)

Africa—EGYPT

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
	0.907	15.5	85.15	11.71	0.892		2.25	(82)

Mixture of paraffin- and asphalt-base oils rich in sulfur.

Asia—INDIA

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Assam								
Digboi*	0.856	15.5	86.3	12.9	0.2	0.45	0.15	(216)
Badarpur†			88.8	10.8	0.2	0.1	0.1	(216)
Burma‡	0.835		86.45	13.25	0.2		0.1	(216)
Rangoon§	0.875	28.2	83.8	12.7	3.5			(169)

* Mixed-base oil with small amount naphthenic acid. Low-boiling distillate contains aromatics.

† No solid paraffins and little asphalt. Empirical composition $C_nH_{1.47n}$.

‡ Mixed-base petroleum containing solid paraffins and asphalt. Aromatics and small amounts of naphthenic acids in the lighter distillates.

§ $C_{20}H_{26}$, $C_{22}H_{22}$, $C_{24}H_{24}$, $C_{26}H_{26}$, xylene and isocumene isolated (205).

JAPAN (138)

Chiefly the C_nH_{2n} series. Aromatics much smaller than in California.

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Amaze	0.8240	20	84.66	13.22	0.35	1.32	0.22	
Hirei	0.8622	20	83.28	13.19	0.74	1.83	0.41	
Katsubo	0.8771	20	84.52	13.12	0.97	0.21	0.82	
Kitatany	0.8952	20	83.05	13.05	0.75	0.24	0.61	
Koguchi	0.9435	20	83.91	13.60	1.34	0.41	0.49	
Kosudsu	0.9210	20	84.49	13.40	1.23	0.30	0.37	
Miyagawa	0.8911	20	84.86	13.83	0.5	0.20	0.32	

PERSIA

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Maidan-I-Naftun*	0.837		85.4	12.8	0.76		1.06	(47)

* Mixed-base oil. Gasolene fraction contains *ca.* 10 % aromatics.

East Indies—BORNEO

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Sarawak*	0.902	15	86.47	12.37	0.13	0.68	0.35	(104)

* Naphthene-base oil, with paraffin-base oils at the 1950-foot level. Small amounts aromatics.

JAVA

Source	Sp. gr. at	t°C	% C	% H	% N	% O	% S	Lit.
Rembang	0.923	0	87.1	12.0	0.9			(169)
Cheribon	0.827	0	83.6	14.0	2.4			(169)
Surabaya	0.972	0	85.0	11.2	2.8			(169)

PROXIMATE COMPOSITION

For comprehensive tables covering the chief producing fields of the world *see* (39, 53.1); for extensive tables of data on North and South American crudes, *see* (108).

Below are given the data for the oil fields of the United States as collected from the reports of the U. S. Bureau of Mines, Reports of Investigations, Nos. 2293, 2595, 2608, 2235, 2364, 2322, 2202, 2416.

The various fractions ("cuts") used in these tables are defined by their distilling ranges or by their Saybolt viscosities (η) at 100°F as follows:

1. Gasolene and naphtha. Below 200°C at 1 atm.
2. Kerosene. Between 200° and 275°C at 1 atm.
3. Gas oil. All vacuum fractions (p = 40 mm) with $\eta < 50$ sec.
4. Light lubricating distillate. All vacuum fractions (p = 40 mm) with η between 50 and 99 sec.
5. Medium lubricating distillate. All vacuum fractions (p = 40 mm) with η between 100 and 199 sec.
6. Viscous lubricating distillate. All vacuum fractions (p = 40 mm) with $\eta > 199$ sec.

Specific gravities (d) are at 60/60F = 15.5/15.5C. % S = % sulfur.

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates					
										Light		Medium		Heavy	
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$
ARKANSAS															
El Dorado	Union	0.83	0.852	30.7	0.735	13.0	0.823	12.0	0.857	11.3	0.882	4.6	0.903		
El Dorado	Union	.79	.853	28.8	.736	12.8	0.824	12.5	.853	10.8	.880	5.6	.908		
CALIFORNIA															
Coalinga (Eastside)	Fresno	.67	.880	19.8	.775			34.1	.863	9.4	0.877–0.904	6.2	0.904–0.913	1.7	0.913–0.915
Coalinga (Eastside)	Fresno	.71	.919	9.2	.782			29.9	.866	7.9	.901– .925	6.5	.925– .938	9.0	.938– .953
Coalinga (Eastside)	Fresno	.45	.910	14.7	.782			29.4	.870	10.2	.898– .918	5.8	.918– .928	7.7	.928– .940
Coalinga (Eastside)	Fresno	.51	.930	6.8	.804			26.8	.871	11.4	.906– .930	7.3	.930– .940	7.9	.940– .953
Coalinga (Oil City)	Fresno	.10	.839	53.0	.788			36.8	.886						
Coalinga (Westside)	Fresno	.71	.963	2.2	.808			18.7	.873	12.0	.901– .926	7.7	.926– .943	8.3	.943– .961
Belridge	Kern	.86	.911	23.8	.776			21.0	.872	5.5	.909– .926	5.0	.926– .940	11.4	.940– .956
North Belridge	Kern	.79	.885	33.4	.781			22.0	.854	6.1	.891– .913	3.8	.913– .929	7.3	.929– .946
North Belridge	Kern	.69	.875	34.5	.785			24.7	.855	6.3	.887– .911	4.4	.911– .924	6.1	.924– .938
Buena Vista	Kern	.50	.869	36.0	.761			21.8	.862	5.7	.904– .921	3.7	.921– .932	6.9	.932– .948
Buena Vista	Kern	.59	.890	28.0	.778			23.4	.864	6.5	.901– .920	6.5	.920– .936	6.7	.936– .946
Buena Vista	Kern	.59	.894	26.9	.783			23.1	.860	6.6	.896– .916	5.1	.916– .932	8.0	.932– .946
East Elk Hills	Kern	.68	.915	12.3	.781			31.4	.860	7.6	.905– .923	7.1	.923– .935	6.7	.935– .948
East Elk Hills	Kern	.61	.895	24.0	.786			25.0	.872	7.1	.900– .918	5.7	.918– .933	6.9	.933– .947
East Elk Hills	Kern	1.04	.948					27.2	.870	7.8	.908– .929	5.9	.929– .937	12.5	.937– .955
West Elk Hills	Kern	0.17	.773	81.1	.754	5.1	.816								
West Elk Hills	Kern	1.06	.917	12.2	.783			29.7	.858	7.2	.891– .916	3.3	.916– .923	9.8	.923– .953
Kern River	Kern	1.14	.977					16.0	.874	9.9	.910– .935	4.1	.935– .945	13.9	.945– .968
Kern River	Kern	1.07	.972					14.0	.868	6.1	.907– .928	5.3	.928– .943	15.1	.943– .960
Kern River	Kern	0.94	.971					12.2	.873	6.5	.901– .921	5.0	.921– .934	15.8	.934– .966
Lost Hills	Kern	0.85	.956	5.1	.798			19.0	.868	8.8	.917– .940	5.5	.940– .953	12.4	.953– .967
Lost Hills	Kern	0.99	.944	7.6	.777			23.6	.871	7.0	.914– .937	4.6	.937– .948	11.5	.948– .962
Lost Hills	Kern	0.66	.879	31.5	.766			20.4	.852	7.5	.883– .902	4.6	.902– .917	6.1	.917– .927
Maricopa Flat	Kern	1.07	.941	13.3	.759			20.9	.871	5.9	.916– .933	3.9	.933– .944	13.6	.944– .970
Maricopa Flat	Kern	0.60	.892	27.2	.771			21.9	.867	7.0	.904– .922	4.0	.922– .937	9.9	.937– .958
Maricopa Flat	Kern	0.75	.925	18.4	.790			21.5	.873	6.8	.913– .931	4.5	.931– .941	12.6	.941– .965
Maricopa Flat	Kern	0.69	.893	23.9	.772			21.1	.860	7.0	.884– .904	5.4	.904– .916	6.7	.916– .928
Maricopa Flat	Kern	1.29	.983					16.6	.877	5.3	.919– .934	5.0	.934– .948	18.3	.948– .974
Maricopa Flat	Kern	0.68	.895	24.1	.774			21.5	.859	7.1	.886– .903	5.2	.903– .915	8.9	.915– .928
McKittrick	Kern	1.02	.965	2.1	.810			19.9	.873	6.9	.911– .932	6.6	.932– .950	17.2	.950– .988
McKittrick	Kern	0.91	.943	11.1	.796			22.3	.874	7.1	.913– .934	5.9	.934– .951	14.4	.951– .970
McKittrick (front)	Kern	1.38	.982					14.5	.878	6.6	.910– .931	6.6	.931– .949	19.9	.949– .984
Midway	Kern	1.00	.967					15.4	.844	7.6	.916– .935	5.4	.935– .950	17.4	.950– .968
North Midway	Kern	0.96	.982					10.8	.880	9.8	.899– .931	5.5	.931– .948	16.6	.948– .978
North Midway	Kern	0.88	.936	7.1	.787			26.7	.870	8.3	.907– .932	4.1	.932– .936	11.9	.936– .963
North Midway	Kern	0.98	.962	3.3	.806			17.5	.879	7.3	.911– .930	5.1	.930– .943	16.7	.943– .966
North Midway	Kern	1.01	.978					15.4	.880	7.4	.909– .937	6.0	.937– .952	16.3	.952– .971
North Midway	Kern	1.63	.987					10.2	.887	7.7	.909– .935	5.4	.935– .949	19.9	.949– .971
North Midway	Kern	1.01	.971					18.2	.874	8.4	.910– .933	6.2	.933– .949	13.7	.949– .977
North Midway	Kern	0.92	.936	9.6	.778			23.7	.874	7.2	.909– .926	4.7	.926– .936	14.4	.936– .958
Sunset	Kern	1.16	.981					19.3	.877	5.2	.904– .928	5.5	.928– .943	20.9	.943– .969
Sunset	Kern	0.84	.956	2.9	.824			18.3	.872	8.2	.889– .912	5.7	.912– .936	10.2	.936– .957
Sunset	Kern	0.73	.878	17.0	.777			26.9	.865	7.5	.908– .923	6.3	.923– .935	8.5	.935– .952
Brea	Los Angeles	2.99	.984	6.6	.805			19.4	.875	6.5	.913– .943	3.0	.943–. 950	16.4	.950– .975
Coyote Hills	Los Angeles	1.46	.899	20.5	.764	4.7	.819	17.9	.847	8.2	.873– .898	5.6	.898– .911	5.7	.911– .924
Long Beach	Los Angeles	1.25	.904	18.9	.763	5.7	.821	17.5	.857	7.0	.882– .903	4.7	.903– .917	5.6	.917– .931
Long Beach	Los Angeles	1.29	.897	19.8	.755	3.7	.823	17.3	.854	8.0	.879– .905	4.5	.905– .917	7.2	.917– .936
Long Beach	Los Angeles	0.80	.872	29.3	.757	4.4	.818	17.7	.848	8.8	.874– .901	5.0	.901– .914	4.2	.914– .926
Long Beach	Los Angeles	1.16	.892	24.1	.762	4.1	.818	17.5	.852	7.2	.879– .898	5.2	.898– .912	5.0	.912– .931
Long Beach	Los Angeles	1.59	.908	15.8	.768			19.4	.850	6.8	.884– .907	5.3	.907– .920	8.1	.920– .938
Long Beach	Los Angeles	1.34	.920	20.0	.763	4.5	.824	16.6	.856	6.5	.884– .905	5.7	.905– .921	7.2	.921– .934
Montebello	Los Angeles	0.96	.951					19.4	.876	10.2	.905– .925	7.3	.925– .936	9.2	.936– .947
Montebello	Los Angeles	2.19	.954	6.7	.785			25.9	.867	5.2	.905– .920	5.1	.920– .929	7.0	.929– .950
Montebello	Los Angeles	0.79	.916	11.1	.794			25.4	.864	10.2	.885– .905	6.5	.905– .916	8.7	.916– .928
Montebello	Los Angeles	0.75	.916	10.6	.800			28.1	.866	9.8	.890– .907	9.3	.907– .920	6.9	.920– .929
Salt Lake	Los Angeles	2.73	.967	8.3	.793			12.8	.868	6.0	.897– .918	7.1	.918– .942	13.5	.942– .964
Santa Fe Springs	Los Angeles	0.54	.867	27.9	.769			31.3	.852	9.2	.873– .894	3.2	.894– .901		
Santa Fe Springs	Los Angeles	0.56	.878	24.6	.778			27.7	.850	10.8	.870– .894	5.4	.894– .907	2.1	.907– .915
Santa Fe Springs	Los Angeles	0.45	.851	36.7	.760	5.3	.819	20.3	.848	8.9	.870– .898	2.9	.898– .907	4.4	.907– .919
Santa Fe Springs	Los Angeles	0.54	.888	18.8	.788			30.8	.850	10.2	.875– .897	4.8	.897– .908	5.8	.908– .921
Santa Fe Springs	Los Angeles	0.45	.853	35.5	.758	5.3	.821	20.3	.850	8.0	.871– .894	4.6	.894– .906	3.1	.906– .912
Santa Fe Springs	Los Angeles	0.45	.854	35.4	.763	5.1	.823	19.0	.847	9.9	.868– .898	3.6	.898– .905	4.0	.905– .913
Santa Fe Springs	Los Angeles	0.40	.855	34.3	.763	5.5	.822	20.8	.851	8.6	.875– .899	6.7	.899– .912	1.2	.912– .914
Santa Fe Springs	Los Angeles	0.44	.859	33.3	.763	6.3	.823	20.1	.850	9.5	.873– .901	4.9	.901– .909	3.0	.909– .914
Torrence	Los Angeles	1.62	.917	14.6	.774			21.5	.853	10.0	.884– .911	5.1	.911– .921	4.3	.921– .930
Whittier	Los Angeles	0.56	.916	18.8	.795			26.4	.869	6.5	.905– .922	4.7	.922– .936	10.3	.936– .951
Whittier	Los Angeles	0.77	.942	8.2	.804			22.4	.872	9.4	.901– .924	4.1	.924– .935	6.3	.935– .949
Fullerton	Los Angeles	1.43	.920	18.1	.771			21.3	.858	7.6	.887– .909	6.7	.909– .923	5.3	.923– .933
Huntington Beach	Orange	1.42	.905	18.4	.750	3.7	.817	15.6	.846	9.2	.869– .896	5.2	.896– .911	5.0	.911– .923
Huntington Beach	Orange	1.29	.897	22.3	.763	4.1	.821	17.2	.853	7.9	.879– .903	5.2	.903– .917	4.9	.917– .929
Huntington Beach	Orange	2.22	.968	2.1	.806			17.8	.867	6.7	.901– .924	5.6	.924– .937	8.0	.937– .950

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates					
										Light		Medium		Heavy	
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$
CALIFORNIA—(*Continued*)															
Huntington Beach	Orange	2.00	0.938	12.0	0.790			19.8	0.858	7.1	0.889–0.910	5.0	0.910–0.923	7.2	0.923–0.940
Huntington Beach	Orange	1.31	.892	25.0	.764	3.5	0.825	16.2	.853	7.0	.878– .900	5.4	.900– .915	5.9	.915– .925
Huntington Beach	Orange	2.07	.922	16.7	.769	3.3	.825	17.1	.854	7.7	.883– .911	4.4	.911– .922	6.5	.922– .934
Rich	Orange	1.09	.920	14.7	.785			21.0	.859	7.9	.884– .906	6.4	.906– .919	5.0	.919– .929
Richfield	Orange	1.60	.899	25.2	.752	3.8	.821	16.8	.854	7.7	.876– .903	5.9	.903– .919	6.9	.919– .933
Casmalia	Santa Barbara	2.84	1.023					26.8	.842	2.0	.897– .917	12.7	.917– .966	7.6	.966– .982
Cat Canyon	Santa Barbara	4.13	.960	9.8	.781			25.5	.854	5.6	.906– .923	5.6	.923– .936	7.8	.936– .949
Santa Maria	Santa Barbara	2.63	.916	21.8	.768			21.2	.856	6.6	.893– .916	4.5	.916– .929	5.7	.929– .943
Summerland	Santa Barbara	0.54	.975					14.8	.873	6.6	.913– .939	5.5	.939– .956	13.1	.956– .978
Sargent	Santa Clara	0.86	.952	8.3	.776			23.3	.878	7.7	.920– .944	4.1	.944– .953	11.7	.953– .972
Arroyo Grande	San Luis Obispo	1.30	.967	5.3	.805			17.3	.872	6.2	.904– .926	4.2	.926– .939	11.9	.939– .963
Bardsdale	Ventura	0.83	.873	26.8	.762	5.1	.817	20.0	.844	9.3	.873– .902	7.3	.902– .918	2.3	.918– .923
Conejo	Ventura	0.52	.970					11.0	.885	8.4	.902– .920	7.6	.920– .935	20.7	.935– .959
Ojai	Ventura	1.63	.952	13.0	.780			18.6	.869	6.5	.907– .932	4.6	.932– .947	10.9	.947– .963
Santa Paula	Ventura	0.55	.918	13.1	.789			29.5	.860	7.4	.899– .923	3.6	.923– .936	12.4	.936– .945
Simi	Ventura	0.68	.864	32.9	.759	5.2	.820	18.9	.853	7.4	.876– .900	4.6	.900– .915	5.4	.915– .929
South Mountain	Ventura	1.73	.886	25.5	.753	4.5	.817	16.9	.848	8.7	.871– .899	7.0	.899– .915	2.1	.915– .922
Ventura	Ventura	1.15	.875	28.6	.749	4.4	.820	17.2	.847	8.5	.873– .898	4.9	.898– .911	4.5	.911– .923
Ventura	Ventura	0.47	.794	64.4	.757	15.9	.812	8.1	.843						
Ventura	Ventura	0.90	.880	22.4	.756	11.0	.816	15.2	.847	14.1	.865– .902	7.5	.902– .917	1.2	.917– .920
Composite sample	Ventura	1.79	.907	23.7	.757	4.5	.825	17.1	.858	8.3	.882– .912	4.6	.912– .923	5.6	.923– .936
COLORADO															
Florence	Fremont and Pueblo	0.17	.880	8.9	.758	14.5	.808	16.2	.842	13.3	0.871	8.3	0.892		
Rangely	Rio Blanca	.06	.819	34.6	.748	19.3	.810	12.3	.844	11.7	.860	5.6	.880		
ILLINOIS															
	*	.24	.863	20.4	.769	14.5	.834	8.0	.856	10.7	.877	6.0	.893		
INDIANA															
Lima	†	.48	.846	26.0	.753	19.2	.817	10.2	.843	10.9	.869	6.8	.885		
KANSAS															
Iola	Allen	.66	.937	.8	.800	8.4	.842	4.7	.876	14.0	.891	8.2	.907	6.9	0.923
Moran and Elsmore	Allen	.32	.875	20.2	.758	15.3	.826	6.9	.856	12.6	.875	10.8	.898		
Augusta	Butler	.41	.865	24.2	.761	20.5	.830	11.1	.863	11.4	.890	5.5	.904		
Cattlemen	Butler	.30	.838	32.8	.736	15.3	.819	9.8	.859	10.0	.879	5.1	.895		
Elbing	Butler	.29	.856	29.8	.751	20.7	.826	13.3	.864	10.8	.888	5.0	.908		
Eldorado	Butler	.29	.853	27.3	.754	20.5	.822	12.1	.861	11.1	.885	5.7	.902		
Potwin	Butler	.14	.807	45.0	.730	17.1	.813	9.9	.850	8.2	.872	3.9	.890		
Peru Sedan	Chautauqua	.25	.875	19.0	.760	16.6	.824	10.7	.863	6.4	.876	11.0	.895		
Peru Sedan	Chautauqua	.24	.882	12.6	.791	18.4	.839	5.3	.863	14.9	.878	14.0	.895		
Peru Sedan	Chautauqua	.12	.858	20.6	.755	17.1	.817	11.3	.856	11.9	.875	7.3	.891		
Peacock	Cowley	.23	.853	25.9	.763	20.2	.821	11.2	.860	11.7	.878	6.3	.896		
Elrod	Cowley	.20	.853	25.9	.753	18.6	.820	11.2	.858	10.9	.878	6.7	.897		
New Albany	Elk	.27	.866	24.7	.748	13.9	.822	10.7	.857	9.9	.878	5.5	.896		
Rantoul	Franklin	.51	.880	22.4	.740	14.0	.824	9.2	.864	5.8	.878	6.7	.898		
Sallyyard	Greenwood and Butler	.24	.839	33.2	.737	16.6	.821	9.8	.857	9.7	.877	5.0	.893		
Tester	Greenwood	.19	.841	30.1	.752	18.5	.819	11.3	.857	10.9	.875	5.3	.895		
Florence and Peabody	Marion	.23	.861	25.1	.761	18.2	.829	13.3	.859	12.1	.884	6.4	.901		
Osawatomie	Miami	.57	.892	17.1	.753	16.3	.820	9.8	.862	5.5	.880	11.8	.901		
Independence	Montgomery	.24	.855	25.3	.767	17.0	.821	13.4	.857	5.5	.878	10.8	.894		
Tyro	Montgomery	.34	.879	14.2	.771	15.4	.828	11.5	.859	6.2	.875	12.7	.894		
Wayside	Montgomery	.37	.885	17.3	.754	14.6	.821	11.1	.862	5.3	.877	9.8	.891		
Chanute	Neosho	.31	.878	15.9	.768	17.6	.828	11.5	.864	12.9	.884	7.8	.900		
Erie	Neosho	.30	.870	21.2	.745	16.2	.823	11.9	.864	6.6	.880	5.7	.894	6.1	.906
Urbana	Neosho	.32	.876	18.8	.759	16.3	.828	4.7	.861	19.1	.877	6.0	.900		
Altoona	Wilson	.25	.865	16.2	.761	17.0	.812	11.4	.853	12.5	.872	6.7	.893		
Neodesha	Wilson	.23	.846	29.9	.741	15.0	.818	10.5	.855	11.1	.875	4.4	.894		
Yates Center	Woodson	.46	.889	7.8	.808	18.9	.838	14.6	.859	15.2	.879	6.7	.896		
KENTUCKY															
Olympia	Bath	.23	.853	11.2	.757	24.5	.804	11.5	.841	12.8	.860	6.5	.872		
Ragland	Bath	.31	.902	12.6	.767	16.0	.826	8.7	.856	11.6	.878	5.4	.898		
	Lawrence	.21	.835	33.1	.744	18.4	.818	7.7	.846	10.1	.873	6.0	.896		
Big Sinking	Lee and Estell	.14	.844	31.2	.751	17.3	.819	10.6	.849	10.8	.876	5.9	.891		
Composite from several counties		.23	.835	35.4	.735	16.2	.824	9.3	.851	9.5	.874	4.6	.894		
	Wayne	.49	.869	35.9	.751	17.3	.839	11.0	.862	10.5	.887	5.0	.898		
Cow Creek	Wolf and Estell	.13	.866	19.7	.771	16.7	.828	10.4	.855	12.6	.871	7.1	.883		
Ross Creek	Wolf, Lee and Jackson	.12	.838	35.9	.744	14.6	.826	9.7	.848	10.3	.874	5.9	.894		
Compton	Wolf	.23	.842	30.8	.747	16.7	.821	10.3	.850	10.4	.870	6.0	.882		
LOUISIANA (North)															
Elmgrove	Bossier	.27	.879	13.5	.793	18.5	.841	16.7	.858	15.8	.878	7.2	.904		
Caddo	Caddo	.25	.850	25.7	.751	18.9	.806	12.5	.841	11.7	.864	5.9	.879		

* Lawrence, Crawford, Jasper and Cumberland.

† Composite from Allen and other counties.

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates					
										Light		Medium		Heavy	
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{1.55}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$
Louisiana (North) (*Continued*)															
Caddo	Caddo	0.21	0.820	35.2	0.748	22.4	0.795	11.1	0.842	9.9	0.864	5.2	0.884		
Pine Island	Caddo	.42	.901	3.0	.828	18.3	.868	7.5	.892	17.1	.899	15.6	.907		
Homer	Claiborne	.63	.844	30.2	.736	15.5	.812	10.5	.854	11.0	.875	5.9	.892		
DeSoto, Red River and Bull Bayou.	DeSoto and Red River	.21	.822	27.6	.764	36.1	.805	11.8	.845	8.4	.868	3.7	.895		
Louisiana (South)															
Jennings	Acadia	.37	.911					40.5	.880	12.4	0.909–0.922	7.5	0.922–0.929	13.6	0.929–0.944
Jennings	Acadia	.36	.908					45.6	.873	14.7	.902– .921	8.1	.921– .930	8.7	.930– .944
Edgerly	Calcasieu	.68	.925					25.9	.879	15.0	.896– .914	8.0	.914– .935	14.2	.935– .972
Vinton	Calcasieu	.33	.936					22.9	.884	13.8	.913– .935	8.2	.935– .945	16.8	.945– .962
Anse La Butte	St. Martin's	.22	.919					34.8	.881	14.6	.909– .920	8.0	.920– .928	16.1	.928– .944
Anse La Butte	St. Martin's	.30	.903					34.1	.867	16.1	.896– .912	9.5	.912– .920	8.2	.920– .930
Montana															
Winnett	Musselshell	.36	.781	63.2	.747	25.5	.814								
New York															
	Alleghany	.10	.828	30.0	.748	17.5	.802	10.3	.838	11.3	0.854	6.3	0.873		
Ohio															
North Lima	Allen	.55	.835	31.0	.749	19.2	.815	9.9	.843	10.7	.870	5.5	.890		
South Lima	Allen, Auglaize and Mercer	.55	.842	27.0	.758	20.0	.818	10.8	.841	11.5	.869	4.9	.889		
Lima	Composite from Allen and others	.48	.846	26.0	.753	19.2	.817	10.2	.843	10.9	.869	6.8	.885		
Corning	Washington	.10	.838	27.8	.740	17.0	.805	9.7	.835	10.5	.854	6.3	.871		
Penn Grade	Washington	.05	.805	33.5	.739	20.2	.798	11.3	.834	11.2	.855	5.5	.868		
Oklahoma															
Cement	Caddo	.19	.852	20.2	.766	20.7	.809	14.0	.846	6.7	.864	13.3	.880		
Healdton	Carter	.72	.870	22.3	.753	15.8	.825	10.5	.862	6.5	.880	12.1	.897		
Hewitt	Carter	.72	.858	26.6	.737	14.3	.817	9.5	.860	4.8	.877	12.4	.899		
Walters	Cotton	.42	.859	27.7	.747	17.7	.813	10.9	.860	5.2	.877	9.3	.899		
North Bristow	Creek	.25	.824	38.8	.743	18.1	.820	10.7	.858	9.2	.880	4.6	.899		
Cushing	Creek	.28	.828	37.5	.743	18.0	.818	11.5	.855	9.6	.876	4.7	.896		
Glen	Creek and Tulsa	.30	.862	24.8	.762	17.4	.827	12.5	.860	5.2	.878	11.5	.898		
Kellyville	Creek	.28	.883	14.6	.771	15.9	.830	5.9	.861	12.1	.891	6.3	.892	5.8	0.903
Mounds	Creek	.26	.853	28.2	.750	15.8	.829	9.5	.861	11.2	.883	6.0	.899		
Slick	Creek	.44	.875	22.9	.746	13.0	.832	5.9	.856	11.4	.884	4.5	.902		
Garber	Garfield	.14	.799	52.4	.737	15.7	.816	3.9	.844	11.9	.870	2.7	.891		
Blackwell or Dilsworth	Kay	.24	.830	36.3	.748	18.0	.817	10.7	.856	9.3	.877	4.8	.898		
Newkirk or Mervine	Kay	.15	.823	35.9	.743	18.9	.815	11.2	.850	11.1	.868	4.1	.884		
Arbuckle	Marshall	.06	.794	46.2	.726	17.8	.804	9.4	.839	8.2	.858	3.4	.874		
Madill	Marshall	.06	.769	85.5	.748	10.5	.806								
Boynton	Muskogee	.15	.841	24.1	.762	19.6	.816	13.0	.850	12.4	.870	5.9	.879		
Muskogee	Muskogee	.23	.852	19.5	.762	17.8	.820	13.9	.850	12.2	.868	7.3	.883		
Billing	Noble	.16	.823	40.4	.739	17.6	.819	10.7	.858	9.6	.875	4.8	.890		
Bluff and Alluwe	Nowata	.19	.865	22.1	.763	19.5	.829	10.7	.863	13.8	.886	5.1	.906		
Delaware Extension	Nowata	.23	.859	25.3	.757	17.6	.827	13.2	.862	12.4	.886	6.1	.902		
Delaware and Lenapak	Nowata	.19	.869	19.9	.765	19.1	.826	11.4	.865	6.0	.880	11.5	.901		
Deaner	Okfuskee	.13	.826	32.1	.740	16.4	.817	11.3	.853	10.6	.876	5.9	.893		
Lyons	Okfuskee	.14	.836	28.3	.752	17.4	.816	11.5	.853	11.1	.869	6.1	.888		
Bald Hill	Okmulgee	.15	.816	37.6	.737	16.4	.817	10.5	.854	10.4	.874	4.8	.890		
Beggs	Okmulgee	.15	.830	29.9	.749	14.9	.823	6.4	.853	14.1	.876	5.5	.894		
Henryetta	Okmulgee	.13	.842	25.3	.754	18.3	.819	12.1	.854	11.1	.873	5.9	.885		
Okmulgee	Okmulgee	.13	.854	17.3	.759	17.3	.815	14.7	.849	12.8	.867	7.5	.878		
Philipsville	Okmulgee	.17	.809	39.6	.728	15.4	.817	9.0	.850	10.0	.870	4.1	.886		
Youngstown	Okmulgee	.32	.870	22.2	.760	16.0	.828	13.0	.862	4.7	.879	5.4	.890	6.8	.901
Bigheart	Osage	.19	.846	28.1	.754	19.1	.827	11.4	.862	6.6	.879	10.9	.892		
Burbank	Osage	.32	.837	29.7	.746	16.9	.822	4.7	.846	12.7	.868	10.6	.894		
Hominy	Osage	.13	.840	30.9	.745	19.1	.827	11.6	.862	6.9	.883	9.7	.893		
Osage	Osage	.23	.846	28.9	.751	18.0	.824	5.2	.858	13.1	.870	10.8	.889		
Pershing	Osage	.17	.846	26.4	.751	19.9	.825	6.4	.860	12.2	.874	5.5	.895	6.2	.903
Cleveland	Pawnee	.26	.841	30.6	.753	19.8	.821	8.3	.858	5.5	.875	10.1	.897		
Jennings	Pawnee	.33	.840	32.9	.750	18.6	.820	11.7	.855	10.2	.876	5.4	.894		
Yale or Quay	Payne	.33	.858	24.8	.756	17.8	.818	9.7	.862	10.6	.879	4.9	.897		
Allen	Pontotoc	.62	.878	22.7	.751	16.5	.826	9.7	.867	5.6	.888	14.9	.901		
Claremore	Rogers	.14	.855	23.8	.761	19.2	.822	12.0	.855	11.6	.878	6.5	.895		
Comanche	Stephens	.41	.857	26.3	.755	17.1	.820	11.0	.864	5.2	.878	10.5	.895		
Duncan	Stephens	.40	.848	31.4	.746	18.0	.815	10.4	.857	6.0	.875	11.6	.897		
Owasso	Tulsa and Rogers	.27	.851	26.9	.761	18.8	.826	12.6	.858	5.9	.875	11.1	.888		
Skiatook, Sperry and Turley	Tulsa	.23	.868	20.3	.773	18.5	.833	6.4	.864	12.8	.875	13.6	.901		
Broken Arrow	Wagoner and Tulsa	.19	.853	26.2	.764	17.8	.825	10.9	.858	11.5	.881	5.2	.896		
Wagoner	Wagoner	.15	.864	16.9	.765	17.5	.820	11.1	.852	12.4	.872	7.2	.897		
Bartlesville	Washington	.25	.871	19.0	.779	18.5	.837	7.3	.867	13.6	.881	13.2	.899		
Canary	Washington	.32	.867	20.4	.771	19.2	.830	13.5	.864	6.1	.882	12.9	.894		
Ochelata Hogshooter	Washington	.27	.864	22.0	.767	17.7	.826	6.5	.859	13.1	.875	5.1	.891	8.4	.910

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates					
										Light		Medium		Heavy	
		% S	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$	%	$d^{15.5}_{15.5}$
PENNSYLVANIA															
	Allegheny and Wash.	0.08	0.800	37.8	0.733	20.2	0.792	9.6	0.831	9.3	0.848	5.7	0.859		
	Green	.08	.815	29.0	.745	18.7	.803	10.2	.834	11.9	.850	6.1	.865		
	McKean	.10	.823	32.5	.739	17.8	.802	9.4	.839	10.6	.853	5.7	.867		
Special Franklin Crude	Mercer	.09	.863	9.0	.824	15.1	.842	13.7	.850	13.5	.866	8.4	.876		
Composite		.08	.811	33.9	.734	19.9	.802	9.7	.835	11.1	.852	6.3	.865		
	Venango	.10	.819	29.6	.746	17.3	.806	10.9	.826	12.2	.850	5.2	.870		
	Venango	.08	.832	24.4	.761	16.4	.811	12.5	.827	12.2	.850	7.1	.870		
TEXAS (North)															
Holiday	Archer	.41	.839	38.2	.734	16.3	.819	11.0	.858	9.1	.885	4.9	.908		
Brownwood	Brownwood	.17	.850	24.5	.747	16.5	.821	12.5	.862	13.7	.891	5.8	.905		
Petrolia	Clay	.38	.841	34.0	.752	18.7	.818	10.9	.856	5.1	.877	5.2	.890	5.7	0.907
Santa Anna	Coleman	.16	.828	15.3	.782	18.6	.828	16.3	.852	14.6	.870	4.7	.885		
Desdemona	Comanche and Eastland	.14	.839	29.4	.761	19.4	.817	14.0	.855	5.5	.873	11.0	.893		
Ranger	Eastland	.17	.840	30.2	.759	19.7	.821	12.1	.858	12.6	.867	9.9	.895		
Mexia	Limestone	.19	.847	17.3	.768	28.4	.807	17.3	.845	12.3	.869	4.9	.894		
Corsicana	Navarro	.24	.855	19.7	.765	23.8	.811	14.7	.859	6.7	.877	11.5	.896		
Strawn	Palo Pinto	.13	.847	24.4	.763	20.2	.819	11.7	.857	12.5	.876	6.7	.890		
Moran	Shackelford	.16	.830	34.4	.743	17.2	.816	11.6	.854	10.0	.877	4.7	.897		
Breckenridge	Stepheno	.28	.844	30.0	.757	18.8	.822	11.4	.860	10.9	.880	5.0	.900		
Caddo	Stepheno	.20	.839	30.5	.756	19.1	.820	11.8	.844	11.7	.864	4.3	.885		
Burkburnett	Wichita	.38	.838	36.3	.749	17.7	.822	10.8	.862	10.4	.885	5.1	.906		
Burkburnett	Wichita	.39	.841	36.7	.742	17.0	.820	10.8	.857	5.1	.880	9.4	.899		
Electra	Wichita	.25	.824	40.8	.734	16.1	.822	8.9	.860	6.0	.876	9.0	.896		
K. M. A	Wichita	.33	.836	35.1	.746	18.1	.821	10.4	.860	5.6	.878	6.2	.895	5.4	.915
K. M. A	Wichita	.72	.854	31.2	.746	16.1	.819	9.4	.858	6.3	.880	9.6	.899		
Texhoma	Wichita	.33	.866	38.0	.739	17.2	.818	10.2	.858	5.0	.877	10.1	.897		
Thrall	Williamson	.15	.837	26.4	.763	20.8	.809	12.2	.847	11.7	.866	5.7	.880		
Young	Young	.26	.833	34.6	.750	18.7	.823	10.3	.859	5.5	.875	10.8	.892		
TEXAS (South)															
Somerset	Atascosa	.42	.823	38.8	.735	18.3	.812	8.4	.851	10.8	0.858–0.889	5.2	0.889–0.904		
Somerset	Atascosa	1.40	.855	31.0	.746	10.7	.818	14.6	.854	8.4	.874– .898	7.4	.898– .916		
Yturri	Bexar	0.45	.863	24.6	.752	10.8	.813	14.3	.840	11.0	.858– .883	6.6	.883– .901	2.7	0.901–0.909
Damon Mound	Brazoria	.28	.923					36.9	.886	14.9	.915– .933	8.4	.933– .939	14.1	.939– .948
Damon Mound	Brazoria	.36	.921	5.8	.818			36.5	.874	16.4	.913– .933	6.0	.933– .940	17.5	.940– .965
West Columbia	Brazoria	.29	.934					27.0	.851	13.8	.917– .933	8.2	.933– .943	20.7	.943– .958
West Columbia	Brazoria	.21	.906					48.8	.878	10.4	.911– .916	13.2	.916– .923	8.0	.923– .927
West Columbia	Brazoria	.45	.940					28.6	.886	12.0	.918– .934	7.5	.934– .945	15.9	.945– .957
Barbers Hill	Chambers	.67	.858	31.0	.757	5.5	.825	18.6	.854	8.0	.885– .906	4.7	.906– .912	5.9	.912– .918
Pierdes-Pintos	Duvall	.55	.927					33.9	.870	10.8	.894– .919	9.4	.919– .948	21.9	.948– .960
Blue Ridge	Fort Bend	.45	.944					21.8	.883	11.4	.922– .937	7.6	.937– .947	18.1	.947– .968
Blue Ridge	Fort Bend	.39	.894	16.2	.784			23.7	.867	12.7	.896– .909	5.9	.909– .927	11.2	.927– .960
Batson	Hardin	.61	.903	8.2	.789			34.9	.876	11.4	.908– .920	8.2	.920– .928	8.1	.928– .939
Saratoga	Hardin	.57	.977					16.8	.883	9.0	.919– .934	8.6	.934– .950	15.3	.950– .977
Sour Lake	Hardin	.43	.884	16.7	.765			30.6	.874	10.6	.907– .927	6.0	.927– .932	9.4	.932– .939
Goose Creek	Harris	.22	.926					28.5	.887	14.2	.911– .926	8.3	.926– .935	15.3	.935– .952
Goose Creek	Harris	.20	.917					36.0	.882	14.2	.914– .924	7.4	.924– .930	14.7	.930– .943
Goose Creek	Harris	.21	.910					39.2	.876	13.7	.909– .919	7.5	.919– .928	11.2	.928– .961
Goose Creek	Harris	.55	.897					51.7	.872	13.2	.900– .915	7.4	.915– .927	7.1	.927– .943
Goose Creek	Harris	.49	.931					31.0	.886	9.3	.915– .926	7.3	.926– .935	18.2	.935– .956
Humble	Harris	.43	.938					24.8	.885	3.2	.912– .918	20.0	.918– .947	17.1	.947– .961
Humble	Harris	2.40	.948	3.7	.823			24.9	.882	14.4	.913– .931	7.7	.931– .942	10.6	.942– .962
Piërce Junction	Harris	0.29	.921					36.2	.880	16.4	.922– .940	5.8	.940– .946	13.8	.946– .963
Spindle Top	Jefferson	2.31	.936					28.5	.880	13.8	.910– .925	8.6	.925– .937	17.8	.937– .955
Hull	Liberty	0.35	.863	26.6	.762			27.3	.858	10.4	.886– .905	7.0	.905– .918	7.7	.918– .932
Hull	Liberty	.44	.926	3.8	.800			22.0	.871	11.1	.901– .916	6.6	.916– .924	15.6	.924– .945
North Dayton	Liberty	.50	.899	9.8	.796			45.5	.884	11.8	.924– .937	7.2	.937– .939	8.6	.939– .942
Markham	Matagorda	.18	.831	50.2	.782	9.3	.809	26.5	.850						
Nacogdoches	Nacogdoches	.39	.923					19.5	.877	14.9	.891– .905	12.6	.905– .915	8.8	.915– .921
Orange	Orange	.45	.912					31.9	.869	13.6	.896– .911	9.7	.911– .926	8.0	.926– .930
Terry	Orange	.34	.881					27.0	.880	13.6	.901– .920	7.2	.920– .928	16.0	.928– .939
Mirando	Zapata	.25	.923					49.8	.893	14.0	.915– .931	4.5	.931– .941	14.8	.941– .969
WEST VIRGINIA															
Maryland Grade	Hancock	.084	.783	45.9	.718	16.5	.794	8.4	.839	8.3	0.848	4.3	0.858		
Maryland Grade	Harrison and Doddridge	.20	.808	29.5	.741	18.9	.795	9.0	.823	11.5	.840	7.2	.859		
Maryland Grade	Harrison and others	.27	.800	33.4	.735	20.4	.795	9.8	.823	12.1	.843	4.0	.864		
Blue Creek	Kanawha	.11	.810	40.2	.727	18.0	.797	9.2	.829	9.1	.849	4.6	.862		
Cabin Creek	Kanawha	.19	.797	40.5	.730	21.0	.797	8.0	.827	8.9	.844	4.2	.856		
Kelly Creek	Kanawha	.11	.799	39.6	.731	18.4	.798	9.9	.829	9.8	.847	4.5	.859		
Eureka Grade	*	.10	.805	31.3	.739	18.5	.799	12.1	.825	11.0	.844	5.6	.856		
Eureka Grade	*	.24	.806	37.7	.734	17.7	.801	9.2	.829	9.6	.845	6.0	.848		

* Ritchie, Wood, Wirt, Calhoun, Roan and Kanawha.

Field	County	Crude		Gasolene and naphtha		Kerosene		Gas oil		Lubricating distillates					
										Light		Medium		Heavy	
		% S	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$	%	$d_{15.5}^{15.5}$
WEST VIRGINIA (*Continued*)															
Maryland Grade	*	0.28	0.805	38.3		18.0	0.804	9.3	0.825	9.3	0.852	5.2	0.872		
Maryland Grade	Tyler	.095	.804	35.8	0.744	20.8	.795	10.6	.824	11.2	.844	4.8	.862		
Eureka Grade	Tyler, Doddridge, and Wetzel	.098	.808	34.0	.748	19.4	.810	9.9	.828	10.3	.844	5.3	.857		
Maryland Grade	Tyler, Doddridge, and Wetzel	.094	.803	37.1	.737	18.7	.798	10.1	.827	9.8	.839	4.8	.852		
Maryland Grade	Wetzel and Marshall	.11	.804	34.6	.732	19.1	.798	10.7	.827	10.0	.846	5.1	.862		
WYOMING															
Greybull	Bighorn	.08	.803	38.6	.738	17.8	.806	11.0	.830	10.9	.844	4.7	.858		
Ferris	Carbon	.19	.842	31.1	.747	13.4	.823	10.8	.847	11.7	.864	6.0	.881		
Lost Soldier	Carbon	.11	.875	16.7	.804	18.5	.854	18.6	.864	15.7	.875	6.7	.898		
Rock Creek	Carbon	.27	.843	31.4	.744	14.2	.826	10.0	.854	10.3	.876	5.4	.890		
Big Muddy	Converse	.17	.863	22.2	.762	15.7	.832	9.0	.860	11.1	.877	5.9	.890		
Dallas	Fremont	2.42	.914	12.8	.772	14.5	.827	10.8	.873	7.5	.897	7.0	.916	7.2	0.935
Lander	Fremont	2.62	.913	11.0	.755	16.0	.825	11.1	.869	15.1	.899	6.1	.921		
Maverick	Fremont	2.46	.922	8.6	.765	14.7	.824	10.9	.869	13.7	.901	8.0	.924		
Pilot Butte	Fremont	0.22	.848	24.0	.765	19.7	.815	13.2	.846	12.8	.864	5.9	.884		
Plunkett	Fremont	.55	.846	21.0	.779	22.6	.827	16.3	.852	14.0	.868	6.5	.883		
Grass Creek	Hot Springs	.14	.809	42.6	.741	20.0	.820	9.9	.850	9.3	.865	4.5	.881		
Hamilton Dome	Hot Springs	2.09	.903	17.6	.746	15.8	.826	8.7	.876	5.7	.893	12.4	.917		
Pine Mountain	Natrona	0.51	.953					Decomposed when heated at atmospheric pressure							
Salt Creek	Natrona	.18	.841	29.3	.750	15.7	.824	10.8	.847	11.1	.865	5.8	.880		
Shannon	Natrona	.20	.909	3.1	.838	11.1	.867	4.9	.884	19.1	.892	8.0	.905	8.4	.909
Lance Creek	Niobrara	.18	.823	33.5	.754	16.2	.812	11.3	.849	10.7	.859	6.0	.876		
Mule Creek	Niobrara	.14	.867	11.7	.768	17.4	.821	13.1	.850	14.6	.869	7.4	.882		
Elk Basin	Park	.14	.827	40.5	.748	17.4	.829	10.6	.862	9.8	.875	4.8	.890		
New Castle	Weston	.15	.840	31.6	.754	17.4	.826	10.3	.856	11.0	.871	5.6	.887		
Osage Range	Weston	.29	.837	34.8	.746	15.8	.825	9.8	.857	10.5	.873	5.1	.893		

* Ritchie, Wood, Wirt, Calhoun, Roan, Kanawha and Gilmer.

SPECIFIC GRAVITY AND THERMAL EXPANSION

In this section, S will be used to represent $d_{15.56}^{15.56°}\text{C} = d_{60}^{60°}\text{F}$.

CONVERSION FORMULAE

All weights in vacuo

$$°\text{API} = \frac{141.5}{S} - 131.5. \quad °\text{Bé (American)} = \frac{140}{S} - 130$$

$$\text{Lb. per gal. (U. S.)} = 8.328 \times S$$

$$\text{Lb. per gal. (Brit.)} = 10.00 \times S$$

$$\text{Gal. (U. S.) per lb.} = 0.1201 \times S$$

$$\text{Gal. (Brit.) per lb.} = 0.1000 \times S$$

For other conversion factors, *v.* vol. I, p. 23. For elaborate computed conversion tables convenient for interpolation, *v.* (10).

Crude Petroleums

The specific gravity of crudes varies with locality between the extreme limits 0.65 to 1.07. Below are given only those crudes for which values above 0.95 or below 0.75 have been recorded. The recorded data for all other crudes lie between the above values. For these *v.* (26, 39, 53.1, 87, 120, 169).

SPECIFIC GRAVITY OF CRUDE PETROLEUM FROM VARIOUS PARTS OF THE WORLD

Sp. gr. > 0.95

Source	Sp. gr.
AFRICA	
Algeria	0.79 to 0.98
Egypt	0.83 to 0.97
Gold Coast	0.87 to 0.98
Ivory Coast	0.96
Sidi Brahim	**1.02**
Tunis	0.97
ASIA	
Assam	0.86 to 0.98
Burma	0.81 to 1.00
Japan	0.80 to 0.98
Malay Archipelago	
Borneo	0.86 to 0.97
Java	0.81 to 0.97
Roengkoet	0.97
Persia	0.78 to 1.06
AUSTRALIA	0.84 to 0.97
New Zealand	0.84 to 0.97
EUROPE	
Galicia (Drohobycz)	0.84 to 0.96
Germany	0.81 to 1.00
Greece	1.05
Hungary	0.80 to 0.98
Italy	0.75 to 0.97
Russia (Daghestan)	0.85 to 0.96
NORTH AMERICA	
Canada	0.75 to 0.97
Cuba	0.73 to 0.96
Haiti	0.92 to 0.96
Mexico	0.79 to 1.06
United States	
Alaska	0.79 to 0.99
California	0.77 to 1.01
Louisiana	0.80 to 0.97
Oklahoma	0.79 to 0.88
Texas	0.80 to 0.97
Utah	0.83 to 0.95
Wyoming	0.80 to 1.00
SOUTH AMERICA	
Argentina	0.90 to 1.00
Barbados	0.88 to 0.97
Colombia	0.86 to 0.97
Ecuador	0.88 to 0.99
Peru	0.82 to 0.95
Trinidad	0.81 to 0.98

SPECIFIC GRAVITY OF CRUDE PETROLEUM.—*(Continued)*

Source	Sp. gr.
Sp. gr. < 0.75	
EUROPE	
Italy	0.75 to 0.97
Russia (Caucasus)	**0.65**
NORTH AMERICA	
Canada	0.75 to 0.97
Cuba	0.73 to 0.96
United States	
Pennsylvania	0.70 to 0.89

STRAIGHT RUN PETROLEUM PRODUCTS (113)

Approximate specific gravity range at 15.5°C = 60°F

Product	Range
Paraffin-base Crude	
Cymogene (rare)	0.588
Light petroleum ether	0.633–0.626
Heavy petroleum ether	0.654–0.639
Natural gas gasolene	0.675–0.622
Gasolene	0.747–0.709
Kerosene	0.816–0.797
Mineral seal oil (300 burning oil)	0.825–0.811
Gas oil	0.845–0.816
Non-viscous neutrals	0.865–0.850
Viscous neutrals	0.882–0.865
Paraffin oils	0.904–0.876
Paraffin wax	0.947–0.871
Red oils	0.910–0.904
Filtered cylinder stock	0.896–0.887
Bright stock	0.916–0.893
Steam-refined oils	0.928–0.898
Naphthene-base Crude	
Natural gas gasolene	0.702–0.669
Light gasolene (if any)	0.720–0.702
Gasolene (if any)	0.763–0.731
Kerosene (if any)	0.825–0.816
Gas oil	0.876–0.855
Low pour test machine oil (low viscosity)	0.928–0.922
Low pour test machine oil (medium viscosity)	0.934–0.928
Low pour test machine oil (high viscosity)	0.940–0.934
Black oil	0.947–0.940
Flux	0.986–0.973

GASOLENE FRACTIONS (177)

Kind of gasolene	Sp. gr. of fraction. 15.5°/15.5°C = 60°/60°F						
	Fractionation temperatures						
	Up to 50°C	50° to 75°C	75° to 100°C	100° to 125°C	125° to 150°C	150° to 175°C	175° to 200°C
Eastern "straight" refinery	0.633 to 0.639	0.666 to 0.672	0.699 to 0.712	0.727 to 0.736	0.742 to 0.755	0.764 to 0.770	
Mid-Continent "straight" refinery	0.630 to 0.645	0.672 to 0.696	0.712 to 0.736	0.736 to 0.761	0.755 to 0.779	0.773 to 0.779	0.788 to 0.795
California "straight" refinery	0.639 to 0.645	0.678 to 0.693	0.723 to 0.739	0.752 to 0.764	0.773 to 0.788		
Blended casing head (eastern)	0.624 to 0.633	0.663 to 0.675	0.703 to 0.715	0.733 to 0.739	0.752 to 0.761	0.767 to 0.776	0.782 to 0.785
Cracked (Mid-Continent)	0.636 to 0.645	0.675 to 0.684	0.712 to 0.721	0.736 to 0.749	0.752 to 0.767	0.767 to 0.785	0.788 to 0.801

Blending Chart.—For use in determining % of naphtha to be added to gasolene to obtain blend of given density, *v.* (8).

LUBRICATING OIL AT LOW TEMPERATURES

This sample had the following properties: $S_{15.5}^{15.5} = 0.9427$; Fl. P., 224°C; η at 98.9°C, 92 sec Saybolt; Pour point, −18°C. The density data were $d_4^t = 0.9740$, (−35° to −40°C); and $d_4^t = 0.9523 - 0.000665t$, (−30° to +20°C) (76).

PARAFFINS

Solid.—$d_{15}^{15} = 0.87 - 0.94$; $d_{15}^{50} = 0.84 - 0.89$. Recorded data on thermal expansion very conflicting, possibly due to enclosed air (19, 158, 166, 211). Between −190° and 17°C Dewar found $\frac{1}{V}\frac{\Delta V}{\Delta t} = 0.000357$ per deg (43).

Liquid.—$d_{15}^{50} = 0.777 - 0.785$; $d_{15}^{80} = 0.755 - 0.780$. $d_{15}^t =$ const. $(= 53 \text{ to } 85) \times 10^{-5}t$ (between *ca.* 50° and 100°C) (19, 158, 166, 211).

MISCELLANEOUS

Petrolatum ("Vaseline").—$d_4^t = 0.873$, 23°; 0.868, 32°; 0.862, 42°C (206).

Petroleum Ether.—$V_t = V_0(1 + 146 \times 10^{-5}t + 16.0 \times 10^{-7}t^2)$, −190° to 0°C (90).

THERMAL EXPANSION

$$d_t = d_s - \alpha(t - t_s) + \beta(t - t_s)^2$$

$$\alpha = (66 \pm 5) \times 10^{-5};\ \text{for } S \nless 0.84$$

$$\alpha = [(189.4 - 146.5S) \pm 3] \times 10^{-5};\ \text{for } S \ngtr 0.84$$

$$\beta = [(-15.4 + 19S) \pm 2] \times 10^{-7}$$

$$d_t = d_4^t \text{ or } d_{15.5}^t$$

$$d_s = d_4^{t_s} \text{ resp. } d_{15.5}^{t_s} \text{ when } 15^\circ < t_s < 35^\circ$$

S = the density or specific gravity (two decimal places sufficient) at any temperature between *ca.* 15° and 35°.

Example: Given $d_{15.5}^{17} = 0.6935$, to find $d_{15.5}^{60}$

$$d_{60} = 0.6935 - (189.4 - 146.5 \times 0.69) \times 10^{-5} \times (60 - 17) + (-15.4 + 19 \times 0.69) \times 10^{-7}(60 - 17)^2 = 0.6551 \pm ca.\ 0.0003.$$

For all practical purposes, the above relations appear to be applicable to all petroleum oils, both crude and refined, between 0° and 50°C (and probably to 100°C) as long as they continue to remain homogeneous liquids sufficiently fluid to be measured with a hydrometer (18). For elaborate computed tables convenient for temperature conversions and based substantially on the above relations *v.* (10, 41).

Additional Literature on Thermal Expansion.—Crudes (51, 94, 148, 182, 183, 197). Derivatives (94, 102, 117, 181).

Expansion above 100°C.—A recent investigation (225) of California petroleum products yields the equations:

$$v_t = v_{15.56}[1 + \alpha(t - 15.56^\circ) + \beta(t - 15.56^\circ)^2] \quad \text{(Range, 15° to 260°C)}$$

and

$$v_t = v_{260}[1 + \alpha'(t - 260^\circ) + \beta'(t - 260^\circ)^2] \quad \text{(Range, 260° to 400°C)}$$

$$\alpha = [2.32 - 1.7S] \times 10^{-3};\ \text{for } S \nless 0.82$$

$$\alpha = [4.36 - 4.2S] \times 10^{-3};\ \text{for } 0.82 < S < 0.75$$

$$\beta = [4.86 - 4.5S] \times 10^{-6}$$

For S =	1.0	0.95	0.90	0.89
$10^3 \alpha'$ =	0.75	0.83	1.05	1.20

$$\beta' = [20.29 - 19.45\,S] \times 10^{-6}$$

where v_t is the volume (cm³) at t°C, and S is the specific gravity at 15°C.

COMPRESSIBILITY

The mean coefficient of compressibility between P_1 and P_2 is defined by the equation

$$\beta = \frac{V_{P_1} - V_{P_2}}{V_{P_1}(P_2 - P_1)}$$

Kerosene and Lubricating Oils.—Within the accuracy of the measurements, all available data are correctly expressed by the equation

$$\frac{10^{-6}}{\beta} = \mathrm{a} + \mathrm{b}P - \mathrm{c}P^2 + \mathrm{d}P^3,$$

in which $\beta = \dfrac{V_0 - V_P}{V_0 P}$ is the mean coefficient between 0 and P.

Conversion Factors.—To convert a pressure, in any of the following units, into atmospheres, multiply it by the factor given.

Megabarye	kg cm^{-2}	Lb. in. $^{-2}$
0.98692	0.96784	0.068047

Kerosene.—Between 1 and 11 atmospheres and 0–100°C, β in atm.$^{-1}$ is expressed by the equation $\beta = (67.5 + 0.458t) \times 10^{-6}$ (161).

PARAFFIN (17)

M. P. 55°C $\qquad \beta = \dfrac{V_{20} - V_P}{V_{20}P}$

P	$10^6\,\beta$ at t°C			
atm.	64°	100°	185°	310°
20				
100	83	106	172	331
200	83	103	156	289
300	84	99	147	257
400	solid	94	137	236

P in atmospheres. "Range" = pressure limits within which the equation may be used to calculate $\dfrac{V_{P_1} - V_{P_2}}{V_{P_1}}$

Name of oil	t°C	10^3a	10^6b	10^{12}c	10^{15}d	Range atmospheres	$\dfrac{10^5(V_0 - V_{1000})}{V_0 \times 1000}$	Lit.
Kerosene	20	(13.05)	4.417_5	160.2_4	5.11_4	2000–12 000	5.776	(1)
Kerosene	20	13.05	4.205_9	135.9_4	3.68_7	0–12 000	5.839	(23)
Kerosene	40	11.60	4.222_0	135.3_9	3.34_3	0–12 000	6.374	(23)
Kerosene	60	10.48	4.037_9	113.6_9	2.48_4	0–12 000	6.941	(23)
Kerosene	80	9.55	3.807_9	91.1_5	1.79_4	0–12 000	7.537	(23)
"Paraffin oil"*	34	12.0	4.631	280.6	24.3	0– 4 300	6.107	(153)
Lubricating oils								
"F. F. F. cylinder"	40	17.7	4.3	0.0	0.0	0– 1 400	4.545	(95.1)
"Mobile A"	40	17.4	4.3	0.0	0.0	0– 1 400	4.608	(95.1)
"Mobile BB"	40	18.0	4.3	0.0	0.0	0– 1 400	4.484	(95.1)
"Victory red"	40	18.9	5.0	0.0	0.0	0– 1 400	4.184	(95.1)
"Bayonne"	40	$17._1$	4.3	0.0	0.0	0– 1 500	4.673	(95.1)

* $d_4^0 = 0.812$; $d_4^{34} = 0.78_8$; flash point 55°C.

VISCOSITY

See also Lubricants and Lubrication, p. 164.

Viscosity Units and Their Interconversion. *See* vol. I, p. 25.

Viscosity at Room Temperatures.—Typical values in poises are:

(*a*) Gasolenes, 0.003–0.006;
(*b*) Kerosene, 0.02;
(*c*) Light lubricating oils, 0.025–1.5;
(*d*) Medium lubricating oils, 1.5–3.5;
(*e*) Heavy lubricating oils, 3.5–20;
(*f*) Petrolatum (M. P., 85°–95°F), 1.3 at 130°, 0.24 at 210°F.

Variation of Viscosity with Temperature.—If the viscosity of an oil is known at two temperatures, its viscosity at a third temperature may be obtained graphically with the aid of Fig. 1. When the viscosity temperature values for any oil are graphed on this chart a straight line will be obtained for all portions of the temperature range within which the oil remains a homogeneous liquid of constant composition (11). Copies of this chart may be obtained by addressing The Texas Company, New York City.

SURFACE TENSION

Below are summarized the reported data on the surface tension (γ, in dynes per cm) of various products.

Crudes.—24–38 at 20°C (63, 84, 160, 176). The lower values, 24–26, are reported for crudes from Pennsylvania and California (176); the higher values, 35–38, for crudes from California fields at Montebello, Sunset, and Kern (84).

Petroleum Distillates.—For distillates up to 300°C, γ = 19–29 at 20° and is approximately a linear function of the density. *See* Fig. 12 (p. 157). $d\gamma/dt$ = *ca.* −0.1 per °C between 0° and 50° (63, 64, 140, 176).

Naphthas.—(B. P. up to 150°C). γ = 19–23 at 20° (176).

Kerosenes.—(B. P. 150°–300°C). γ = 23–32 at 20° (77, 176).

Gas Oils.—γ = 28–29 (175).

"Gas Oil Distillates."—(150°–300°C). γ = 21–28 (175).

"Tar Oils."—γ = 34–37.6 (175).

"Tar Oil Distillates."—(150°–300°C). γ = 27–36 (175).

Lubricating Oils.—Oklahoma and California. γ = 36–37.5 at 30°C (63, 78).

"Wax Distillates."—γ = 34–36 at 30°C (63).

Paraffin.—γ = 30.6 at 54°C (162).

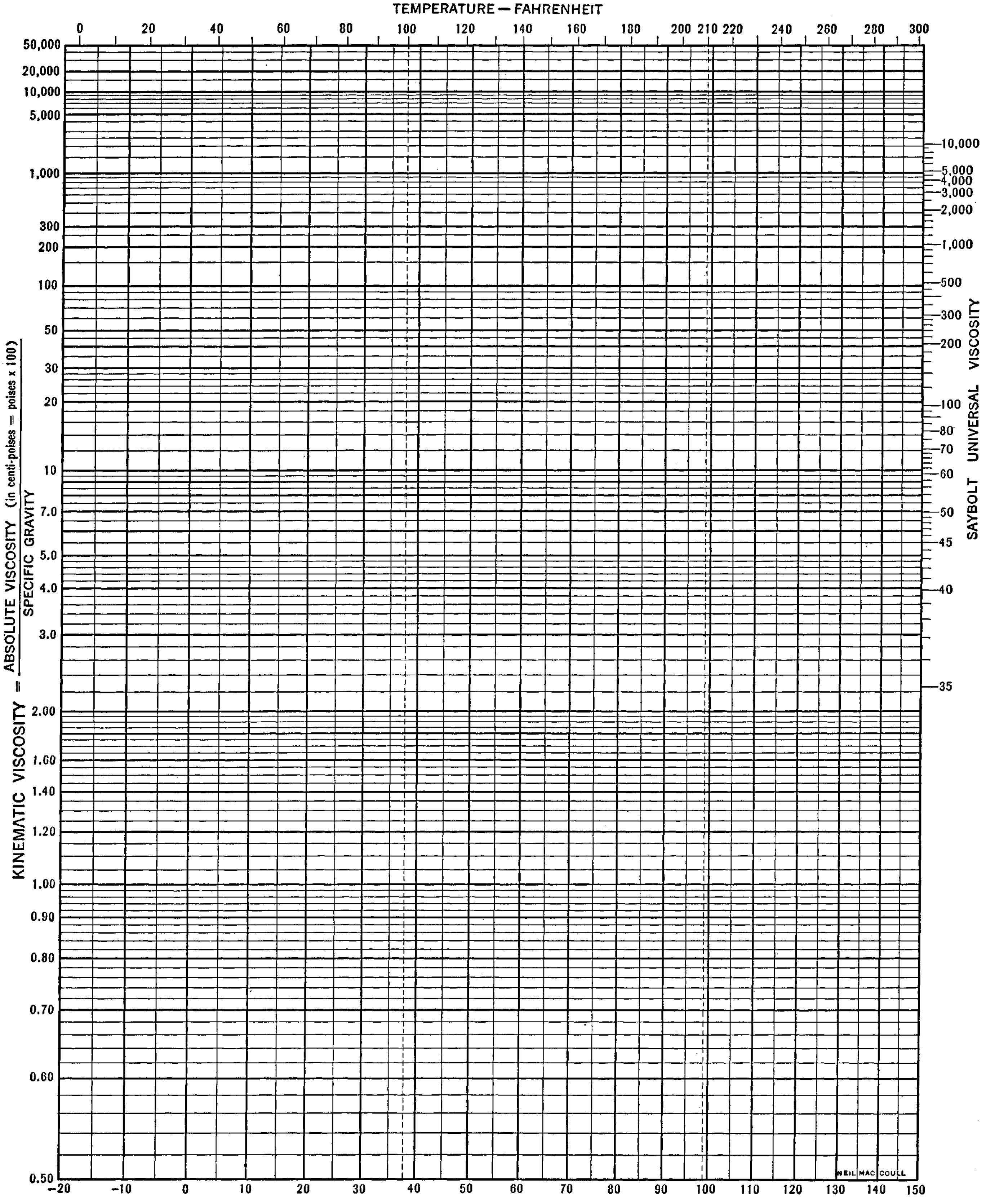
INTERFACIAL TENSIONS

Oil-Water Interface.—Dyne cm^{-1}. Gasolenes and naphthas, 39–51: kerosene, 47–49: mineral seal, 47–50: lubricating oils, 33–54: cylinder oils, petrolatum, paraffin at higher temperatures, 35–50, increasing after filtration. Several days' exposure to light produces decreases up to 30% (70, 99). $d\gamma/dt$ = *ca.* −0.1 between 4° and 8°C.

Addition of fatty acids lowers the interfacial tension against both H_2O and Hg (20, 213).

PENETRATIVITY (1)

The penetrativity, z, of a liquid is measured by the ratio $\gamma/2\eta$ where η is the viscosity (206). If z for H_2O is taken as 1 at room temperature, z for kerosene is 0.05 at 20°C; z for paraffin is 0.092 at 65°, 0.39 at 185° and 0.45 at 215°C. z for petrolatum ("vaseline") in absolute units is $0.063(t - 30)^2$ cm sec^{-1}, where t is the temperature in °C between 100 and 200.



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PETROLEUM AND ITS PRODUCTS

VISCOSITY---TEMPERATURE CHART

Fig. 1.

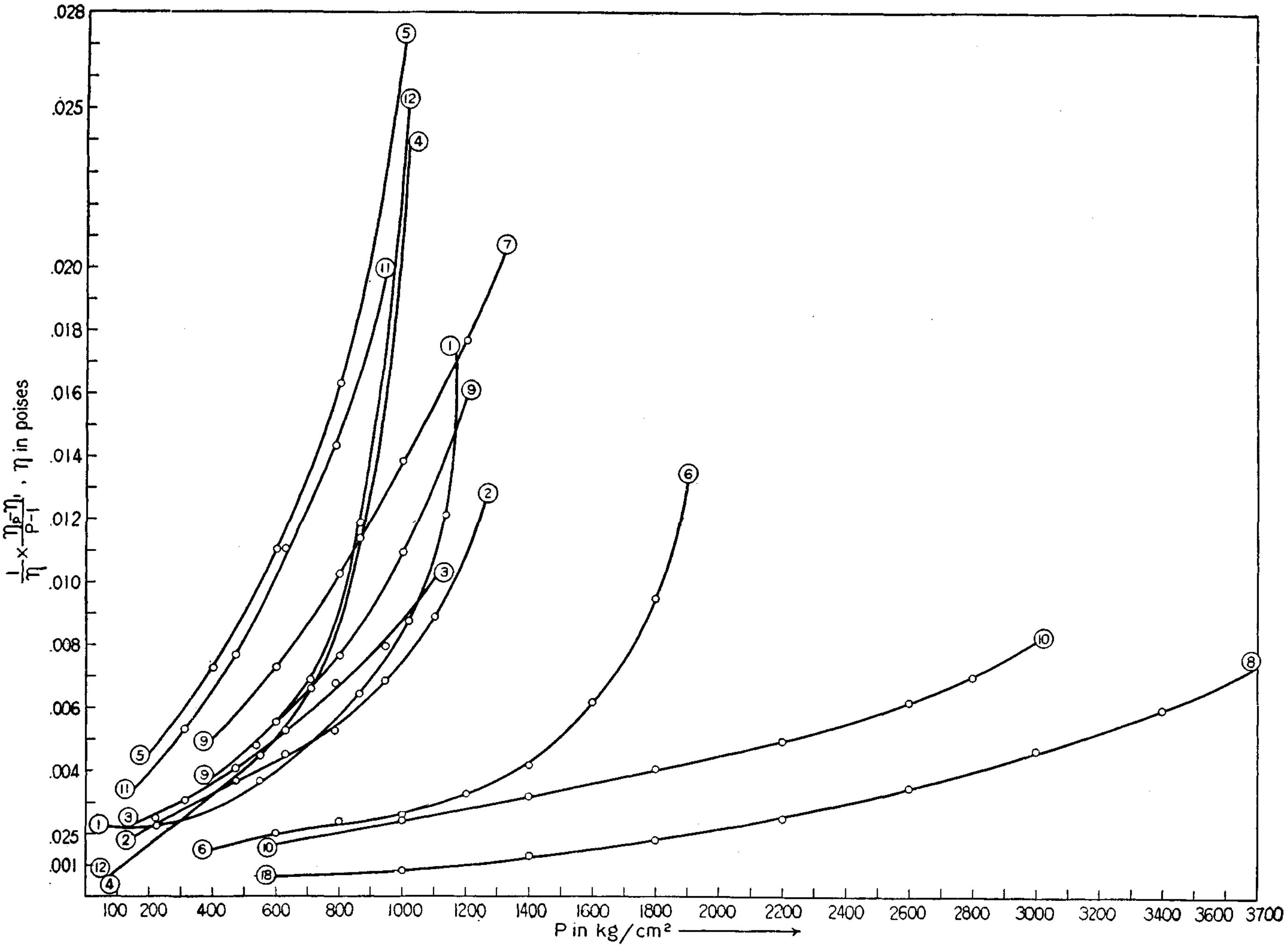


Fig. 2.—Variation of viscosity with pressure.

Curve No.	Designation of oil	t, °C	Lit.
1	Mobiloil "A"	40	(95)
2	Bayonne: d_{15}^{15} 0.906; Fl. P. 191°C; η_{100} 330 Saybolt; pour test 0°C		(95)
3	F. F. F. cylinder: d_{15}^{15} 0.892; Fl. P. 260.0°C; η_{100} 2400 Saybolt; pour test 5.6°C	40	(95)
4	Mobiloil "B. B."	40	(95)
5	Mobiloil "A"	24	(85)
6	Mobiloil "A"	100	(85)
7	Texaco	24	(85)
8	Texaco	100	(85)
9	Veedol	22	(85)
10	Veedol	100	(85)
11	Victory red mineral: d_{15}^{15} 0.914; Fl. P. 183.9°C; η_{100} 1140 Saybolt; pour test 2.8°C	40	(95)
12	Mobiloil "B": d_{15}^{15} 0.908; Fl. P. 201.7°C; η_{100} 390 Saybolt	40	(95)

MELTING POINT

The petroleum products of commerce are all mixtures, and consequently possess no sharp melting or freezing point; but exhibit instead a *melting range.* It is, of course, possible by suitable blending to obtain a product with almost any initial melting or freezing point between the extreme limits of −150°C (0.70 specific gravity gasolene) and +60°C (the high melting waxes).

Typical Values.—The limiting values recorded below show the regions of the temperature scale within which the melting or freezing ranges of some typical commercial products may be expected to lie (For "pour test" *see* p. 156).

Material	Typical melting or freezing range, °C
Gasolene 0.704 sp. gr. 15.5/15.5	−122 to −150
.719 sp. gr. 15.5/15.5	−120 to −147
Petroleum jelly—pale	39 to 51
Paraffin waxes:	
Match wax	40.5 to 46
White crude scale (Pa.)	50 to 52.2
Semi-refined (Pa.)	50 to 51
Fully refined (Pa.)	49 to 50
Fully refined (Calif.)	59 to 60
Ceresins:	
General range	60 to 80
Normal wax	65 to 66
Pure	79 to 80

Melting Point of Paraffins

Variation of melting point with oil content (221)

Material	% of pressed oil	Refractive index at 25°C	Melting point °C
"Parowax"	0.16	1.4481	51.7
Refined wax	0.28	1.4487	50.0
Refined wax	0.25	1.4485	50.0
Refined wax	0.17	1.4481	51.7
Refined wax	0.16	1.4479	51.7
Refined wax	0.09	1.4476	54.4
Refined wax	0.08	1.4475	54.4
Scale wax	2.58	1.4570	48.3
Scale wax	2.56	1.4568	48.3

Variation of Melting Point of Paraffin with Pressure

$t_P = t_0 + 0.029776 \quad (P - 1) - 0.0000523 \quad (P - 1)^2$, between 1 and 200 atm.

t_P (resp. t_0) = melting point of paraffin under pressure P (resp. 1 atm.).

SOLUBILITY OF PARAFFIN

For solubility of various kinds of paraffin in gasolenes, kerosene, lubricating oil, paraffin oil, fuel oil, benzene, alcohols, and acetic acid *see* (184).

VAPOR PRESSURE AND BOILING POINTS

The few available data when graphed (log p against $1/T$) are found empirically to give approximately straight lines. p = the vapor pressures at T°K. In the table below are given, (1) typical or limiting values of the B. P. (at 1 atm.) for the class, (or, in parentheses, the B. P. at 1 atm. as obtained by extrapolation of the vapor pressure curve); (2) the range covered by the available vapor pressure data; (3) the value of d $\log_{10} p/\text{d}(1/T)$, the slope of the vapor pressure curve; and (4) the source of the experimental data.

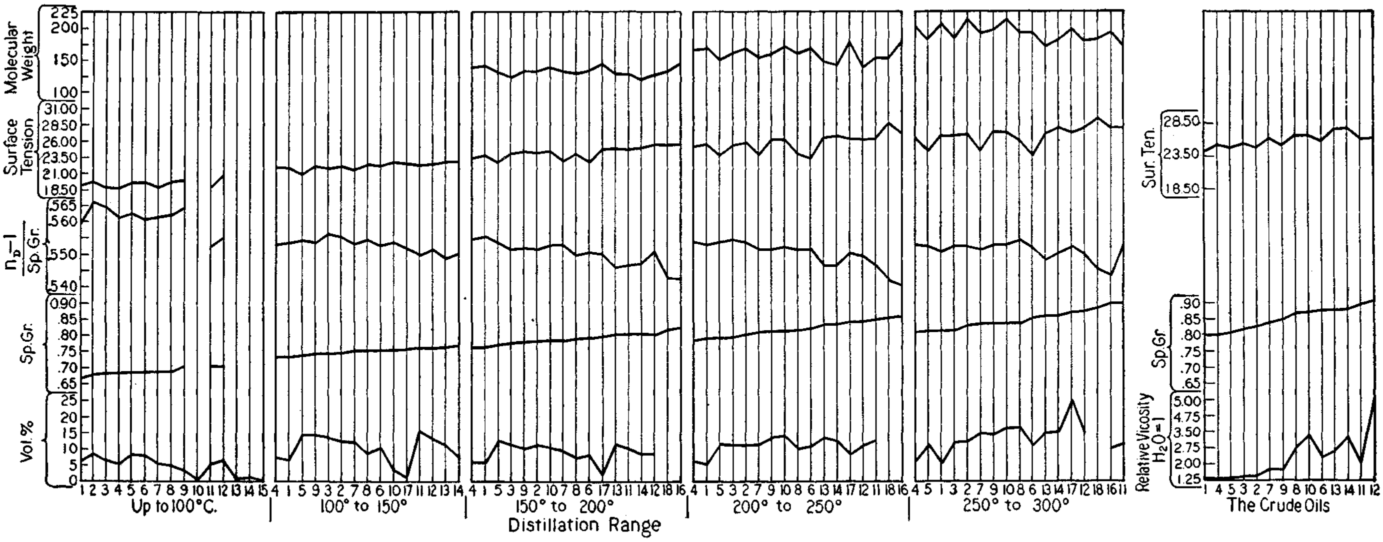


FIG. 3.—Comparison of the physical properties of petroleum distillates from different crudes (176).

Source of Crude Petroleums Used

1. Pa., Brandon, Pleasantville (580 ft.).
2. Okla., Collinsville.
3. Pa., Emlinton (1050 ft.).
4. Pa., Emlinton (1195 ft.).
5. Pa., Brandon, Pleasantville (650 ft.).
6. Calif., Piru Ventura Co.
7, 9, 10. Okla., Collinsville.
8. Okla., Healdton.
11. Calif., Piru, Ventura Co.
12. Calif., Santa Maria.
13, 14. Russia.
15, 16, 18. Calif., Midway, Kern Co.
17. Mexico.

Vapor Pressure Data—Petroleum Products

Designation of material	No. of samples	Normal B. P. °C	Pressure range mm Hg	$\frac{\text{d}\log_{10} p}{\text{d}(1/T)}$	Lit.
Gasolenes	6	93–198	30– 2 500	1600–1700	(25, 35, 45, 61, 171, 217, 218, 219)
Kerosene	1	215–255	50– 630	2230	(218, 219)
Kerosene	1	(240)	1800–30 000	3100	(42)
Gasolene	1	(63)	1800–30 000	1160	(42)
Paraffin-base oil	1	(315)	10– 100	1240	(222)
Transformer oil	1	200	300– 700	740	(33)
Vaseline	1	(215)	2000–16 000	2950	(42)
C_6H_6	1	80.5	160–40 000	1670	(44, 115, 217)
n-$C_{19}H_{40}$	1	330	130– 8 000	3600	(217)
Kerosene W. W.	1	125	250– 3 000	860	(33)
Casinghead gasolene	1	(48)	1000–13 000	1130	(33)
Gasolene	1	(81)	1000– 6 400	1320	(33)

See also (200, 215, 220).

Correction of B. P. for Barometric Pressure.—In the present state of our knowledge, it is necessary to know the slope of the log p, $1/T$ curve for the particular type of product under examination (*i.e.*, the B. P. must be determined at two pressures), in order to be able to make this correction with any degree of certainty for pressures not close to 760 mm.

DEW POINTS

Definitions and Abbreviations.—The temperature at which condensation begins, when a mixture of air and motor fuel is cooled, is called the *dew point*, t_D. The *dew-point index*, I_D, is the sum of the °C boiling points at the 10, 20, 50, 70, 90, and 100% points of the 100 cc standard Engler distillation procedure. For °F it is one-half this sum. The 85% *point*, t_{85}, is the boiling point corresponding to the 85% point of the Engler distillation.

The following generalizations have been put forward.

Thirteen commercial gasolenes with I_D values ranging from 612 to 1025 give, when mixed with 15 parts of air by weight, values of t_D ranging from 10° to 88°C, the relation being

Mabery and Quayle, *65*, **41**: 89; 05. (136) Mabery and Quayle, *11*, **35**: 404; 06. (137) Mabery and Smith, *65*, **25**: 278; 89. (138) Mabery and Takano, *65*, **36**: 295; 00. (139) Mabery and Wesson, *1*, **42**: 1014; 20.

(140) Magie, *8*, **25**: 421; 85. (141) Mahler, *10*, **2**: 717; 13. (142) Markounikov, *13*, **234**: 89; 86. (143) Markounikov and Oglobin, *6*, **6**: 2, 372; 84. (144) M'Arthur, *54*, **7**: 64; 88. (145) Masmejean and Berehare, *Le Pétrole*, p. 36. (146) Mautuschek, *367*, **4**: 209; 01. (147) Melmer, *75*, **120**: 269; 11. (148) Mendelejeff, *in* Rakusin, *Untersuchung des Erdöls*, 1906. (149) de Metz, *8*, **41**: 663; 90.

(150) Moore, *Liquid Fuels*, p. 90, 1920. (151) Morpugo, *216*, **4**: 15; 21. (152) Ognodzinski and Pitat, *136*, **38**: 1275; 14. (153) Parsons and Cook, *5*, **85**: 346; 11. (154) Patterson, *54*, **32**: 218; 13. (155) Peczalski, *16*, **7**: 185; 17. (156) Peltzer, *112*, **189**: 61; 68. (157) Physikalisch-Technische Reichsanstalt, *Beilage zum Beglaubigungsschein für den Abelschen Petroleumprober*, 1910. (158) Piotrowski, *7*, **93**: 596; 18. (159) Predescu, *377*, **6**: 148; 19.

(160) Predescu, *377*, **6**: 188; 19. (161) Protz, *8*, **31**: 141; 10. (162) Quincke, *8*, **138**: 141; 69. (163) Radcliffe and Polychronis, *54*, **35**: 340; 16. (164) Rakusin, *Die Untersuchung des Erdöls*, p. 81, 179; 1906 (Vieweg). (164.1) Rathbun, *359*, **9**, No. **3**: 98; 20. (165) Rathbun, *359*, **10**, No. **9**: 39; 22. (166) Redwood, *54*, **8**: 162; 89. (167) Redwood, *Treatise on Petroleum*, 3rd ed. **1**: 219; 13 (Lippincott). (168) Redwood, *Treatise on Petroleum*, p. 297, 1921 (Griffin and Co.). (169) Redwood, *Treatise on Petroleum*, 1922. p. 286.

(170) Ricardo, *Internal Combustion Engine*, **2**: 30; 23 (Blackie and Son). (171) Rhodes and McConnel, *45*, **15**: 1273; 23. (172) Richardson, *143*, **162**: 57; 06. (173) Richardson and Wallace, *54*, **20**: 690; 01. (174) Richardson and Wallace, *54*, **21**: 316; 02. (175) Rittman and Egloff, *45*, **7**: 481; 15. (176) Rittman and Egloff, *45*, **7**: 578; 15. (177) Rittman, Jacobs and Dean, *30*, No. **163**; 16. (178) Roberts, *374*, **1904**; 1328. (179) Robson and Withrow, *33*, **21**: 244; 19.

(180) Röderer, *92*, **33**: 235; 20. (181) Rossbacher, *45*, **7**: 578; 15. (182) Sainte-Claire Deville, *34*, **66**: 442; 68. **68**: 349, 485, 686; 69. (183) Sainte-Claire Deville, *34*, **72**: 192; 71. (184) Sakhanov and Vassiliev, *361*, **21**: 735; 25. (185) Scheller, *361*, **8**: 730; 13. (186) Schmitt, *366*, **2**: 369; 14. (187) Schwarz, *136*, **35**: 1417; 11. (188) Schwartz and Marcusson, *92*, **26**: 387; 13. (189) Sherman and Kropff, *1*, **30**: 1628; 08.

(190) Sherman and Snell, *1*, **23**: 164; 01. (191) Smith and Tuttle, *32*, No. **37**; 14. (192) Steinkopf, *136*, **36**: 653; 12. (193) Stevenson and Stark, *45*, **17**: 679; 25. (194) Stohmann, *7*, **6**: 334; 90. (195) Strache, *367*, **27**: 19; 24. (196) Strong and Stone, *29*, No. **43**; 13. (197) Takano, *Oest. Chem. Tech. Ztg.*, **8**: 2; 01. (198) Takano, *359*, **6**: 1050; 11. (199) Tausz, *92*, **32**: 317; 19.

(200) Tizard and Marshall, *358*, **8**: 217; 22. (201) Utz, *252*, **12**: 295; 05. (202) Utz, *54*, **25**: 1140; 06. (203) Utz, *361*, **17**: 1292; 21. (204) Vlès and Gex, *350*, **17**: 7107; 25. (205) Warren and Storrer, *370*, **9**: 208; 65. (206) Washburn and Bunting, *38*, **4**: 983; 21. (207) Weber, *242*, **23**: 209; 78. (208) Weber, *149*, **33**: 590; 95. (209) Weber, *8*, **11**: 1047; 03.

(210) Weber and Wynne, *78*, **46**: 197; 24. (211) Weinstein, *136*, **12**: 875; 88. (212) Weise, *375*, **49**: 378; 71. (213) Wells and Southcombe, *54*, **39**: 51; 20. (214) White, *in* Allen, *Commercial Organic Analysis*, 4th ed., **3**: 220; 1914. (215) Williamson, *33*, **22**: 1151; 20. (216) Wilson, *364*, **11**: 511; 24. (217) Wilson and Bahlke, *45*, **16**: 115; 24. (218) Wilson and Barnard, *45*, **13**: 906; 21. (219) Wilson and Barnard, *244*, **12**: 287; 23.

(220) Wilson and Davis, *45*, **15**: 947; 23. (221) Wilson and Wilkins, *45*, **16**: 9; 24. (222) Wilson and Wylde, *45*, **15**: 801; 23. (223) Wimplinger, *112*, **328**: 539; 13. (224) Zaloziecki and Klarfeld, *136*, **31**: 1155; 07. (225) Zeitfuchs, Standard Oil Co. (California), *O*.

FLASH POINTS OF SATURATED VAPORS OF COMBUSTIBLE LIQUIDS

E. H. Leslie and J. C. Geniesse

1. Pure Substances.—The flash point of the vapor above a liquid is the temperature at which ignition will occur. The observed value is materially dependent upon the type of apparatus used (*v.* p. 150 for comparison of values with different types of apparatus). The lower limit of the flash point of a pure liquid is approximately the temperature at which its vapor pressure is equal to B/kN where B is the barometric pressure, N is the number of moles of O_2 required for complete combustion of one mole of the liquid, and k is a constant varying with the type of apparatus employed *cf.* (4). The flash point varies with the barometric pressure at the same rate as the boiling point.

In the accompanying table are shown for a number of liquids; (*a*) the value of N, (*b*) the observed flash point as recorded in the literature and (*c*) the flash point as calculated from the above relation, assuming $k = 8$. A better agreement between observed and calculated flash point might perhaps be obtained by using different values of k for different types of apparatus but the recorded flash points vary greatly and a careful and comprehensive investigation is needed.

Formula	Name	N	Flash point		Lit.
			Observed	Calculated, min.	
CS_2	Carbon disulfide	3	−25.5 to −20	−27	(4)
	HYDROCARBONS				
C_6H_6	Benzene	7.5	−12 to 10	−13	(4, 5)
C_6H_{12}	Cyclohexane	9	−17	−17	
C_6H_{14}	Hexane	9.5	−18	−26	(4)
C_7H_8	Toluene	9	6.5 to 30	6.5	(4, 5)
C_7H_{16}	Heptane	11	−1 to 17	− 5	(5)
C_8H_{10}	Ethylbenzene	10.5	15.5	23	(4)
C_8H_{10}	Xylene	10.5	29 to 50	25	(5)
C_8H_{18}	Octane	12.5	17	15	(4)
C_9H_{12}	*n*-Propylbenzene	12	30.5	40.5	(4)
$C_{10}H_8$	Naphthalene		86		(4, 5)
$C_{10}H_{12}$	Tetralin		78		(3)
$C_{10}H_{14}$	*sec.*-Butylbenzene		52		(4)
$C_{10}H_{18}$	Dekalin		58		(3)
	HALIDES				
$C_2H_4Cl_2$	Dichloroethylene		17		(8)
$C_6H_4Cl_2$	*o*-Dichlorobenzene		77		(8)
$C_6H_4Cl_2$	*p*-Dichlorobenzene	9.5	67 to 78	55	(5, 8)
C_6H_5Br	Bromobenzene	8.5	65	42	(8)
C_6H_5Cl	Chlorobenzene	8.5	27.5 to 39	23.5	(5, 8)
	ALCOHOLS and PHENOLS				
CH_4O	Methyl alcohol	1.5	−1 to 32	13	(4, 5)
C_2H_6O	Ethyl alcohol	3	9.0 to 32.0	14	(4, 5)
C_3H_8O	*n*-Propyl alcohol	4.5	22.5 to 45.5	25	(4, 5)
C_3H_8O	Isopropyl alcohol		11.75 to 14.5		(4)
$C_4H_{10}O$	*n*-Butyl alcohol		35 to 35.5		(4)
$C_4H_{10}O$	Isobutyl alcohol	6	27.5	28	(4)
$C_5H_{12}O$	Isoamyl alcohol	7.5	40 to 42	44	(4)
C_6H_6O	Phenol		79		(4)
$C_6H_6O_2$	Catechol		127		(4)
$C_6H_6O_2$	Resorcinol	6.5	152	160	(4)
$C_6H_6O_2$	Hydroquinol	6.5	165	167.5	(4)
C_6H_7O	Cyclohexanol (hexalin)		68		(3)
C_7H_8O	*o*-Cresol	8.5	81 to 83	79	(4, 5)
C_7H_8O	*m*-Cresol	8.5	86	89.5	(4)
C_7H_8O	*p*-Cresol	8.5	86	90.5	(4)
$C_{10}H_8O$	*β*-Naphthol	11.5	161	139	(5)
	ALDEHYDES, KETONES AND ETHERS				
C_2H_6O	Methyl ether		−41		(5)
C_3H_6O	Acetone	4	−18 to 2	−19	(2, 5)
$C_4H_{10}O$	Ethyl ether	6	−41 to −20	−43	(5)
C_7H_6O	Benzaldehyde	8	62.5	63	(5)
	ACIDS				
$C_7H_6O_2$	Benzoic acid	7.5	121 to 131	136	(4, 5)
	ESTERS				
$C_3H_6O_2$	Ethyl formate	3.5	−19.5	−18	(4)
$C_3H_6O_2$	Methyl acetate	3.5	−15.5 to 4.6	−15	(4)
$C_4H_7ClO_2$	Chloroethyl acetate		67		(8)

ESTERS.—(*Continued*)

Formula	Name	*N*	Flash point		Lit.
			Observed	Calculated, min.	
$C_4H_7ClO_2$	Ethyl chloroacetate...		54		(8)
$C_4H_8O_2$	Ethyl acetate........	5	−5.0 to 5	−5	(4)
$C_4H_8O_2$	Methyl propionate...	5	−2.0	−3	(4)
$C_4H_8O_2$	*n*-Propyl formate.....	5	−3.0	−2	(4)
$C_4H_8O_2$	Isopropyl formate....		−5.5		(4)
$C_5H_{10}O_2$	*n*-Butyl formate......		17.5		(4)
$C_5H_{10}O_2$	Ethyl propionate.....	6.5	12.5	9	(4)
$C_5H_{10}O_2$	Methyl *n*-butyrate...	6.5	14	11	(4)
$C_5H_{10}O_2$	*n*-Propyl acetate.....	6.5	14.5	10.5	(4)
$C_5H_{10}O_2$	Isopropyl acetate.....		4.5		(4)

NITROGEN COMPOUNDS

Formula	Name	*N*	Flash point		Lit.
			Observed	Calculated, min.	
$C_6H_3ClN_2O_4$	Dinitrochlorobenzene.		187		(5)
$C_6H_4ClNO_2$	Nitrochlorobenzene...		127		(5)
$C_6H_4N_2O_4$	*m*-Dinitrobenzene....		150		(5)

NITROGEN COMPOUNDS.—(*Continued*)

Formula	Name	*N*	Flash point		Lit.
			Observed	Calculated, min.	
$C_6H_5NO_2$	Nitrobenzene........	7.5	88 to 90	89.5	(4, 5)
C_6H_7N	Aniline..............	9	71	70	(5)
$C_8H_{11}N$	Dimethylaniline......	12	61 to 76	70	(5)
$C_{10}H_9N$	α-Naphthylamine....	13.5	157	144	(5)

2. Mixtures.—*See* p. 150.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Battle, *Handbook of Industrial Oil Engineering*, p. 262; Philadelphia, Lippincott, 1920. (2) Coste, *173*, **42**: 168; 17. (3) Gardner, Paint Mfgrs. Assoc. U. S., *Circular* **248**: 62; 25. (4) Mack, Boord and Barham, *45*, **15**: 963; 23. (5) Ormondy and Craven, *Chem. Trade J.*, **70**: 41; 22. (6) Schrauth, *416*, **2**: 184; 21. (7) Sherman, Gray and Hammerschlag, *45*, **1**: 13; 09. (8) Weber and Wynne, *78*, **46**: 197; 24.

QUANTITATIVE EFFECTS OF SOME COMPOUNDS UPON DETONATION IN INTERNAL COMBUSTION ENGINES

T. A. BOYD

The detonation or "knock" that characterizes combustion in gasoline engines under certain conditions is influenced primarily by the chemical composition or structure of the fuel, and secondarily by the compression to which the combustion mixture is subjected, by its temperature, and by the point in the cycle at which ignition occurs, as well as by some more minor factors, such as the shape of the combustion chamber and the location of the spark plug (1, 8). The principal types of compounds that may be used as fuels in the gasoline engine arrange themselves in the order of decreasing tendency to knock as follows (2, 8): ethers, paraffins, olefins, naphthenes, aromatics, alcohols. The tendency of any given fuel to detonate may either be increased or decreased as desired by the addition of a suitable compound to the combustion mixture, the amount required being very small in some cases.

La détonation ou le "cognage" qui caractérise la combustion dans les moteurs à benzine sous certaines conditions, est influencée premièrement par la composition chimique ou la structure du carburant et secondairement par la compression à laquelle le mélange combustible est soumis, par sa température, et par le point du cycle auquel l'allumage se produit, de même que par quelques autres facteurs de moindre importance, tels que la forme de la chambre de combustion et la situation de la bougie d'allumage (1, 8). Les principaux types de composés qui peuvent être utilisés comme carburants dans les moteurs à essence peuvent être classés dans l'ordre de leur tendance décroissante à détoner, comme suit (2, 8): Ethers, Paraffines, Oléfines, Naphthènes, Aromatiques et Alcools. La tendance de chaque carburant à détoner peut être augmentée ou diminuée suivant le désir, par l'addition d'un composé convenable au mélange de combustion, la quantité requise pour produire l'effet étant dans certains cas très faible.

Die Detonation oder das Klopfen (knock), welche die Verbrennung in Benzinmotoren unter gewissen Bedingungen kennzeichnet, ist zunächst von der chemischen Zusammensetzung oder Struktur des Brennstoffes beeinflusst, in zweiter Linie von der Kompression, dem das Verbrennungsgemisch ausgesetzt ist, von seiner Temperatur und von der Lage des Zündpunktes im Kreisprozess. In gleicher Weise hängt es noch von kleineren Faktoren ab, wie der Form des Verbrennungsraumes und der Lage der Zündkerze (1, 8). Die hauptsächlichsten Arten die als Motorbetriebsstoffe in Frage kommen, ordnen sich selbst in abnehmender Ordnung ihrer Fähigkeit zu klopfen, in folgender Weise (2, 8): Äther-Arten, Paraffine, Olefine, Naphtene, Stoffe der aromatischen Reihe und Alkohole. Die Neigung irgend eines gegebenen Betriebsstoffes zu detonieren, kann nach Bedarf erhöht oder erniedrigt werden, durch Hinzufügung einer passenden Verbindung zum Betriebsstoff. Die dazu notwendige Menge ist in manchen Fällen sehr gering.

La detonazione (Knock) che, in certe condizioni, caratterizza la combustione nei motori a essenza, è influenzata anzitutto dalla composizione chimica o struttura del carburante, e in secondo luogo dal grado di compressione della miscela, dalla sua temperatura, e dal momento in cui l'accensione avviene durante il ciclo. Essa dipende pure da altri fattori secondari, come la forma della camera di combustione e la posizione della candela (1, 8). I principali tipi di composti che possono adoperarsi come carburanti nei motori a essenza si possono disporre nell'ordine seguente graduandoli secondo la tendenza decrescente a detonare (2, 8): eteri, paraffine, olefine, nafteni, sostanze aromatiche, alcoli. La tendenza di un dato combustibile a detonare può essere accresciuta o diminuita a piacere aggiungendo alla miscela combustibile un adatto composto. La quantità di sostanza a ciò necessaria è in alcuni casi molto piccola.

Esters.—(*Continued*)

Formula	Name	*N*	Flash point		Lit.
			Observed	Calculated, min.	
$C_4H_7ClO_2$	Ethyl chloroacetate...		54		(8)
$C_4H_8O_2$	Ethyl acetate........	5	−5.0 to 5	−5	(4)
$C_4H_8O_2$	Methyl propionate...	5	−2.0	−3	(4)
$C_4H_8O_2$	*n*-Propyl formate.....	5	−3.0	−2	(4)
$C_4H_8O_2$	Isopropyl formate....		−5.5		(4)
$C_5H_{10}O_2$	*n*-Butyl formate......		17.5		(4)
$C_5H_{10}O_2$	Ethyl propionate.....	6.5	12.5	9	(4)
$C_5H_{10}O_2$	Methyl *n*-butyrate...	6.5	14	11	(4)
$C_5H_{10}O_2$	*n*-Propyl acetate.....	6.5	14.5	10.5	(4)
$C_5H_{10}O_2$	Isopropyl acetate.....		4.5		(4)

Nitrogen Compounds

Formula	Name	*N*	Flash point		Lit.
			Observed	Calculated, min.	
$C_6H_3ClN_2O_4$	Dinitrochlorobenzene.		187		(5)
$C_6H_4ClNO_2$	Nitrochlorobenzene..		127		(5)
$C_6H_4N_2O_4$	*m*-Dinitrobenzene....		150		(5)
$C_6H_5NO_2$	Nitrobenzene........	7.5	88 to 90	89.5	(4, 5)
C_6H_7N	Aniline..............	9	71	70	(5)
$C_8H_{11}N$	Dimethylaniline......	12	61 to 76	70	(5)
$C_{10}H_9N$	α-Naphthylamine....	13.5	157	144	(5)

2. Mixtures.—*See* p. 150.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Battle, *Handbook of Industrial Oil Engineering*, p. 262; Philadelphia, Lippincott, 1920. (2) Coste, *173*, **42**: 168; 17. (3) Gardner, Paint Mfgrs. Assoc. U. S., *Circular* **248**: 62; 25. (4) Mack, Boord and Barham, *45*, **15**: 963; 23. (5) Ormondy and Craven, *Chem. Trade J.*, **70**: 41; 22. (6) Schrauth, *416*, **2**: 184; 21. (7) Sherman, Gray and Hammerschlag, *45*, **1**: 13; 09. (8) Weber and Wynne, *78*, **46**: 197; 24.

QUANTITATIVE EFFECTS OF SOME COMPOUNDS UPON DETONATION IN INTERNAL COMBUSTION ENGINES

T. A. Boyd

The detonation or "knock" that characterizes combustion in gasoline engines under certain conditions is influenced primarily by the chemical composition or structure of the fuel, and secondarily by the compression to which the combustion mixture is subjected, by its temperature, and by the point in the cycle at which ignition occurs, as well as by some more minor factors, such as the shape of the combustion chamber and the location of the spark plug (1, 8). The principal types of compounds that may be used as fuels in the gasoline engine arrange themselves in the order of decreasing tendency to knock as follows (2, 8): ethers, paraffins, olefins, naphthenes, aromatics, alcohols. The tendency of any given fuel to detonate may either be increased or decreased as desired by the addition of a suitable compound to the combustion mixture, the amount required being very small in some cases.

Die Detonation oder das Klopfen (knock), welche die Verbrennung in Benzinmotoren unter gewissen Bedingungen kennzeichnet, ist zunächst von der chemischen Zusammensetzung oder Struktur des Brennstoffes beeinflusst, in zweiter Linie von der Kompression, dem das Verbrennungsgemisch ausgesetzt ist, von seiner Temperatur und von der Lage des Zündpunktes im Kreisprozess. In gleicher Weise hängt es noch von kleineren Faktoren ab, wie der Form des Verbrennungsraumes und der Lage der Zündkerze (1, 8). Die hauptsächlichsten Arten die als Motorbetriebsstoffe in Frage kommen, ordnen sich selbst in abnehmender Ordnung ihrer Fähigkeit zu klopfen, in folgender Weise (2, 8): Äther-Arten, Paraffine, Olefine, Naphtene, Stoffe der aromatischen Reihe und Alkohole. Die Neigung irgend eines gegebenen Betriebsstoffes zu detonieren, kann nach Bedarf erhöht oder erniedrigt werden, durch Hinzufügung einer passenden Verbindung zum Betriebsstoff. Die dazu notwendige Menge ist in manchen Fällen sehr gering.

La détonation ou le "cognage" qui caractérise la combustion dans les moteurs à benzine sous certaines conditions, est influencée premièrement par la composition chimique ou la structure du carburant et secondairement par la compression à laquelle le mélange combustible est soumis, par sa température, et par le point du cycle auquel l'allumage se produit, de même que par quelques autres facteurs de moindre importance, tels que la forme de la chambre de combustion et la situation de la bougie d'allumage (1, 8). Les principaux types de composés qui peuvent être utilisés comme carburants dans les moteurs à essence peuvent être classés dans l'ordre de leur tendance décroissante à détoner, comme suit (2, 8): Ethers, Paraffines, Oléfines, Naphthènes, Aromatiques et Alcools. La tendance de chaque carburant à détoner peut être augmentée ou diminuée suivant le désir, par l'addition d'un composé convenable au mélange de combustion, la quantité requise pour produire l'effet étant dans certains cas très faible.

La detonazione (Knock) che, in certe condizioni, caratterizza la combustione nei motori a essenza, è influenzata anzitutto dalla composizione chimica o struttura del carburante, e in secondo luogo dal grado di compressione della miscela, dalla sua temperatura, e dal momento in cui l'accensione avviene durante il ciclo. Essa dipende pure da altri fattori secondari, come la forma della camera di combustione e la posizione della candela (1, 8). I principali tipi di composti che possono adoperarsi come carburanti nei motori a essenza si possono disporre nell'ordine seguente graduandoli secondo la tendenza decrescente a detonare (2, 8): eteri, paraffine, olefine, nafteni, sostanze aromatiche, alcoli. La tendenza di un dato combustibile a detonare può essere accresciuta o diminuita a piacere aggiungendo alla miscela combustibile un adatto composto. La quantità di sostanza a ciò necessaria è in alcuni casi molto piccola.

RELATIVE EFFECTS OF SOME MISCELLANEOUS COMPOUNDS FOR SUPPRESSING DETONATION IN ENGINES

Aniline in concentration of 2% of the fuel by volume taken as standard of effect. All measurements made with bouncing-pin apparatus, using kerosene as fuel (1, 3, 4). The values given below are, respectively, (*a*) amount in grams required to give an "anti-knock" effect equivalent to 1 g of aniline, and (*b*) reciprocal of the number of mols required to give an "anti-knock" effect equivalent to 1 mol of aniline.

Compound	Formula	(*a*) Wt. for given effect	(*b*) Rel. mol. effectiveness	Lit.
Aniline	$C_6H_5NH_2$	1	1	
Benzene	C_6H_6	9.8	0.085	(1)
Toluene	$C_6H_5CH_3$	8.8	0.112	(1)
Xylene	$C_6H_4(CH_3)_2$	8.0	0.142	(1)
Alcohol	C_2H_5OH	4.75	0.104	(5)
Ethyl iodide	C_2H_5I	1.55	1.09	(6)
Diethyl selenide	$(C_2H_5)_2Se$	0.214	6.9	(6)
Diphenyl selenide	$(C_6H_5)_2Se$	0.49	5.2	(6)
Diethyl telluride	$(C_2H_5)_2Te$	0.075	26.6	(6)
Diphenyl telluride	$(C_6H_5)_2Te$	0.139	22.0	(6)
Triphenylphosphine	$(C_6H_5)_3P$	3.08	0.91	(7)
Triphenylarsine	$(C_6H_5)_3As$	2.44	1.35	(7)
Triphenylstibine	$(C_6H_5)_3Sb$	1.56	2.42	(7)
Tetraethyl tin	$(C_2H_5)_4Sn$	0.66*	3.8*	(7)
Tetraethyl lead	$(C_2H_5)_4Pb$	0.0295	118	(3)
Tetraphenyl lead	$(C_6H_5)_4Pb$	0.080†	69.5†	(9)
Diphenyl diethyl lead	$(C_6H_5)_2$-$(C_2H_5)_2Pb$	0.041†	110†	(9)
Triethylbismuthine	$(C_2H_5)_3Bi$	0.135†	23.8†	(9)
Triphenylbismuthine	$(C_6H_5)_3Bi$	0.22†	21.5†	(9)
Nickel carbonyl	$Ni(CO)_4$	0.053†	35†	(9)
Dimethyl cadmium	$(CH_3)_2Cd$	1.23†	1.25†	(9)
Titanium tetrachloride	$TiCl_4$	0.64†	3.2†	(9)

* Values for tetraethyl tin in doubt because of preignition induced by the compound.

† These figures computed from the data of the original article, and converted to the aniline scale used for the other values in the table, on which tetraethyl lead is 118, instead of 100 as it is in the system of comparison used by the authors.

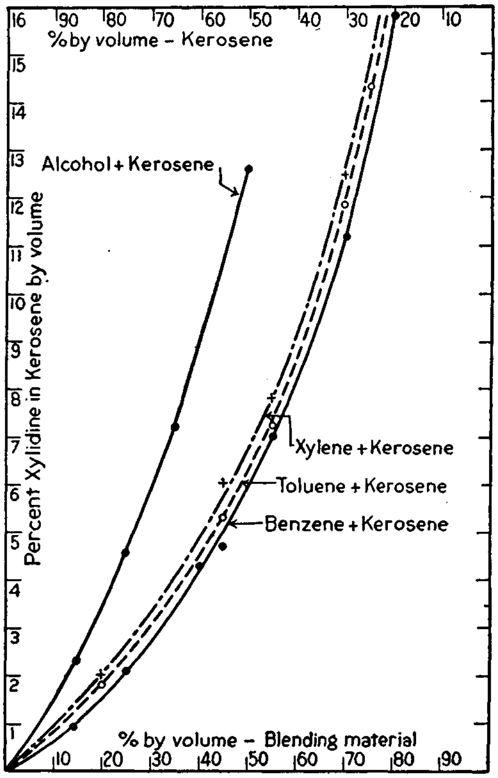
RELATIVE EFFECTS OF SOME COMPOUNDS OF NITROGEN FOR SUPPRESSING DETONATION IN ENGINES

Aniline in concentrations up to 3% of the fuel by volume taken as standard of effect. All measurements made with bouncing-pin apparatus, using kerosene as fuel (4). The values given below are, respectively, (*a*) amount in grams required to give an "anti-knock" effect equivalent to 1 g of aniline, and (*b*) reciprocal of the number of mols required to give an "anti-knock" effect equivalent to 1 mol of aniline. Negative values are marked (−).

Compound	Formula	(*a*) Wt. for given effect	(*b*) Rel. mol. effectiveness
Aniline	$C_6H_5NH_2$	1	1
Cumidine	$(CH_3)_3C_6H_2NH_2$	0.96	1.51
Diphenylamine	$(C_6H_5)_2NH$	1.21	1.5
m-Xylidine	$(CH_3)_2C_6H_3NH_2$	0.92	1.4
Monomethylaniline	$C_6H_5NHCH_3$	0.83	1.4
Toluidine	$CH_3C_6H_4NH_2$	0.94*	1.22*
Amylaminobenzene	$C_5H_{11}C_6H_4NH_2$	1.53	1.15
Ethylaminobenzene	$C_2H_5C_6H_4NH_2$	1.14	1.14
Aminodiphenyl	$C_6H_5C_6H_4NH_2$	1.6	1.14
Methyl-*o*-toluidine(7)	$CH_3C_6H_4NHCH_3$	1.15	1.13
n-Butylaminobenzene	$C_4H_9C_6H_4NH_2$	1.44	1.11
n-Propylaminobenzene	$C_3H_7C_6H_4NH_2$	1.32	1.10
Monoethylaniline	$C_6H_5NHC_2H_5$	1.27	1.02
Mono-*n*-propylaniline	$C_6H_5NHC_3H_7$	1.95	0.75
Ethyldiphenylamine	$C_2H_5N(C_6H_5)_2$	3.65	0.58
Mono-*n*-butylaniline	$C_6H_5NHC_4H_9$	3.1	0.52
Diethylamine	$(C_2H_5)_2NH$	1.59	0.495
Di-*n*-propylaniline	$C_6H_5N(C_3H_7)_2$	7.15	0.27
Mono-isoamylaniline	$C_6H_5NHC_5H_{11}$	7.1	0.248
Diethylaniline	$C_6H_5N(C_2H_5)_2$	6.7	0.24
Dimethylaniline	$C_6H_5N(CH_3)_2$	6.2	0.21
Ethylamine	$C_2H_5NH_2$	2.4	0.20
Triethylamine	$(C_2H_5)_3N$	7.95	0.14
Triphenylamine	$(C_6H_5)_3N$	30.0	0.09
Ammonia	NH_3	2.0(−)	0.09(−)
Isopropyl nitrite	$C_3H_7NO_2$	0.085(−)†	11.5(−)†

* Average of *o*-, *m*-, and *p*-values.

† Approx. only. Organic nitrates and nitrites in general are inducers of detonation, the former being more effective than the latter, and the alkyl compounds much more effective than the aryl. Chlorine and bromine, as well as some of their compounds, induce detonation also.



Relative effect of hydrocarbons for suppressing detonations in engines (1, 5). Kerosene as fuel; xylidine as standard of effect upon detonation.

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(For a key to the periodicals see end of volume)

(1) Midgley and Boyd, *45*, **14:** 589; 22. (2) Midgley, *244*, **7:** 495; 20. (3) Midgley and Boyd, *45*, **14:** 894; 22. (4) Boyd, *45*, **16:** 893; 24. (5) Midgley and Boyd, *244*, **10:** 451; 22. (6) Midgley, *45*, **15:** 421; 23. (7) Boyd, *O.* (8) Ricardo, *381*, **11:** 92; 21. (9) Charch, Mack and Boord, *45*, **18:** 334; 26.

LUBRICANTS AND LUBRICATION

J. H. HYDE

For density, viscosity and other physical properties of lubricants, *see* p. 136.

JOURNAL BEARING FRICTION

In the following tables the value of the coefficient of friction of a journal bearing is given for different values of the quantity:

$$\frac{60\eta N}{P} = 60 \times \frac{\text{Absolute viscosity of lubricant at bearing temperature} \times \text{r. p. s.}}{\text{Pressure on bearing}},$$ where pressure on bearing = $$\frac{\text{Total load on bearing}}{\text{Length of bearing} \times \text{diameter of journal}}.$$

COEFFICIENT OF KINETIC FRICTION FOR DIFFERENT VALUES OF THE RATIO $\frac{\text{CLEARANCE}}{\text{DIAMETER}}$ (4)

$\frac{60\eta N}{P}$	Lasche	Sommerfeld calc.	Lasche	Sommerfeld calc.	Lasche	Sommerfeld calc.	Lasche	Sommerfeld calc.
	1/1000		1/500		1/250		1/100	
100	0.005	0.006	0.0045	0.0025	0.0035	0.0032	0.003	0.010
250	0.0115	0.012	0.011	0.006	0.0095	0.0035	0.0075	0.010
500	0.018	0.024	0.017	0.012	0.016	0.0060	0.0115	0.0096
750	0.024	0.036	0.021	0.018	0.019	0.0090	0.0135	0.0092
1000	0.030	0.048	0.025	0.024	0.020	0.0125	0.0150	0.0090
1250	0.036	0.060	0.029	0.030	0.021	0.0158	0.0165	0.0090

COEFFICIENT OF KINETIC FRICTION (4)

$\frac{60\eta N}{P}$	100	200	300	400	500	600	700	800	900	1000	1100	1200
Stribeck white metal bearing 5.40 in. long	0.0128	0.0190	0.0245	0.0290	0.0335	0.0370	0.0405	0.0435	0.0462	0.0482	0.0500	0.0512
Bronze bearing 9.06 in. long	0.0085	0.0125	0.0156	0.0182	0.0205	0.0222	0.0240	0.0255	0.0270	0.0282	0.0295	0.0305
Hersey full bearing. $\frac{\text{Clearence}}{\text{Diameter}} = 0.04$	0.0038	0.0055	0.0075	0.0092	0.0110	0.0130	0.0145	0.0165	0.0182	0.0200	0.0220	0.0238

Rupture of Lubricating Film

Values of $\frac{60\eta N}{P}$ for rupture of lubricating film in a journal bearing, for bearings of different clearances (4).

$\frac{60\eta N}{P}$	60	50	40	35	30	25	20	15	12	11
$\frac{\text{Diameter}}{\text{Clearence}}$ at rupture...	260	300	350	400	460	555	700	900	1200	1400

Effect of Various Lubricants on Static Friction

Coefficient of static friction between surfaces of mild steel and various metals when lubricated with various oils, for pressures ranging from 10 to 120 lb./in.^{2} and at a temperature of 16°C; "Deeley" Machine Tests (3).

Lubricant	Coefficient of static friction							
	Mild steel against							Hardened steel against Bronze*
	White metal	Axle steel	Cast iron	Wrought iron	Gun metal	"Stones" bronze	Aluminum	
Rape	0.109	0.137	0.102	0.136	0.155	0.124	0.111	0.080
Lard	0.118	0.110	0.133	0.125	0.155	0.117	0.100	0.082
Castor	0.138	0.121	0.131	0.136	0.166	0.121	0.126	0.109
FFF cylinder	0.165	0.147	0.179	0.159	0.177	0.128	0.137	0.120
Bayonne	0.185	0.157	0.214	0.185	0.207	0.158	0.145	0.132
Mobiloil BB	0.188	0.174	0.182	0.174	0.233	0.152	0.145	
Sperm	0.195	0.121	0.138	0.146	0.214	0.173	0.156	0.111
Mobil E								0.115
Victory red								0.117

* Average between 10 and 120 lb./in.^{2}

Coefficient of Kinetic Friction for Surfaces of Cast Iron and Steel When Lubricated with Various Oils

Pressure 30 lb./in.^{2}; 22° to 24°C. Variation of coefficient of kinetic friction with rubbing speed and quantity of stearic acid addition to lubricant. "Deeley" Type Machine (4).

Rubbing speed, ft. per min	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Mineral auto oil alone	0.26	0.23	0.21	0.19	0.17	0.15_5	0.14	0.12_5	0.115	0.11	0.105	0.105
+½ % stearic acid	0.105	0.090	0.080	0.075	0.070	0.065	0.060					
+2 % stearic acid	0.085	0.075	0.065	0.060	0.055	0.053	0.052	0.050	0.048	0.047	0.046	0.045

Effect of Additions to Bayonne Oil

Effect of additions of rape oil and of fatty acids to Bayonne oil (straight mineral). Coefficient of static friction between surfaces of hardened steel and bronze. "Deeley" Machine Tests. Pressure 10 to 120 lb./in.^{2} 16°C (2).

	For a neutral rape oil. No *free* fatty acid						For a rape oil containing 2.44 % *free* fatty acid						
Per cent of added oil	0	4	8.2	20.5	41.0	100	0	2	4	8.2	20.5	40.9	100
Coeff. of static friction	0.132	0.110	0.105	0.099	0.096	0.083	0.132	0.109	0.102	0.099	0.093	0.088	0.080

	For additions of oleic acid									
Per cent oleic acid added	0	0.20	0.40	0.80	1.50	2	10	40	80	100
Coeff. of static friction	0.132	0.102	0.097	0.092	0.088	0.087	0.086	0.085	0.079	0.075

Effect of Pressure on Coefficient of Static Friction (5)

Pressure between surfaces, lb./in.^{2}	8.6	17.3	26.0	36.6	43.3	52.0
Mild steel and cast iron with rape oil	0.205	0.200	0.203	0.208	0.218	0.229
Mild steel and gun metal with FFF cylinder oil	0.172	0.100	0.081	0.067	0.058	0.052
Mild steel and gun metal with sperm oil	0.020	0.029	0.036	0.045	0.053	0.061

Variation of Static Friction with Lubricant for Various Lubricants under Constant Pressure of 10 Lb./In.^{2} (5)

Mild steel against	Clock oil (HB)	Bayonne	Typewriter	Victory red	FFF cylinder	Manchester spindle	Castor	Sperm	Trotter (hard)	Olive	Rape	Valvoline cylinder
Cast iron	0.271	0.213	0.211	0.195	0.193	0.183	0.153	0.127	0.123	0.119	0.119	0.143
Gun metal	0.275	0.234	0.294	0.246	0.236	0.262	0.169	0.189	0.152	0.196	0.136	

LUBRICATING VALUE OF OILS UNDER CONDITIONS OF HEAVY LOADS AND TEMPERATURES UP TO 100°

Tests made on the Daimler-Lanchester Worm Gear Testing Machine at the National Physical Laboratory, England, show that the value of a straight mineral oil as a lubricant, when the load is great, diminishes rapidly above a certain critical temperature. It has been found by a very large number of tests under the same conditions of speed, load and supply of lubricant at a given temperature, that the efficiency of the worm gear in the testing machine remains remarkably constant at the load selected for the tests, and, as differences of efficiency could be determined to 0.1 % (absolute efficiency to 0.2 %), the efficiency-temperature values obtained give a valuable indication of the quality of the lubricant.

Effect of Temperature on Gear Efficiency

Variation of efficiency of power transmission by worm gear, with temperature of lubricant, for a straight mineral oil (Bayonne oil). This example is typical of all mineral oils (⁵).

°C	15 to 42	45	50	55	60	65	70
Gear efficiency, %	95.0	94.7	94.2	93.8	93.4	93.1	92.9

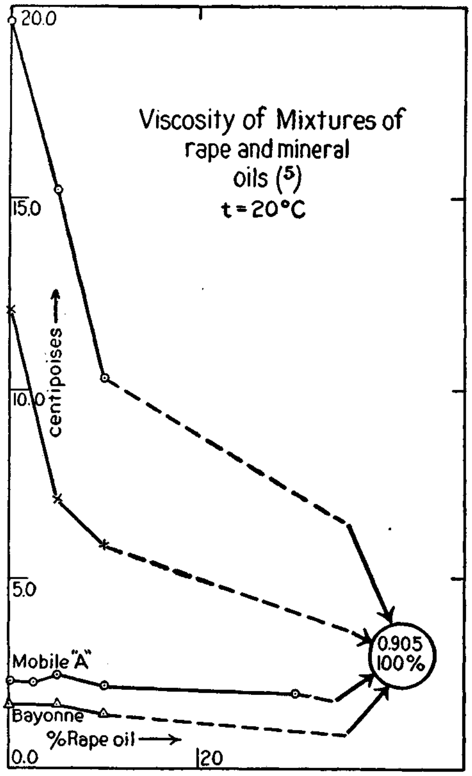
°C	75	80	85	90	95	100
Gear efficiency, %	92.8	92.7	92.6	92.5	92.5	92.4

The following critical temperatures were observed: Bayonne, 42°; FFF cylinder, 71°; Victory red oil, 50°; Mobiloil "A," 56°; Mobiloil "BB," 62°; lard, rape, castor and sperm, none observed. A small addition of fatty oil, fatty acid or graphite raises the critical temperature 10 to 20°.

LITERATURE

(For a key to the periodicals see end of volume)

(¹) Hersey, *306*, **35**: 648; 23. (²) Hyde, *115*, **111**: 708; 21. (³) Hyde, National Physical Laboratory, England, *O*. (⁴) Wilson and Barnard, *45*, **14**: 682; 22. (⁵) *Report of the Lubrications and Lubricants Enquiry Committee*, Dept. of Scientific and Industrial Research, England, 1920.



TYPICAL ANALYSES AND PROPERTIES OF GASEOUS FUELS

E. R. Weaver

The hydrocarbons in natural gases and the hydrogen and saturated hydrocarbons in manufactured gases are usually determined by combustion, and the actual compounds present are not determined. The properties which affect the use of the gas as a fuel (heating value, specific gravity, air required for combustion and products formed by combustion) would be the same for a mixture of the composition stated by the analysis as for the mixture analyzed. For example, a mixture of one volume of hydrogen and one of ethane has the same values for these properties as two volumes of methane; and in an analysis of manufactured gas they would appear as methane. The "illuminants" of manufactured gas generally include all hydrocarbons present except those of the paraffin series. The first table gives the actual compositions of some typical gases; the second table gives analyses stated in the conventional manner. The same index letter in the two tables refers to the same gas.

Actual Composition

The last column of each series of hydrocarbons in which a number is entered includes higher homologs

Gas	Constituents of gas, % by volume															
	H_2	CO	Saturated hydrocarbons					Illuminants						Inerts		
			CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	C_2H_4	C_3H_6	C_4H_8	C_2H_2	C_6H_6	C_7H_8	CO_2	O_2	N_2
Natural gases Appalachian field A			90.7	3.8	3.3	0.8	0.4									1.0
B			84.7	9.4	3.0	1.3										1.6
C			80.4	8.7	4.1	4.0	1.3									1.5
D			44.7	7.9	21.3	9.9	16.2									1.0
Oklahoma E			74.7	13.0	6.0	1.5	0.8									4.0
Texas ("wet gas") F			50.6	3.1	2.4	8.4							*ca.* 1% He			34.5
Gas "F" after removal of gasolene G			54.8	3.3	2.6	0.8							*ca.* 1% He			37.5
Coal gas H	52.5	6.8	30.0	0.8	0.12	0.02		2.0	0.3	0.1	0.01	1.1	0.4	1.7	0.6	3.5
Carburetted water gas I	32.0	29.8	13.1	2.9	0.3			9.8	2.8	1.7		0.9	0.6	4.8		1.3

EFFECT OF TEMPERATURE ON GEAR EFFICIENCY

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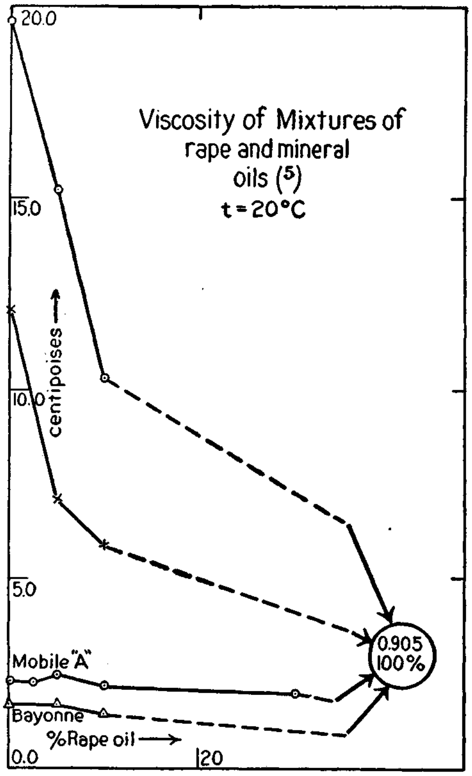

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Natural gases Appalachian field A			90.7	3.8	3.3	0.8	0.4									1.0
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D			44.7	7.9	21.3	9.9	16.2									1.0
Oklahoma E			74.7	13.0	6.0	1.5	0.8									4.0
Texas ("wet gas") F			50.6	3.1	2.4	8.4							*ca.* 1% He			34.5
Gas "F" after removal of gasolene G			54.8	3.3	2.6	0.8							*ca.* 1% He			37.5
Coal gas H	52.5	6.8	30.0	0.8	0.12	0.02		2.0	0.3	0.1	0.01	1.1	0.4	1.7	0.6	3.5
Carburetted water gas I	32.0	29.8	13.1	2.9	0.3			9.8	2.8	1.7		0.9	0.6	4.8		1.3

Composition Given by Conventional Methods of Analysis

Gas	Constituents of gas, % by volume									Specific gravity (air = 1)	Volume air per volume gas required for combustion	Heat of combustion kg-cal per l (1 atm., 15.5°C) to form liquid H_2O and gaseous CO_2 at 15.5°C	Products of combustion volumes per volume of gas			
	H_2	CO	CH_4	C_2H_6	C_3H_8	Illuminants	CO_2	O_2	N_2				CO_2	H_2O	N_2	Total
Natural gases A			84.2	14.8					1.0	0.63	10.5	9.9	1.14	2.13	8.35	11.62
B			79.1	19.3					1.6	0.66	10.8	10.2	1.18	2.16	8.57	11.91
C			63.1	35.4					1.5	0.73	12.0	11.3	1.34	2.32	9.50	13.16
D				38.8	60.2				1.0	1.33	20.9	20.0	2.58	3.57	16.35	22.68
E			62.5	33.5					4.0	0.73	11.6	11.0	1.29	2.26	9.22	12.77
F			23.0	41.5					35.5	0.91	9.2	8.7	1.06	1.70	7.60	10.36
G			50.6	10.9					38.5	0.77	6.7	6.3	0.72	1.36	6.66	8.74
Kern Co., Calif			78.6	10.3			9.7		1.4	0.70	9.2	8.7	1.09	1.88	7.33	10.30
Coal gas H	51.4	6.8	32.0			3.9	1.7	0.6	3.5	0.41	5.4	5.5	0.55	1.25	4.31	6.11
Carburetted water gas I	28.5	29.8	19.8			15.8	4.8		1.3	0.71	6.4	6.2	0.99	1.11	5.05	7.15
Coal and coke-oven gases																
"700 BTU"	44.8	4.3	41.1			6.0	1.1	0.4	2.3	0.42	6.3	6.2	0.61	1.42	4.96	6.99
"600 BTU"	48.7	7.8	33.0			4.3	1.5	0.2	4.5	0.41	5.3	5.3	0.53	1.25	4.21	5.99
"550 BTU"	49.3	9.4	28.4			3.5	2.3	0.6	6.5	0.43	4.8	4.9	0.49	1.15	3.84	5.48
"500 BTU"	51.0	11.0	23.7			3.1	2.6	0.5	8.1	0.44	4.3	4.5	0.45	1.06	3.46	4.97
"450 BTU"	41.5	9.6	22.2			3.0	4.2	0.5	19.0	0.54	3.9	4.0	0.44	0.932	3.26	4.63
Carburetted water gas																
"700 BTU"	31.2	28.2	20.2			15.3	2.0		3.1	0.65	6.1	6.2	0.89	1.08	4.82	6.79
"600 BTU"	34.8	30.6	15.0			11.5	4.2		3.9	0.65	5.1	5.3	0.80	0.93	4.08	5.81
"500 BTU"	40.4	32.7	10.5			8.0	5.1		3.5	0.61	4.1	4.5	0.68	0.81	3.29	4.78
"400 BTU"	45.2	36.5	5.2			4.0	6.0		3.1	0.59	3.2	3.6	0.58	0.66	2.55	3.79
"Blue" water gas	50.5	40.2	1.2			0.0	4.4		3.8	0.54	2.3	2.7	0.46	0.53	1.85	2.84
Oil gas																
"800 BTU"	38.1	2.8	40.9			12.2			6.0	0.49	7.2	7.1	0.77	1.51	5.74	8.02
"700 BTU"	41.5	7.0	36.8			8.4	1.5		4.8	0.47	6.2	6.2	0.67	1.36	4.96	6.99
"600 BTU"	45.8	9.6	31.0			4.7	2.8		6.1	0.46	5.3	5.4	0.58	1.21	4.24	6.03
"550 BTU"	50.3	10.6	27.4			3.5	2.5		5.7	0.43	4.8	4.9	0.50	1.14	3.84	5.48
"500 BTU"	55.2	12.4	23.4			1.6	2.8		4.6	0.40	4.3	4.5	0.45	1.07	3.33	4.85
Producer gas																
"175 BTU"	21.1	19.8	4.0				6.8		48.3	0.80	1.36	1.6	0.31	0.29	1.56	2.16
"150 BTU"	15.3	23.2	2.4				6.1		53.0	0.86	1.15	1.3	0.32	0.20	1.44	1.96
"125 BTU"	11.6	23.0	1.3				5.5		58.6	0.89	0.95	1.1	0.30	0.14	1.34	1.78
"100 BTU"	5.9	23.8	0.4				6.0		63.9	0.95	0.75	0.9	0.30	0.70	1.23	1.60
Blast furnace gas	1.2		27.2				8.0		63.6	1.01	0.68	0.8	0.35	0.01	1.18	1.54

ASPHALTS AND MINERAL WAXES

HERBERT ABRAHAM

Under this heading will be considered the following groups of substances: (1) Mineral waxes; (2) native asphalts; (3) asphaltites; (4) asphaltic pyrobitumens; and (5) pyrogenous asphalts. These five groups are members of the class "Bituminous substances," the first three falling within the group "Bitumens," the fourth within the group "Pyrobitumens," and the fifth within the group "Pyrogenous residues."

NOMENCLATURE

The definitions which follow show the relationship between these respective groups of substances.

Bituminous Substances.—A class of native and pyrogenous substances containing bitumens or pyrobitumens, or resembling them in their physical properties. [This definition includes bitumens, pyrobitumens, pyrogenous distillates (pyrogenous waxes and tars) and pyrogenous residues (pitches and pyrogenous asphalts).]

Bitumen.—A generic term applied to native substances of variable color, hardness and volatility; composed of hydrocarbons substantially free from oxygenated bodies; sometimes associated with mineral matter, the non-mineral constituents being *fusible* and largely *soluble* in carbon disulfide; the distillates, fractionated between 300 and 350°C, yield *considerable sulfonation residue.* [This definition includes petroleums, native asphalts, native mineral waxes and asphaltites.]

Pyrobitumen.—A generic term applied to native substances of dark color; comparatively hard and non-volatile; composed of hydrocarbons, which may or may not contain oxygenated bodies; sometimes associated with mineral matter, the non-mineral constituents being *infusible,* and relatively *insoluble* in carbon disulfide. [This definition includes the asphaltic and non-asphaltic pyrobitumens and their respective shales.]

Mineral Wax.—A term applied to a species of bitumen, also to certain pyrogenous substances; of variable color, viscous to solid consistency; having a *characteristic luster* and *unctuous feel;* comparatively non-volatile; composed of hydrocarbons, substantially free from oxygenated bodies; containing *considerable crystallizable paraffins;* sometimes associated with mineral matter, the non-mineral constituents being easily fusible and soluble in carbon disulfide. [This definition is applied to crude and refined native mineral waxes, also to pyrogenous waxes. Crude native mineral waxes include ozokerite, etc. Refined native mineral waxes include ceresine (refined ozokerite) and montan wax (extracted from lignite or pyropissite by means of solvents). Pyrogenous waxes include the solid paraffins separated from non-asphaltic and mixed-base petroleums, peat, tar, lignite tar and shale tar].

Asphalt.—A term applied to a species of bitumen, also to certain pyrogenous substances of *dark color,* variable hardness, comparatively non-volatile; composed of hydrocarbons, substantially free from oxygenated bodies; containing relatively little to no crystallizable paraffins; sometimes associated with mineral matter, the non-mineral constituents being *fusible,* and largely soluble in carbon disulfide; the distillate, fractionated between 300 and 350°C, yields *considerable sulfonation residue.* [This definition is applied to native asphalts and pyrogenous asphalts. Native asphalts include asphalts occurring naturally in a pure or fairly pure state, also asphalts associated naturally with a substantial proportion of mineral matter, sometimes termed "rock asphalts." The associated mineral matter may be sand, sandstone, limestone, clay, shale, etc. Pyrogenous asphalts include residues obtained from the distillation, blowing, etc., of petroleums (*e.g., residual oil,* produced by the dry distillation of non-asphaltic petroleum, the dry or steam distillation of mixed-base petroleum and the steam distillation of asphaltic petroleum, *blown asphalt,* produced by blowing air through heated residual oils, *residual asphalts,* produced by the steam distillation of mixed-base and asphaltic petroleum, *sludge asphalt,* produced from the acid sludge obtained in the purification of petroleum distillates with sulfuric acid, etc., also from the pyrogenous treatment of wurtzilite (*e.g., wurtzilite asphalt,* produced by depolymerizing wurtzilite in closed retorts).]

Asphaltite.—A species of bitumen, including dark colored, comparatively hard and non-volatile solids; composed of hydrocarbons, substantially free from oxygenated bodies and crystallizable paraffins; sometimes associated with mineral matter, the non-mineral constituents being *difficultly fusible* and largely soluble in carbon disulfide; the distillation residue, fractionated between 300 and 350°C, yields *considerable sulfonation residue.* [This definition includes *gilsonite* (conchoidal fracture and characteristic brown streak on porcelain), *glance pitch* (conchoidal to hackly fracture and black streak) and *grahamite* (conchoidal to hackly fracture and black streak).]

Asphaltic Pyrobitumens.—A species of pyrobitumen, including dark colored, comparatively hard and non-volatile solids; composed of hydrocarbons, *substantially free from oxygenated bodies;* sometimes associated with mineral matter, the non-mineral constituents being *infusible* and largely *insoluble* in carbon disulfide. [This definition includes *elaterite* (characteristic rubbery nature and brown streak), *wurtzilite* (conchoidal to hackly fracture; brown streak; depolymerizes on heating, becoming fusible and soluble), *albertite* (conchoidal to hackly fracture; brownish black streak; depolymerizes partially on heating), *impsonite* (hackly fracture; black streak; does not depolymerize on heating) and the *asphaltic pyrobituminous shales.*]

CHARACTERISTICS

The distinguishing physical and chemical characteristics of the substances enumerated above are given in the following table.

THERMAL PROPERTIES

An asphalt of 2.1_2 specific gravity gave the following values for the *thermal conductivity* in joule $cm^2\ sec^{-1}\ (°C,\ cm^{-1})^{-1}$: 0°, 0.0061; 10°, 0.0065; 20°, 0.0070; 30°, 0.0074 (Poensgen, *98,* **56:** 1653; 12. **60:** 27; 16).

According to Kinoshita (*380,* **39:** 497; 16) the *specific heat* of asphalt is 0.22 g-cal per g per °C.

Genus	Species	Member	Sp. gr. at 25°C (of non-mineral matter)[*]	Penetration at 25°C[†]	Susceptibility factor[‡]	Fusibility °C[§]	Fixed carbon[‖]	Solubility in carbon disulfide[¶]	Non-mineral matter insoluble in carbon disulfide[¶]	Mineral matter[¶]	Carbenes[**]	Soluble in 88° naphtha[††]	Oxygen in non-mineral matter[‡‡]	Paraffin scale[§§]	Sulfonation residue[‖‖]	Saponifiable matter[¶¶]
Bitumens	Petroleums															
	Native mineral waxes	Ozokerite	0.85–1.00	5–10	80	60 to 95	½–10	95–100	0–1	0–5	0–3	75–95	0–2	50–90	90–100	0–2
		Montan wax	0.90–1.00	5	100	75 to 95	2–10	98–100	0–2	0–2	0–2	80–100	3–6	0–10	0–10	50–80
	Native asphalts	Cont'g less than 10% mineral matter	0.95–1.12	0–350	15–100	15 to 165	1–25	60–98	0–40	0–10	0–5	25–95	0–2	0–5	90–100	0–2
		Cont'g more than 10% mineral matter	0.95–1.15	0–150	30–100	15 to 175	5–25	Tr.–90	0–25	10–95	0–5	Tr.–85	0–2	0–5	90–100	0–2
	Asphaltites	Gilsonite	1.05–1.10	3	100	120 to 175	10–20	90–100	0–1	Tr.–1	0–½	40–60	0–2	0–Tr.	85–95	Tr.
		Glance pitch	1.10–1.15	5	100	120 to 175	20–30	95–100	0–1	Tr.–5	0–1	20–50	0–2	0–Tr.	85–95	Tr.
		Grahamite	1.15–1.20	0	100	175 to 320	30–55	45–100	0–5	Tr.–50	0–80	Tr.–50	0–2	0–Tr.	80–95	Tr.
Pyrobitumens	Asphaltic pyrobitumens	Elaterite	0.90–1.05	Rubbery		Inf.	2–5	10–20	70–90	Tr.–10	Tr.–2	5–10	1–5	0–Tr.	80–90	Tr.–15
		Wurtzilite	1.05–1.07	5		Inf.	5–25	5–10	80–95	Tr.–10	Tr.–2	Tr.–2	0–2	0–Tr.	90–98	Tr.
		Albertite	1.07–1.10	0		Inf.	25–50	2–10	85–98	Tr.–10	Tr. 2	Tr. 2	0–3	0–Tr.	90–98	Tr.
		Impsonite	1.10–1.25	0		Inf.	50–85	1–6	90–99	Tr.–10	Tr.–2	Tr.–2	0–3	0–Tr.	90–98	Tr.
		Asphaltic pyrobituminous shales	1.50–1.75	0		Inf.	2–25[***]	Tr.–3	15–70	30–85	0–Tr.	0–Tr.	0–3	Tr.–3	90–98	Tr.
	Non-asphaltic pyrobitumens															
Pyrogenous distillates	Pyrogenous waxes															
	Tars															
Pyrogenous residues	Pyrogenous asphalts	Residual oils	0.85–1.05	100–350		–20 to 25	2–10	98–100	0–½	0–½	0–1	80–99	0–3	0–15	90–100	Tr.–5
		Blown petroleum asphalts	0.90–1.07	25–200	8–40	25 to 200	5–20	95–100	0–5	0–½	0–10	50–90	2–5	0–10	90–100	Tr.–2
		Residual asphalts	1.00–1.17	0–150	40–60	25 to 110	5–40	85–100	0–15	0–1	0–30	25–85	0–2½	0–5	90–100	0–2
		Sludge asphalts	1.05–1.20	0–150	40–60	25 to 110	5–30	95–100	0–5	0–1	0–15	60–95	3–7	0–½	80–95	0–2
		Wurtzilite asphalt	1.04–1.07	5–10	30–40	65 to 150	5–25	98–100	0–½	Tr.–2	0–2	50–80	0–2	0–Tr.	90–95	Tr.
	Pitches															

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[*] Am. Soc. Testing Materials, Tentative Standards, **1922**: 473, 476. [†] *Ibid.*, **1921**; 728. [‡] Abraham, *66*, **11**: 683; 11. [§] Am. Soc. Testing Materials, Standards, **1921**: 739. [‖] *Ibid.*, **1921**: 766. [¶] Anon., *66*, **23 I**: 761; 23. [**] Anon., *66*, **23 I**: 754; 23. *B68*, p. 526. [††] *B68*, p. 527. [‡‡] Am. Soc. Testing Materials, Tentative Standards, **1921**: 779. [§§] *B68*, p. 536. [‖‖] *B68*, p. 537. [¶¶] *B68*, p. 547.

[***] Calculated on mineral-free basis.

BITUMINOUS MATERIALS

JOHN M. WEISS AND CHARLES R. DOWNS

TARS, PITCHES AND DISTILLATES

This section deals with those species of pyrogenous residues known as "tars," together with the products of tar distillation, *i.e.*, "residuals" or "pitches," and "distillates" or "tar oils." These are highly complex materials formed by the pyrogenetic decomposition of various organic materials, so that a particular member or sub-member may vary widely in its physical characteristics.

In the first section are given certain so-called constants in terms of ranges for the various materials. These give general information as to the nature of the various materials. The results are expressed in terms of arbitrary tests which depend upon rigid adherence to details of manipulation; the test methods are those generally used in the United States. The ranges given have been taken partly from the literature, but for the most part from private communications from various commercial concerns dealing with the products (2, 5, 6, 11, 16, 18, 19), and certain U. S. Government laboratories (4, 10). Freak results caused by some unusual procedure in the production of a given material have been eliminated so as to make the ranges representative of the materials as they are ordinarily encountered in industry.

In addition, there are reported the available more or less absolute constants that have been determined. As the materials in a given narrow class vary in ordinary tests, so they also vary in these "absolute" constants between samples in the same class; the accuracy of the figures is only moderate, but, in general, adequate to the commercial need which caused the determinations to be made. Blanks indicate that no authentic results are available. Single figures mean that the test of a single sample only could be obtained.

TABLE 1.—TARS

The figures in Table 1 apply to water-free tar. In attempting to identify tars, it is advisable to distill them and test the oils (*See* Table 3.) Methods of testing are given by Weiss (22). η is Engler viscosity, sec for 100 cm³; % insol. is the % organic insoluble in C_6H_6 and C_7H_8.

Genus	Species	Member	Sub-member	$d_{15.5}^{15.5}$	η	% insol.	% fixed carbon	% ash	% tar acids
Tars	Coal tars	Bituminous coal	Coke oven	1.15–1.26	30–100	3–17	14–40	0–0.5	1–4
			Horizontal gas retort	1.25–1.33	150–650	16–40	15–40	0–0.5	1–4
			Inclined gas retort	1.23–1.24	300	15–20	15–40	0–0.5	4–6
			Vertical gas retort	1.12–1.16	25–50	2–5½	15–30	0–0.5	5–11
			Low temperature processes	0.95–1.12	25–50	0–7	5–15	0–1.5	10–30
			Blast furnace	1.15–1.30	80	10–25	10–30	10–15	5–10
			Gas producer	1.12–1.20	100–α	5–25	10–35	0–25	3–9
		Cannel coal		0.945		0.2		0.1	9.0
		Lignite		0.85–1.05		0–2	5–20	0–1	5–20
	Petroleum tars	Carburetted water gas		1.06–1.15	25– 50	0.2–5.0	10–20	0–0.5	0
		Oil gas		0.95–1.10	25	0–2.0	10–25	0–0.5	0
	Wood tars	Hardwood		1.10–1.21	50	0–5.0	5–20	0–1.0	5–15
		Softwood (pine tars)		1.05–1.15	65	0–7.5	5–15	0–1.0	10–40
	Miscellaneous tars	Bone		0.95–1.05	28	0–5.0	3–15	0–0.5	0.3–40
		Shale		0.85–0.95		0–2.0	5–10	0–1.0	0–2
		Peat		0.90–1.05		0–3.0	5–15	0–1.0	5–15

$d_{15.5}^{15.5}$ of 235–315° fraction (A. S. T. M. distn.): Coke oven, 1.02–1.05; horizontal and inclined gas retort, 1.02–1.04; vertical gas retort, 1.00–1.01; bone tar, 0.950.

TABLE 2.—PITCHES

Method of testing, Weiss (22). The M. P. range given is about the maximum in which they have been known to occur commercially

Genus	Species	Member	Sub-member	Cube M. P.	$d_{15.5}^{15.5}$	% Insol.	% fixed carbon	% ash
Tar pitches	Coal tar pitches	Bituminous coal	Coke oven	30–150	1.20–1.35	8–50	17–60	0–0.5
			Horizontal gas retort	30–100	1.25–1.40	30–55	36–65	0–0.5
			Inclined gas retort	30–100	1.25–1.35	28–37	37–45	0–0.5
			Vertical gas retort	30–150	1.15–1.30	6–30	15–40	0–0.5
			Low temperature processes	30– 90	1.00–1.26	2–15	8–22	0–3.0
			Blast furnace	30–100	1.20–1.30	15–35	10–30	10–20
			Gas producer	30–100	1.20–1.35	15–40	25–45	0–2
		Cannel coal		55	1.067	5.3	14.2	0.2
		Lignite coal		30–115	1.05–1.20	3–16	10–40	0–1.0
	Petroleum tar pitches	Carburetted water gas tar		30–150	1.10–1.25	2–25	25–45	0–0.5
		Oil gas tar		30–150	1.15–1.30	2–30	20–35	0–0.5
	Wood tar pitches	Hardwood		40–100	1.20–1.30	5–70	15–35	0–1.0
		Softwood		40–100	1.10–1.20	2–60	10–25	0–1.0
	Miscellaneous tar pitches	Bone		30–125	1.10–1.20	1–20	15–25	0–0.5
		Shale						
		Peat		35–125	1.05–1.15	0– 5	10–30	0–1.0
Stearine pitch	Fatty acids				0.90–1.10	0– 5	5–35	0–5
Rosin pitch				50–100	1.08–1.15	0– 2	10–20	0–1

TABLE 3.—DISTILLATES

Method of testing: Tar acids, Weiss (22); *d*, *n*, sulfonation residue, Bateman (3)

	d_{60}^{60}				n_{D}^{60}				Sulfonation residue				Tar acids
	235–55°	255–75°	275–95°	295–315°	235–55°	255–75°	275–95°	295–315°	235–55°	255–75°	275–95°	295–315°	Total oil distillate
Coke oven	1.01 –1.04	1.02 –1.06	1.03–1.08	1.06–1.09	1.588–1.609	1.590–1.618	1.594–1.628	1.608–1.635	0–3.5	0–5.0	0–5	0–5	1–12
Horizontal gas retort	1.01 –1.025	1.02 –1.04	1.04–1.07	1.06–1.09	1.580–1.596	1.590–1.602	1.598–1.614	1.610–1.628	0–1.5	0–1.5	0–3	0–3	5–20
Inclined gas retort	1.005–1.015	1.01 –1.035	1.03–1.06	1.04–1.06	1.574–1.593	1.577–1.596	1.586–1.608	1.594–1.623	0.5–4.5	1–7	2–8	3–8	14
Vertical gas retort	1.000–1.01	1.01 –1.025	1.02–1.05	1.04–1.06	1.53 –1.575	1.579	1.587–1.594	1.600–1.612	4–6	5–7	5–6	4–6	20–30
Blast furnace	0.94 –0.95	0.95	0.94–0.96	0.96–0.98	1.523	1.530	1.534	1.543	17	21	21	19	30
Gas producer	0.95			0.98	1.50 –1.52				16				10
Lignite	0.96	0.96	0.96–0.97	0.97–0.98	1.520	1.528	1.534	1.542	21	25	28	29	30–50
Carburetted water gas	0.96 –1.01	0.965–1.03	0.97–1.07	0.98–1.08	1.558–1.598	1.562–1.602	1.572–1.622	1.578–1.630	0–11	0–13	0–16	0–17	0
Oil gas	0.93	0.93	0.93	0.94–0.95	1.533	1.533	1.533	1.530–1.540	26.0	32.0	38.0	34.0	0
Hardwood	0.98	0.97			1.500	1.495			7	9			47
Softwood	0.98 –0.99	0.99	0.99	0.99	1.505	1.514	1.523	1.533	2	3–4	4–5	4.0	15
Bone	0.92	0.94	0.95	0.94					12.0	7.4	3.0	0.0	0.5

Low temperature coke oven shows tar acids in total oil distillate 20–50.

Coefficients of Cubical Expansion

$\alpha = \dfrac{10^6(V_2 - V_1)}{V_1(t_2 - t_1)}$. In each case an average figure for use is suggested, with figures showing the maximum deviation of individual samples from the average suggested. For special cases, reference to the original articles is recommended (3, 8, 13, 21, 23). For effect of solids in creosote oil, *see* (8, 13).

Material	Range °C	α per °C	Max. dev. ±
Water gas tars	15–80	655	25
Vertical retort coal tars	15–80	640	10
Coke oven coal tars	15–80	575	25
Horizontal gas retort coal tars	15–80	550	60
Low temperature coal tars	15–85	760	15
Coal tar and heavy oils (when liquid)	15–80	760	40
Water gas tar and heavy oils	15–60	770	20
Low temperature tar and heavy oils	15–85	760	30
Coal tar middle oils	15–60	800	20
Gas drip (holder oils)	15–60	1000	50
Coal tar and water gas tar pitches	15–250	460	40
Low temperature tar pitches	15–85	660	40

Flash Points

These represent open cup results (3, 5, 6, 18).

40°C M. P. Coal tar pitch	145°C
60°C M. P. Coal tar pitch	211°C
Coal tar creosotes	70–75°C
Low temperature tars	100°C ± 10°C

Specific Heat—G-Cal G^{-1} Deg.$^{-1}$ C

Coal tars—from 0.35 (±.05) at 40°C to 0.45 (±.05) at 200°C. Coal tar oils—0.34 (±.04) at 15°–90°C ((3) and private communications).

Latent Heat of Vaporization

Coal tar oils (24)

Temperature range, °C	Heat of vaporization, g/cal g^{-1}
199–249	84.8
249–296	81.0
296–345	85.1
345–392	73.3
392–438	65.1
438–488	63.1

Viscosity (3, 13.5, 15, 20)

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EXPLOSIONS AND GASEOUS EXPLOSIVES

WILLIAM A. BONE AND DONALD T. A. TOWNEND

IGNITION TEMPERATURE

The ignition temperature of a gaseous mixture is the temperature at which the heat lost by conduction, etc., is more than counterbalanced by the rate at which it is developed by the reaction, the combustion thus becoming self-propellant. This temperature is a function not only of the gaseous mixture employed but also of the means used for heating it. Also, there is often a short "pre-flame" period, during which the combustion is autogenous, but without any actual appearance of flame.

Experimental Methods

A. Mixture passed through tube held at known temperature.

B. Mixture rapidly admitted to hot bulb at known temperature. Pre-flame "lag" sometimes determined by this method.

C. Bulb containing mixture heated rapidly to definite temperature.

D. Mixture passed through small reservoir while temperature was raised until flame at exit tube ran back into it.

E. Constituent gases heated separately in concentric tubes, gas from inner tube being then passed into gas in outer tube. In most recent methods pre-flame "lag" has been controlled.

F. Constituent gases heated separately and mixed in open away from surface contact.

G. Mixture adiabatically compressed and temperature calculated from final volume.

H. Mixture adiabatically compressed and temperature calculation based on final pressure experimentally determined. Correct temperature lies between the values calculated by methods G and H.

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Pressure = 1 atm. unless otherwise noted.

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$\alpha = \frac{10^6(V_2 - V_1)}{V_1(t_2 - t_1)}$. In each case an average figure for use is suggested, with figures showing the maximum deviation of individual samples from the average suggested. For special cases, reference to the original articles is recommended (**3, 8, 13, 21, 23**). For effect of solids in creosote oil, *see* (**8, 13**).

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Pressure = 1 atm. unless otherwise noted.

H_2

Method A (41); cf. (7, 9, 10, 16, 17)		Method B		
		(4)		(24)
t°C*	$2H_2 + O_2 +$	t°C	$2H_2 + O_2 +$	
605	–	550	–	For 15% H_2 in air, 590° in 375 cm^3 vessel and 625° in 9 cm^3 vessel.
605	H_2	552–559	H_2	
611	$4H_2$			
617	$7H_2$	560–570	$3H_2$	
604	O_2	530–532	$1\frac{1}{2}O_2$	
599	$2\frac{1}{2}O_2$			For 60% H_2 in air, 620° in 375 cm^3 vessel and 712° in 9 cm^3 vessel.
594	$4O_2$	552–553	$4N_2$	
589	$4\frac{1}{2}O_2$	560–595	$\frac{1}{2}CO_2$	
584	$7O_2$	562–592	$3CO_2$	

* All at P = 300 mm.

Method C (18); cf. (6, 9)		Method D (13)	Method F (42)
t°C	$2H_2 + O_2 +$		
589	–	650° – $2H_2 + O_2$	642° – $2H_2 + O_2$
560	N_2		
543	$2N_2$		
577	$3N_2$		
609	$4N_2$		

Method E (50, 52, 58); cf. (21, 43): L = lag in sec; (a) = H_2 in O_2; (b) = H_2 in air

L	(a)	(b)	L	(a)	(b)	L	(a)	(b)	L	(a)	(b)
$\frac{1}{2}$	625	630	2	615	619	5	597	602	10	582	585
1	622	625	3	607	613	7	589	592	15	573	577

INFLUENCE OF PRESSURE ON IGNITION TEMPERATURE OF H_2 IN AIR

Method E (50, 52, 58): L = lag in sec; P in mm

P* / L	75	100	200	400	600	760	1000	1200	1520
$\frac{1}{2}$	513	524	558	598	622	630	632	630	628
1	511	521	554	592	614	620	623	621	619
2	509	519	549	581	601	606	609	609	608
3			545	576	592	595	600	600	599

* For P = 7 atm. the ignition temp. = 611° for 0.5 sec lag.

Method G (50, 51, 58); cf. (20, 26, 28)		Method H (37)		Method I (36)	
t°C*	$2H_2 + O_2 +$	t°C	$2H_2 + O_2 +$	t°C	$2H_2 + O_2 +$
521	–	410†	ca. $4N_2$	412	H_2
544	H_2			433	$2H_2$
581	$2H_2$	For 53% H_2 in air, 460°†		397.5	$\frac{1}{3}O_2$
501	O_2			407	O_2
481	$3O_2$				
459	$7O_2$				
439	$15O_2$			Method K (31, 33)	
540	ca. $4N_2$				
468	ca. $3O_2 + 16N_2$				

* Calc. using γ = 1.4.

† Calc. using γ = 1.32 to allow for cooling losses during compression.

$H_2 + Cl_2$

For $Cl_2 + H_2$ by method A (9), 430°–440°; method C (9), 240°–270°; in dark, 190° (11).

H_2S

For $2H_2S + 3O_2$ by method A (9), 315°–320°; method C (9), 250°–270°. For H_2S, by method E (21), in O_2, 220°–235°; in air, 346°–379°.

NH_3

By method E (21), in O_2, 700°–860°. By method not stated (22), in air, 780°.

CO

Method B (4): M = $2CO + O_2$				
t°C	M+	t°C	M+	Method E (43); cf. (21) For CO in O_2, 665° with $\frac{1}{2}$ sec lag; 624° with 10 sec lag For CO in air, 725° with $\frac{1}{2}$ sec lag; 685° with 10 sec lag Method B (24) 20–70% in air, 610°
645–650	CO	650–657	$4N_2$	
630–650	4CO	695–715	$3CO_2$	
650–680	O_2			
For method A and C cf. (9); for method D (13); for method G (19); for method K (31)				

CH_4 Methane

$CH_4 + 2O_2$, by method A (9), 650°–730°; by method C (9), 606°–650°. By method D (13), 656°–678°.

By method B (4), $CH_4 + 2O_2$ at 600°–650°; $5CH_4 + 2O_2$ at 640°–660°; 10% CH_4 by vol. in air at 730°–790°. (First observation of lags prior to explosion.) Method B* (23, 24, 40). % = % CH_4 in air; V_{15} = temp. in 15 cm^3 vessel, V_{275} in 275 cm^3 vessel and V_{81} in 81 cm^3 vessel.

%	V_{15}	V_{275}	%	V_{15}	V_{275}	%	V_{81}	%	V_{81}
3	737	680	10	750	710	2	711	8.8	707
6.5	736	675	12	765	710	3	700	10	714
8.0	735	680	16	807	750	5.9	695	11.8	724
						7.0	697	14.4	742

* The explosion occurs after certain definite time lags.

Method E (43), cf. (21). For CH_4 in O_2, $\frac{1}{2}$ sec lag, 665°; 10 sec lag, 624°. For CH_4 in air, $\frac{1}{2}$ sec lag, 725°; 10 sec lag, 685°. Method E (50, 52, 58). For CH_4 in air. P = mm pressure; L = lag in sec.

P / L	100	200	400	600	760	1520	2280	3800	5320
0.5							705	675	653
0.6	815	788	765	753	746	722			
1	804	768	747	737	728	711	695	666	644
2	782	733	717	712	715	690	680	652	633
3	—	715	702	696	694	676	667	640	624

Method E (58). For CH_4 in O_2. P = mm pressure; L = lag in sec.

P / L	75	100	200	400	600	760
0.5	727	728	732	720	696	670
0.6	715	716	721	715	688	666
1	694	695	697	692	675	657
2	667	665	660	652	645	641
3		651	643	636	631	629
10		633	621	611	604	602

By method G (58), $CH_4 + 3O_2$, 340°; $CH_4 + 5O_2$, 345°; $CH_4 + 15O_2$, 377°; $7\frac{1}{2}$% CH_4 in air, 428°.

C_2H_2 Acetylene

By method E (21), in O_2, 400°–440°; in air, 406°–440°. By method B (24), for 45–55% C_2H_2 in air, 335°; 20% in air, 400°; 10% in air, 500°.

C_2H_4 Ethylene

For $C_2H_4 + 3O_2$, method C (9), 530°–606°. By method B (24), for 4.5–6.5% C_2H_4 in air (vol. vessel = 275 cm^3), 487°. By method E (21), for C_2H_4 in O_2, 500°–519°; in air, 542°–547°. *Cf.* (9), method A; (13), method D; (31), method K.

C_2H_6 Ethane

By method B (47). % = % C_2H_6 in air (vol. vessel = 85 cm³)

%	1.9	2.3	4.05	4.85	5.7	8.15	10.60
t°C	594	571	560	555	550	540	534

For C_2H_6, method A, *cf.* (9); method D (13). By method C (9), for $C_2H_6 + 3.5O_2$, 530°–606°. By method B (24), for 4–8% C_2H_6 in air (275 cm³ vessel), 560°.

C_3H_8 Propane

By method D (13), in O_2, 545°–548°. By method E (21), in O_2, 490°–570°. Method B (47), vol. of vessel = 85 cm³

% C_3H_8 in air	1.25	2.50	3.05	4.90	6.50	7.85
t°C	588	552	544	525	516	514

C_4H_{10} *n*-Butane

Method B (47), vol. of vessel = 85 cm³

% *n*-C_4H_{10} in air	1.25	2.00	2.60	3.65	4.85	7.65
t°C	569	545	531	515	502	489

C_4H_{10} Isobutane

For *iso*-C_4H_{10} by method D (13), in O_2, 545°–550°.

C_5H_{12} *n*-Pentane

For 2–3% C_5H_{12} in air, 512° by method B (24). For 6.7% in air, 320°–336° by method H (37). Method B (47), vol. of vessel = 85 cm³.

% C_5H_{12} in air	1.5	2.15	2.75	3.75	5.30	7.65
t°C	548	532	520	502	486	476

C_6H_6 Benzene

Method	B	J			K
Lit.	(24)	(30)	(38)	(45)	(31, 33)
	In air	In O_2	In O_2	In air	
	5%, 587°	566°	570	490	

C_6H_{14} *n*-Hexane

By method H (37), for 6.7% in air, 300°–306°.

C_7H_{16} *n*-Heptane

By method H (37), for 6.7% in air, 285°; (39) 5% in air, 280°(39).

C_8H_{18} *n*-Octane

By method H, for 6.7% in air, 275° (37); 280° (39).

Petroleum

Method	B	J				K
Lit.	(24)	(30)			(27)	(31, 33)
	In air		In O_2	In air	In air	
	2.2% 481°	Texas Borneo Mexico	256° 269° 274°	387° 380° 424°	Borneo 400°	

C_2H_6O Ethyl Alcohol

Method	B (in air)			J		
Lit.	(24)	(34)*		(30)	(38)	(45)
	27–38% 450°	2%, 515–520° 3%, 505°	4%, 455–500° 5%, 480–495°	395°‡ 518°†	355°‡	360°†

* Sub-ignition temp.
† In air.
‡ In O_2.

$C_4H_{10}O$ Ether

In air by method A (32), 190°; method B (35), 185°–193°; method J (30), 347°. In O_2 by method J (30), 190°.

By method B* (34), for 4.8% in air, 178°–184°; for 4.1%, 179°–185°; for 3.5%, 180.5°–188°. By method H (39), for 6.6% in air, 212°. Method K, *cf.* (31, 33).

* Giving sub-ignition temp. with incomplete combustion.

CS_2

Method E (48)

In O_2, °C	132	128	123	118	114	110	107
In air, °C	156	151	145	138	130	124	120
Lag in sec	0.5	1	2	3	5	7	10

By method B (5), for $CS_2 + 10O_2$ at P = 750 mm, 160° with 1–2 sec lag. At P = 300 mm and with 15 sec lag, for $CS_2 + 5O_2 + 5N_2$, 155°; for $CS_2 + \frac{1}{2}O_2 + 8N_2$, 290°. By method F (42), in O_2, 236°. By method H (39), for 12.5% in air, 253°.

C_2N_2 Cyanogen

By Method E (21), in O_2, 803°–818°

Miscellaneous

(a) = acetone, (b) = paraffin, (c) = turpentine, (d) = creosote oil, (e) = palm oil, (f) = aldehyde, (g) = aniline, (h) = toluene, (i) = xylene, (j) = methyl alcohol, (k) = amyl alcohol, (l) = anthracene, (m) = naphthalene.

	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Method	B* ‡	J†	J	J*	J*	?*	?*
Lit.	(34)	(30)	(30, 45)	(27)	(27)	(22)	(22)
	4%, 500° 8%, 500°	251°	275°*† 240°*	550°	400°	380°	530°

	(h)	(i)	(j)	(k)	(l)	(m)
Method	J†	?*	J†	J†	J†	J†
Lit.	(38, 30)	(22)	(38)	(38)	(38)	(38)
	563° 516°	500°	500°	315°	472°	500°

* In air.
† In O_2.
‡ Satd. at 15°, 505°.

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(30) Moore, *54*, **36:** 109; 17. (31) McDavid, *4*, **103:** 1003; 17. (32) Alilaire, *34*, **168:** 729; 19. (33) White and Price, *4*, **115:** 1248; 19. (34) White and Price, *4*, **115:** 1462; 19. (35) McClelland and Gill, *117*, **16:** 109; 20. (36) Fiesel, *7*, **97:** 158; 21. (37) Tizard, *411*, **37:** 381; 21. (38) Wollers and Emcke, *Krupp's Monatsheft*, 1921. (39) Tizard and Pye, *3*, **44:** 79; 22.

(40) Mason and Wheeler, *4*, **121:** 2079; 24. (41) Mitscherlich and Reuter, *93*, **121:** 53; 22. (42) Wartenburg and Kannenberg, *7*, **105:** 205; 23. (43) Dixon, *398*, **68:** 1; 23. (44) Tauss and Schulte, *98*, **68:** 574; 24. (45) Jentzsch, *98*, **68:** 1150; 24. (46) Ormandy, *358*, **10:** 335; 24. (47) Mason and Wheeler, *4*, **125:** 1869; 24. (48) Dixon, *70*, **44:** 305; 25. (49) David, *133*, **1925;** 303.

(50) Dixon, *133*, **1925;** 303. (51) Dixon and Harwood, *398*, **1925.** (52) Dixon and Higgins, *398*, **69:** 19; 25. (53) Parr, *45*, **17:** 1215; 25. (54) Coward and Wheeler, Safety in Mines Research Board, *Paper* No. **8;** 25. (55) Naylor and Wheeler, *Ibid.* No. **9;** 25. (56) Tizard and Pye, *3*, **1:** 1094; 26. (57) Pignot, *34*, **182:** 376; 26. (58) Dixon, Harwood and Higgins, *83*, preprint, 1926. (59) Dixon and Russell, *4*, **75:** 600; 99.

ELECTRICAL IGNITION

In the case of electrical ignition and probably also in contact with direct flame or with an incandescent wire, ionization of the gas is an important factor. In the case of electric spark ignition, attempts have been made to determine experimentally the minimum igniting current or spark energy. Unfortunately, however, quantitative values are not easily determined owing to experimental difficulties. Consequently, much of the experimental evidence is of a contradictory nature, so that the part played by ionization in determining the least energy required to inflame a given explosive mixture remains an unknown factor. Representative curves showing least igniting currents are given in Figs. 1 to 4.

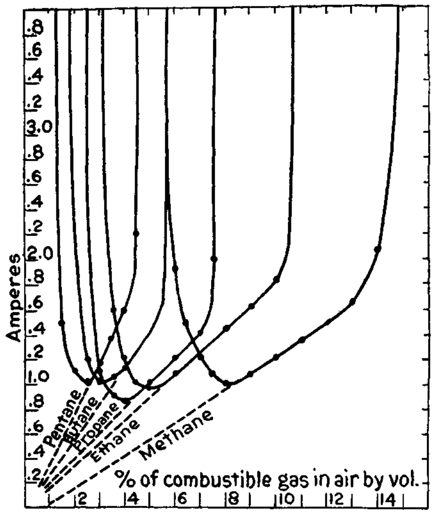

FIG. 1.—Least igniting currents for mixtures in air of members of the paraffin series, using break-sparks. Iron poles. 100 volts (5).

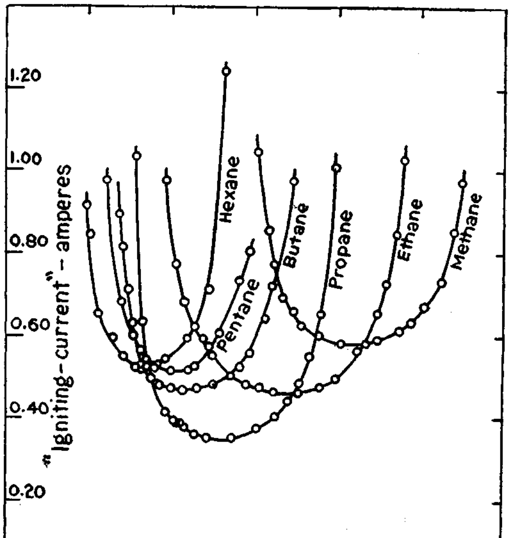

FIG. 2.—Least igniting currents for mixtures in air of members of the paraffin series, using impulsive electrical discharges (33).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Thornton, *80*, **44 I**: 145; 12. **46 II**: 112; 13. (2) Thornton, *115*, **94**: 348; 13. *396*, **120**: 295; 13. *121*, **70**: 62; 13. (3) Thomson, *63*, **14**: 11; 13. (4) Thornton, *121*, **71**: 1012; 13. (5) Thornton, *5*, **90**: 272; 14. (6) Thornton, *121*, **73**: 822; 14. (7) Thornton, *5*, **91**: 17; 14. (8) Thornton, *3*, **28**: 734; 14. (9) Hauser, *329*, **1916**; 521.

(10) Thornton, *5*, **92**: 9; 16. (11) Thornton, *5*, **92**: 381; 16. (12) Morgan, *115*, **102**: 427; 16. (13) Morgan, *121*, **76**: 536; 16. *399*, **111**: 66; 16. (14) Thornton, *399*, **112**: 504; 16. (15) Sastry, *4*, **109**: 523; 16. (16) Wheeler, *4*, **111**: 130; 17. (17) Wheeler, *4*, **111**: 411; 17. (18) Wright, *4*, **111**: 643; 17. (19) Paterson and Campbell, *67*, **31**: 168; 19.

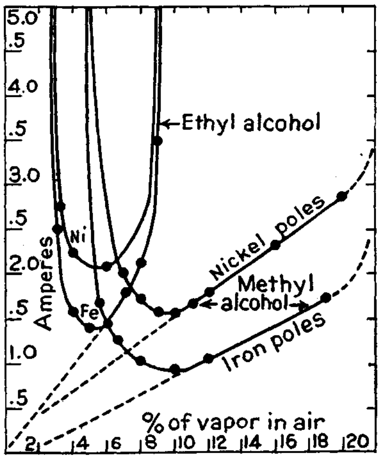

FIG. 3.—Influence of the nature of the pole on the least igniting current for mixtures of methyl or ethyl alcohol vapor with air, using break-sparks. Iron and nickel poles. 100 volts (5).

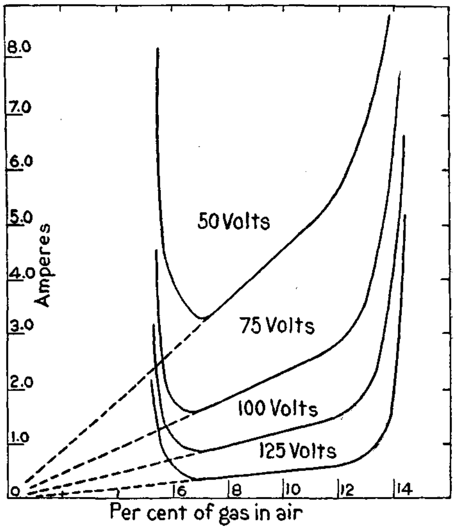

FIG. 4.—Influence of current voltage on the least igniting current for methane-air mixtures, using break-sparks. Iron poles, continuous current (5).

(20) Thornton, *3*, **38**: 613; 19. (21) Morgan, *4*, **115**: 94; 19. (22) Thornton, *3*, **40**: 345; 20. (23) Thornton *3*, **40**: 450; 20. (24) Wheeler, *4*, **117**: 903; 20. (25) Morgan, *3*, **41**: 462; 21. (26) Morgan and Wheeler, *4*, **119**: 239; 21. (27) Thornton, *400*, **11**: 524; 22. (28) Jones, Morgan and Wheeler, *3*, **43**: 359; 22. (29) Thornton, *133*, **1923**; 469.

(30) Morgan, *4*, **123**: 1304; 23. (31) Morgan, *3*, **45**: 968; 23. (32) Thornton, *46*, **62**: 481; 24. (33) Wheeler, *4*, **125**: 1858; 24. (34) Wheeler, *4*, **127**: 14; 25. (35) Morgan, *3*, **49**: 323; 25. (36) Thomson, *The Conduction of Electricity through Gases*, London, Cambridge Univ. Press, 1903. (37) Morgan, *Principles of Electric Spark Ignition in Internal Combustion Engines.* London, Lockwood, 1923. (38) Wheeler, Safety in Mines Research Board, *Paper* No. **20**; 26. (39) Bone and Weston, *5*, **110**: 615; 26.

PRE-FLAME CONDITION

(40) Kirkby, *3*, **7**: 223; 04. (41) Kirkby, *3*, **13**: 289; 07. (42) Kirkby, *5*, **85**: 151; 11. (43) Lind, *78*, **21**: 177; 12. (44) Finch and Cowln, *5*, **111**: 257; 26.

LIMITS OF INFLAMMABILITY

The limits are given in volume % and apply to atmospheric conditions of temperature and pressure unless otherwise stated. The first value in the limits column is the lowest lower limit, and the second the highest higher limit of the experimentally found values, which usually agree within a few tenths of 1%.

Abbreviations

E_v	Explosion in closed vessel of volume v, cm³ generally stated.
Fl_D	Downward propagation of flame.
Fl_H	Horizontal propagation of flame.
Fl_U	Upward propagation of flame.
Atm.	Nature of atmosphere.
Exper. condn.	Experimental conditions.
Tb_x	Tube whose diameter = x cm.
$Sat._x$	Gases saturated with H_2O vapor at x°.
$P_{xat.}$	Pressure, x atmospheres.
P_{xmm}	Pressure, x mm Hg.

All temperatures are in °C.

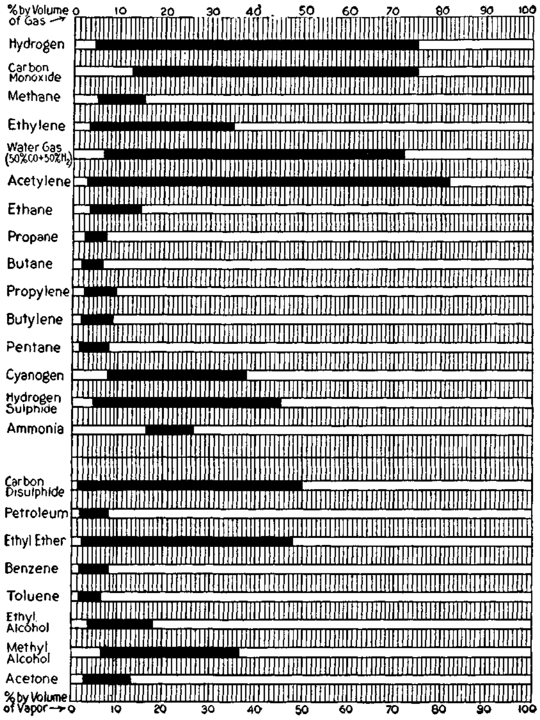

FIG. 4*a*.—Limits of inflammability of mixtures of gases and vapors with air.

H_2

Atm.	Limits	Exper. condn.	Lit.
O_2	9.4–91.0	15° Fl_H, Tb_4, $Sat._{17.5}$	(12)
	9.0–93.3	100°	
Air	9.2–65.0	15° Fl_H, Tb_4, $Sat._{17.5}$	(12)
	9.2–68.5	100°	
Air	9.0–62.8	15° Fl_H, Tb_4, dried by P_2O_5	(12)
	9.0–68.6	100°	
CO_2:O_2	11.7–68.4	15° Fl_H, Tb_4, $Sat._{17.5}$	(12)
79:21	11.4–69.4	100°	
Air	5.0–72.0	Glass, $Tb_{7.5}$, Fl_U	(14)
Air	10.0–	E_{2000}	(18)
Air	9.5–66.3		(19)
Air	9.45–66.4	E_{110}, Sat.	(23)
Air	9.73–63.6	$Tb_{1.4}$, Fl_D	(25)

H_2.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
O_2	5.45–94.7	$Sat._{15-18}$	(28)
Air	8.7 –	E_{100}, Fl_D	(34)
O_2	8.7 –		(34)
Air	9.05–68.6	$P_{2-3at.}$ E_{1940}, Fl_D	(36)
	9.28–68.0	$P_{5-6at.}$	(36)
	9.47–67.5	$P_{10at.}$	(36)
Air	4.1 –	$E_{170\,000}$, Fl_U, $Sat._{17-18}$	(39)
Air	4.1 –60.0		(51)
Air	10 –66.0	E_v	(52)
Air	–74.2	$Sat._{room}$ 15 l vessel	(56)
Air	9.4 –65.3	E_{120}	(60)
O_2	9.1 –91.7	E_{120}	(60)
O_2:N_2 40.1:59.9	9.2 –81.2	E_{120}	(60)
O_2:N_2 56.2:43.8	9.2 –86.4	E_{120}	(60)
Air	9.46–64.5	Glass pipette	(73)
	9.42–65.9	Glass bulb	(73)
	10.78–59.8	(20°) Iron tube	(73)
	9.27–67.5	100°	
	8.98–72.2	200°	
	8.62–79.1	300°	
Air	4.15–75.0	Fl_U, $Tb_{7.5}$	(74)
	6.50–	Fl_H, $Tb_{7.5}$	(74)
	8.8 –74.5	Fl_D, $Tb_{7.5}$	(74)
Air	9.40–71.5	17 ± 3° Fl_D, $Tb_{2.5}$	(78)
	9.2 –	50°	
	8.8 –73.5	100°	
	8.3 –	150°	
	7.9 –76.0	200°	
	7.5 –	250°	
	7.1 –79.0	300°	
	6.7 –	350°	
	6.3 –81.5	400°	

H_2S

Atm.	Limits	Exper. condn.	Lit.
Air	4.5 –19.0		(51)
Air	5.9 –27.2	Fl_H, Tb_6	(72)
Air	4.30–45.5	Fl_U, $Tb_{7.5}$	(74)
	5.30–35.0	Fl_H, $Tb_{7.5}$	(74)
	5.85–21.3	Fl_D, $Tb_{7.5}$	(74)

NH_3

Atm.	Limits	Exper. condn.	Lit.
Air	16.2–27.0	E_{500}, sphere	(34)
O_2	15 –80	Found by altering burner mixture	(45)
Air	16.1–26.6	Fl_U, Tb_5, 18°	(65)
	18.2–25.5	Fl_H, Tb_5, 18°	(65)
	22.1–23.3	Fl_D, Tb_5, 70°	(65)
	21.0–24.6	Fl_D, Tb_5, 90°	(65)
	15.0–28.7	Fl_U, Tb_5, 140°	(65)
	17.0–27.5	Fl_H, Tb_5, 140°	(65)
	19.9–26.3	Fl_D, Tb_5, 140°	(65)
	14.0–30.4	Fl_U, Tb_5, 250°	(65)
	15.9–29.6	Fl_H, Tb_5, 250°	(65)
	17.8–28.2	Fl_D, Tb_5, 250°	(65)
	13.0–32.2	Fl_U, Tb_5, 350°	(65)
	14.7–31.1	Fl_H, Tb_5, 350°	(65)
	16.0–30.0	Fl_D, Tb_5, 350°	(65)
	12.3–33.9	Fl_U, Tb_5, 450°	(65)
	13.5–33.1	Fl_H, Tb_5, 450°	(65)
	14.4–32.0	Fl_D, Tb_5, 450°	(65)

NH_3.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
	17.1–26.4	Fl$_U$, Tb$_{7.5}$, 18°	(65)
	17.4–26.3	Fl$_H$, Tb$_{7.5}$, 18°	(65)
O_2	15.3–79.0	Fl$_U$, Tb$_5$, 18°	(65)
	16.7–79.0	Fl$_H$, Tb$_5$, 18°	(65)
	14.8–	Fl$_H$, Tb$_5$, 250°	(65)
	15.8–	Fl$_D$, Tb$_5$, 250°	(65)
	12.6–	Fl$_H$, Tb$_5$, 450°	(65)
	13.5–	Fl$_D$, Tb$_5$, 450°	(65)
	14.8–	Fl$_U$, Tb$_{7.5}$, 18°	(65)
	15.6–	Fl$_H$, Tb$_{7.5}$, 18°	(65)
	17.3–	Fl$_D$, Tb$_{7.5}$, 18°	(65)

CO

Atm.	Limits	Exper. condn.	Lit.
O_2	15.4–94.1	15° Fl$_H$, Tb$_4$, Sat.$_{17.5}$	(12)
	14.4–94.8	100°	
Air	14.1–74.8	15° Fl$_H$, Tb$_4$, Sat.$_{17.5}$	(12)
	13.0–77.6	100°	
$CO_2:O_2$ 79:21	21.6–73.1	15° Fl$_H$, Tb$_4$, Sat.$_{17.5}$	(12)
	20.0–75.1	100°	
Air	13.0–75.0	Fl$_U$, Tb$_{7.5}$	(14)
	15.9–74.5	Fl$_H$, Tb$_4$	(14)
Air	19.1–61.7	Tb$_{0.6}$	(17)
	38.0–57.0	Tb$_{0.3}$*	(17)
	16.4 –	P_{430}	(17)
	18.6 –	P_{130}	(17)
	27.9 –	P_{85}	(17)
	14.2 –	400°	(17)
	9.3 –	470°	(17)
	7.4 –	575°	(17)
Air	16.0 –		(18)
Air	17.3–74.8		(19)
Air	16.5–75.0	E$_{110}$, Sat.	(23)
Air	14.5 –	100° E$_{100}$, Fl$_D$, Sat.$_{15-18}$	(34)
O_2	15.7 –	100°	(34)
Air	15.9–72.9	$P_{1\text{at.}}$, E$_{1940}$	(36)
	18.4–62.0	$P_{10\text{at.}}$, Fl$_D$	(36)
Air	12.5 –	E$_{170\,000}$, Fl$_D$, Sat.$_{17-18}$	(39)
Air	12.6–70.0		(51)
Air	15.0–73.0	Sat.$_{\text{room}}$	(52)
Air	–74.2	15 l vessel	(56)
Air	15.55–71.0	E$_{120}$	(60)
O_2	16.63–93.6	E$_{120}$	(60)
$O_2:N_2$			
37.8:63.2	15.85–83.6	E$_{120}$	(60)
50.8:49.2	15.85–87.7	E$_{120}$	(60)
Air	15.75–68.9	Glass pipette	(73)
	15.4–71.6	Glass bulb	(73)
	15.8–63.8	(20°) Iron tube	(73)
	14.05–69.6	100°	
	13.80–76.6	200°	
Air	12.8–75.0	Fl$_U$, Tb$_{7.5}$	(74)
	13.6 –	Fl$_H$, Tb$_{7.5}$	(74)
	15.3–70.5	Fl$_D$, Tb$_{7.5}$	(74)
Air	16.3–70.0	17 ± 3° Fl$_D$, Tb$_{2.5}$	(78)
	15.7 –	50°	
	14.8–71.5	100°	
	14.2 –	150°	
	13.5–73.0	200°	
	12.9 –	250°	
	12.4–75.0	300°	
	12.0 –	350°	
	11.4–77.5	400°	

* No mixture can propagate flame through glass Tb < 0.23.

CH_4 Methane

Atm.	Limits	Exper. condn.	Lit.
O_2	6.0–57.3	15° Fl$_H$, Tb$_4$, Sat.$_{17.5}$	(12)
	5.7–57.4	100°	
Air	5.7–13.2	15° Fl$_H$, Tb$_4$, Sat.$_{17.5}$	(12)
	5.5–13.2	100°	
	5.8–12.8	15° Fl$_H$, Tb$_4$, dried over P_2O_5	(12)
	5.8–13.6	100°	
$CO_2:O_2$			
79:21	8.7–11.9	15° Fl$_H$, Tb$_4$, Sat.$_{17.5}$	(12)
	8.5–12.2	100°	
Air	5.0–13.0	Fl$_U$, Tb$_{7.5}$	(14)
	6.0–11.0	Fl$_D$, Tb$_{7.5}$	(14)
Air	6.0 –	E$_{2\,000}$	(18)
Air	6.4–12.8		(19)
Air	6.1–12.8	E$_{110}$, Sat.	(23)
	6.3 –	Fl$_D$, Tb$_{6.2}$	(23)
Air	5.6 –	E$_V$, sphere 16 cm diam., central ignition	(30)
Air	6.0 –	100° Fl$_D$, E$_{100}$, Sat.$_{15-18}$	(34)
O_2	6.25–	100°	
Air	6.0–13.0	$P_{1\text{at.}}$ Fl$_D$, E$_{1940}$	(36)
	6.6–14.0	$P_{10\text{at.}}$	
$N_2:O_2:CO_2$			
81:19	5.5–13.5	Limits given are for explosion in a large steel bomb	(33)
31:19:50	8.0–11.3		
83:17	5.7–11.8		
40:17:43	8.3–8.7		
85:15	5.9–9.6		
64:15:21	7.3–7.5		
87:14	6.3–7.1		
85:13:2	6.6–6.8		
O_2	5.99–		
$O_2:N_2$			
80:20	5.95–		
60:40	5.90–		
40:60	5.82–		
30:70	5.77–	E$_V$, sphere 16 cm diam.	(38)
25:75	5.76–	E$_V$, sphere 16 cm diam.	(38)
20:80	5.78–		
19:81	5.84–		
13.4:86.6	6.41–		
13:87	6.63–		
Air	5.3 –	E$_{170\,000}$, Sat.$_{15-17}$	(39)
Air		Ignition at:	
	5.6–14.8	Center E$_V$, 16 cm sphere	(41)
	5.4–14.8	Top	
	6.0–13.4	Bottom	
	5.4–14.3	Fl$_H$, E$_V$, Tb$_6$	(41)
$O_2:N_2$			
20.9:79.1	5.60–14.8		(42)
19.2:80.8	–12.9		
18.3:81.7	–11.9		
17.0:83.0	5.80–10.6		
15.8:84.2	5.83–8.96		
14.9:85.1	6.15–8.36		
13.9:86.1	6.35–7.26		
13.5:86.6	6.50–6.70		
13.2:86.8	*		
Air	5.76–	Fl$_D$	(43)
	5.56–	Fl$_H$	(43)
	5.52–	Fl$_U$	(43)

* No mixture capable of propagating flame.

CH_4 Methane.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
Air	4.9 –	Fl_U Box, 5.75 ft., cube	(47)
	5.7 –	Fl_D	
	5.5 –	Fl_H	
Air	5.0 –	Fl_U, E_{2300}	(47)
	–13.9	Fl_D, Tb_{30}	(47)
	–15.4	Fl_U, Tb_{30}	(47)
	5.5 –13.2	Fl_D, E_{100}	(47)
Air	5.46–	25°, E_{100}	(48)
	4.98–	200°, E_{700}	(48)
	4.75–	300°, E_{100}	(48)
	4.55–	400°, E_{100}	(48)
	3.75–	500°, E_{100}	(48)
	5.5 –	$P_{1-5\text{at.}}$, E_{100}	(48)
Air	5.6 –14.8		(51)
Air	5.5 –14.5		(52)
Air	6.00–13.4	20°, Fl_D, E_V	(55)
	5.45–13.5	100°, Fl_D, E_V	(55)
	5.20–13.6	150°, Fl_D, E_V	(55)
	5.05–13.9	200°, Fl_D, E_V	(55)
	4.60–14.0	250°, Fl_D, E_V	(55)
	4.40–14.3	300°, Fl_D, E_V	(55)
	4.15–	350°, Fl_D, E_V	(55)
	4.00–14.7	400°, Fl_D, E_V	(55)
	3.65–15.4	500°, Fl_D, E_V	(55)
	3.35–16.4	600°, Fl_D, E_V	(55)
	3.25–18.8	700°, Fl_D, E_V	(55)
	–23.6	750°, Fl_D, E_V	(55)
	–29.0	800°, Fl_D, E_V	(55)
	6.00–13.0	P_{760}, Fl_D, E_V	(55)
	6.05–13.2	P_{1250}, Fl_D, E_V	(55)
	–13.4	P_{2100}, Fl_D, E_V	(55)
	6.20–13.6	P_{2900}, Fl_D, E_V	(55)
	6.25–	P_{3350}, Fl_D, E_V	(55)
	–13.8	P_{3750}, Fl_D, E_V	(55)
	6.40–14.1	P_{4650}, Fl_D, E_V	(55)
Air	–15.4	15 l vessel, Sat. room	(56)
$O_2:N_2$			
13.7:86.3	6.4 –6.9	Fl_H, $Tb_{2.5}$	(58)
17.0:83.0	6.1 –8.9	Fl_H, $Tb_{2.5}$	
21.0:79.0	5.8 –13.3	Fl_H, $Tb_{2.5}$	
33.0:67.0	5.8 –25.1	Fl_H, $Tb_{2.5}$	
50.0:50.0	5.8 –38.8	Fl_H, $Tb_{2.5}$	
66.0:34.0	5.8 –47.5	Fl_H, $Tb_{2.5}$	
O_2	5.7 –59.2	Fl_H, $Tb_{2.5}$	(58)
Air	6.05–12.1	E_{120}	(60)
O_2	6.39–52.1	E_{120}	(60)
$O_2:N_2$			
45.2–54.8	6.26–29.7	E_{120}	(60)
62.2–37.8	6.30–38.6	E_{120}	
86.3–13.7	6.44–47.8	E_{120}	
Air	6.12–13.6	Glass pipette	(73)
	5.82–13.6	Glass bulb	(73)
	6.25–12.8	(20°) Iron tube	(73)
	6.02–13.9	100°	
	5.91–14.1	200°	
	5.80–14.1	300°	
Air	5.35–14.9	Fl_U, $Tb_{7.5}$	(74)
	5.40–14.0	Fl_H, $Tb_{7.5}$	(74)
	5.95–13.4	Fl_D, $Tb_{7.5}$	(74)
Air	6.30–12.9	17 ± 3° Fl_D, $Tb_{2.5}$	(78)
	6.20–	50°	
	5.95–13.7	100°	
	5.75–14.1	150°	

CH_4 Methane.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
	5.5 –14.6	200° Fl_D, $Tb_{2.5}$	(78)
	5.30–	250°	
Air	5.10–15.5	300°	
	4.95–	350°	
	4.80–16.6	400°	
	4.55–	450°	
Air	5.4 –14.1	E_V, $Tb_{1.5}$	(75)
Air +			
0.8% $C_2H_2Cl_2$	7.35–10.2		(75)
0.8% $C_2H_2Cl_4$	7.15– 9.2		
1.0% C_2HCl_5	5.95–10.3		
20% $C_2H_2Cl_2$.	*		
5.5% C_2HCl_3.	*		
8.5% CCl_4	9.0 –9.9		
12.2% CCl_4	*		

* No propagation of flame.

See also p. 191.

C_2H_2 Acetylene

Atm.	Limits	Exper. condn.	Lit.
Air		Fl_H, $Tb_{0.05}$	(13)
	7.7 –10.0	Fl_H, $Tb_{0.08}$	(13)
	5.0 –15.0	Fl_H, $Tb_{0.2}$	(13)
	4.5 –25.0	Fl_H, $Tb_{0.4}$	(13)
	4.0 –40.0	Fl_H, $Tb_{0.6}$	(13)
	3.5 –55.0	Fl_H, $Tb_{2.0}$	(13)
	3.1 –62.0	Fl_H, $Tb_{3.0}$	(13)
	2.9– 64.0	Fl_H, $Tb_{4.0}$	(13)
Air	2.8 –65.0	Continuous propagation, large vol.	(18)
O_2	2.8 –93.0		
Air	3.8 –40.0		(19)
Air	3.0 –82.0	Fl_D, $Tb_{7.5}$	(14)
Air	3.35–52.3	E_{110}, Sat.	(23)
Air	1.53–58.7	Fl_D, $Tb_{1.4}$	(25)
Air	2.82–51.7	Fl_D, E_{100}	(46)
	–73.0	Fl_U, E_{2800}	(46)
	2.98–	Fl_{U-D}, E_{2800}	(46)
	2.53–	Fl_U, E_{28317}	(46)
	2.87–	Fl_D, E_{28317}	(46)
Air	3.0 –46.0		(51)
Air	3.0 –73.0		(52)
Air	3.4 –52.5	E_{120}	(60)
O_2	3.4 –90.0	E_{120}	(60)
$O_2:N_2$			
40.5:59.5	3.4 –74.4	E_{120}	(60)
58.0:42.0	3.4 –82.4	E_{120}	
78.5:21.5	3.4 –87.4	E_{120}	
Air	2.68–	Glass pipette	(73)
	2.39– Upper limit indefinite	Glass bulb	(73)
	3.12–	(20°) Iron tube	(73)
	1.95–	100°	
	1.95–	200°	
Air	2.60–80.5	Fl_U, $Tb_{7.5}$	(74)
	2.68–78.5	Fl_H, $Tb_{7.5}$	(74)
	2.78–71.0	Fl_D, $Tb_{7.5}$	(74)
Air	2.90–55.0	17 ± 3° Fl_D, $Tb_{2.5}$	(78)
	2.83–59.0	50°	
	2.68–65.0	100°	
	2.52–73.0	150°	
	2.39–81.0	200°	
	2.30–	250°	
	2.19–	300°	

C_2H_4 Ethylene

Atm.	Limits	Exper. condn.	Lit.
Air..........	4.0–22.0	Fl_U, $Tb_{7.5}$	(14)
Air..........	4.1–14.6	E_{110}, Sat.	(23)
	3.4–	Fl_D, $Tb_{6.2}$, Sat.	(23)
Air..........	5.7–17.5		(51)
Air..........	3.8–14.2	E_{120}	(60)
O_2..........	4.0–62.0	E_{120}	(60)
$O_2:N_2$			
40.4:59.6....	4.0–47.7	E_{120}	(60)
74.7–25.3....	4.0–56.4	E_{120}	
Air..........	3.4–14.1	Fl_H, $Tb_{2.5}$	(62)
	3.6–13.7	Fl_D, $Tb_{2.5}$	(62)
	3.2–25.6	Fl_U, $Tb_{2.5}$	(62)
Air..........	3.52–	Glass pipette	(73)
	3.34–	Glass bulb	(73)
	3.69–	(20°) Iron tube	(73)
	3.22–	100°	
	3.40–	200°	
Air..........	3.02–34.0	Fl_U, $Tb_{7.5}$	(74)
	3.20–23.7	Fl_H, $Tb_{7.5}$	(74)
	3.33–15.5	Fl_D, $Tb_{7.5}$	(74)
Air..........	3.45–13.7	17 ± 3° Fl_D, $Tb_{2.5}$	(78)
	3.35–	50°	
	3.20–14.1	100°	
	3.10–	150°	
	2.95–14.9	200°	
	2.85–15.7	250°	
	2.75–17.9	300°	
	2.60–	350°	
	2.50–	400°	

C_2H_6 Ethane

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.10–	Center ignit. E_V, sphere 16 cm diam.	(30)
Air..........	3.10–10.7		(51)
Air..........	2.5–5.0		(52)
Air..........	3.3–10.6	Fl_H	(58)
Air..........	3.9–9.6	$Tb_{2.5}$	(60)
O_2..........	3.9–46.2	$Tb_{2.5}$	(60)
$O_2:N_2$			
37.4:63.6....	3.80–21.9	E_{120}	(60)
59.5:40.5....	3.90–33.6	E_{120}	
74.7:25.3....	3.80–39.7	E_{120}	
Air..........	3.12–15.0	Fl_U, $Tb_{7.5}$	(74)
	3.15–12.9	Fl_H, $Tb_{7.5}$	(74)
	3.26–10.2	Fl_D, $Tb_{7.5}$	(74)

C_3H_6 Propylene

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.18–9.7	Fl_U, $Tb_{7.5}$	(74)
	2.22–9.3	Fl_H, $Tb_{7.5}$	(74)
	2.26–7.4	Fl_D, $Tb_{7.5}$	(74)

C_3H_8 Propane

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.15–	Center ignit. E_V, sphere 16 cm diam.	(30)
Air..........	2.17–7.35		(51)
Air..........	2.4–7.3	Fl_H, $Tb_{2.5}$	(58)

C_4H_8 Butylene

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.70–9.0	Fl_U, $Tb_{7.5}$	(74)
	1.75–9.0	Fl_H, $Tb_{7.5}$	(74)
	1.80–6.3	Fl_D, $Tb_{7.5}$	(74)

C_4H_{10} *n*-Butane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.60–	Center ignit. E_V, sphere 16 cm diam.	(28)
Air..........	1.55–5.7		(51)
Air..........	1.9–6.5	Fl_H, $Tb_{2.5}$	(58)

C_5H_{12} *n*-Pentane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.1–		(18)
Air..........	1.35–	E_V, sphere 16 cm diam.	(30)
Air..........	2.4–4.9	E_{110}, Sat.	(23)
Air..........	1.35–4.5		(51)
Air..........	1.6–5.4	Fl_H, $Tb_{2.5}$	(58)
Air..........	1.42–8.0	Fl_U, $Tb_{7.5}$	(74)
	1.44–7.45	Fl_H, $Tb_{7.5}$	(74)
	1.48–4.64	Fl_D, $Tb_{7.5}$	(74)
Air..........	1.53–4.5	17 ± 3° Fl_D, $Tb_{2.5}$	(78)
	1.50–	50°	
	1.44–4.75	100°	
	1.39–4.90	150°	
	1.34–5.05	200°	
	1.30–	250°	
	1.22–5.35	300°	

C_5H_{12} Isopentane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.30–	Center ignit. E_V, sphere 16 cm diam.	(30)

C_6H_6 Benzene

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.5–	E_{2000}	(18)
Air..........	1.4–4.7	E_{2000}	(21)
Air..........	2.65–6.5	E_{110}	(23)
	1.4–	Fl_D, $Tb_{6.2}$	(23)
Air..........	1.5–8.0		(51)
Air..........	2.6–7.2	E_{120}	(60)
O_2..........	2.6–30.1	E_{120}	(60)
$O_2:N_2$			
40.5:59.5....	–15.5	E_{120}	(60)
58.0:42.0....	2.6–21.0	E_{120}	
78.5:21.5 ...	–27.5	E_{120}	
Air..........	1.41–7.45	Fl_U Wide tube	(64)
	1.46–5.55	Fl_D	

C_6H_{14} Hexane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.3–	E_{2000}	(18)

C_7H_8 Toluene

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.3–	E_{2000}	(18)
Air..........	1.4–	E_{2000}	(21)
Air..........	1.27–6.75	Fl_U Wide tube	(64)
	1.28–4.60	Fl_D	

C_7H_{16} Heptane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.1–	E_{2000}	(18)

C_8H_{18} Octane

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.0–	E_{2000}	(18)

Petroleum

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.4–4.9	E_{110}	(23)
	1.1–	Fl_D, $Tb_{6.2}$	(23)
Air..........	2.94–8.22	E_V, 60° fraction	(40)
Air..........	1.9–5.3	Fl_D, E_{100}	(48)
	1.5–6.4	Fl_U, E_{100}	(48)
	1.50–	23°	(48)
	1.42–	200°	(48)
	1.22–	300°	(48)
	1.02–	400°	(48)
Air..........	1.5–6.0	E_{2300}	(51)
Air..........	1.8–5.15	E_{120}	(60)
O_2..........	1.9–28.8	E_{120}	(60)

Petroleum.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
O_2:N_2			
44.0:56.0....	1.8 –14.1	E_{120}	(60)
59.5:40.5....	2.1 –19.2	E_{120}	
74.7:25.3....	1.9 –28.8	E_{120}	

CH_4O Methyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	5.5 –21.0		(51)
Air..........	7.8 –18.0		(21)
Air..........	6.0 –		(18)
Air..........	7.05–36.5	Fl_U Wide tube	(64)
	7.45–26.5	Fl_D	

C_2H_4O Acetaldehyde

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.97–57.0	Fl_U Wide tube	(64)
	4.27–13.4	Fl_D	

C_2H_6O Ethyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.07–		(18)
Air..........	4.0 –		(21)
Air..........	3.95–13.7	E_{110}	(23)
Air..........	4.0 –13.7		(29)
Air..........	2.8 –9.5		(51)
Air..........	3.56–18.0	Fl_U Wide tube	(64)
	3.74–11.5	Fl_D	
Air..........	5.02–	Fl_U $\mathrm{Tb}_{2.5}$, 60°	(56)
	5.18–	Fl_H	
	5.21–	Fl_D	
	4.24–19.0	Fl_U Tb_5, 60°	(56)
	4.32–13.8	Fl_H	
	4.44–11.5	Fl_D	
	4.16–	Fl_U Tb_{15}, 60°	(56)
	4.37–	Fl_H	
	4.23–	Fl_D	

C_3H_6O Acetone

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.9 –		(18)
Air..........	2.7 –		(21)
Air..........	5.0 –12.0		(29)
Air..........	2.15– 9.7	Fl_U	(52)
	2.35– 8.5	Fl_D	(52)
Air..........	2.3 – 7.5	Fl_U $\mathrm{Tb}_{2.5}$	(56)
	2.4 – 6.7	Fl_H	
	2.75– 6.5	Fl_D	
	2.2 – 9.5	Fl_U Tb_5	(56)
	2.25– 9.3	Fl_H	
	2.40– 8.3	Fl_D	
	2.15– 9.7	Fl_U Tb_{10}	(56)
	2.20– 9.5	Fl_H	
	2.35– 8.5	Fl_D	
	2.88–12.4	Fl_U Tb_{15}	(56)
	2.89–12.4	Fl_H	
	3.11–10.9	Fl_D	
Air..........	2.89–13.0	Fl_U Wide tube	(64)
	2.93– 8.6	Fl_D	
Air..........	3.59– 9.6	Glass pipette	(73)
	4.03– 8.5	Glass bulb	(73)
	3.68– 8.6	(20°) Iron tube	(73)
	3.30–10.1	100°	

C_3H_6O Allyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.04		(18)

C_3H_5O *n*-Propyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.55–	E_{2000}	(18)

C_3H_8O Isopropyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.65–	E_{2000}	(18)

C_4H_8O Ethylmethyl Ketone

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.97–10.1	Fl_U Wide tube	(64)
	2.05– 7.6	Fl_D	

$C_4H_8O_2$ Ethyl Acetate

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.26–11.4	Fl_U Wide tube	(64)
	2.33– 7.1	Fl_D	

$C_4H_{10}O$ Ether

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.9 –		(18)
Air..........	1.8 – 5.2		(21)
Air..........	2.75– 7.7	E_{110}	(23)
	1.6 –	Fl_D, $\mathrm{Tb}_{6.2}$	(23)
Air..........	0.59–0.195*		(25)
Air..........	2.7 – 7.7		(29)
Air..........	2.35–18.5	Fl_U $\mathrm{Tb}_{2.5}$	(56)
	2.38– 6.2	Fl_H	
	2.34– 6.3	Fl_D	
	1.93–15.8	Fl_U Tb_5, 20°	(56)
	2.05– 8.0	Fl_H	
	2.15– 6.2	Fl_D	
	1.93–17.1	Fl_U Tb_5, 60°	(56)
	2.05–13.0	Fl_H	
	2.15– 7.5	Fl_D	
	1.73–23.3	Fl_U Tb_{15}	(56)
	1.93–22.3	Fl_H	
	1.80– 6.5	Fl_D	
	1.87–	P_{770}, Fl_H	(56)
	–12.9	P_{751}, Fl_H	(56)
	–10.5	P_{600}, Fl_H	(56)
	– 9.2	P_{520}, Fl_H	(56)
	1.88–	P_{460}, Fl_H	(56)
	– 8.2	P_{450}, Fl_H	(56)
	– 7.8	P_{400}, Fl_H	(56)
	1.92– 7.3	P_{300}, Fl_H	(56)
	2.08– 6.8	P_{200}, Fl_H	(56)
	2.33– 6.1	P_{100}, Fl_H	(56)
	2.99– 5.0	P_{50}, Fl_H	(56)
	– 6.2	P_{600}, Fl_D	(56)
	– 6.2	P_{300}, Fl_D	(56)
	– 5.9	P_{200}, Fl_D	(56)
	– 5.5	P_{100}, Fl_D	(56)
		P_{50}	(56)
Air..........	1.71–48.0	Fl_U Wide tube	(64)
	1.85– 6.4	Fl_D	
Air..........	2.26–6.90	Glass pipette	(73)
	2.38–6.51	Glass bulb	(73)
	2.34–6.15	(20°) Iron tube	(73)
	1.97–	100°	
	1.63–	200°	

* Gm per l.

$C_4H_{10}O$ Isobutyl Alcohol

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.68–	E_{2000}	(18)

CS_2

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.94–		(18)
Air..........	4.1 –		(21)
Air..........	2.5 –45.0		(51)
Air..........	1.06–50.0	Fl_U Wide tube	(64)
	1.91–35.0	Fl_D	

CS_2.—(*Continued*)

Atm.	Limits	Exper. condn.	Lit.
Air..........	2.11–31.7	Glass pipette	(73)
	2.22–31.2	Glass bulb	(73)
	3.38–29.2	(20°) Iron tube	(73)
	1.35–33.1	100°	

C_2N_2 Cyanogen

Atm.	Limits	Exper. condn.	Lit.
Air..........	7.6–38.0		(51)

C_5H_5N Pyridine

Atm.	Limits	Exper. condn.	Lit.
Air..........	1.81–12.4	Fl_U Wide tube	(64)
	1.88– 7.2	Fl_D	

$C_2H_5NO_3$ Ethyl Nitrate

Atm.	Limits	Exper. condn.	Lit.
Air..........	3.01– 7.5	Fl_U Wide tube	(64)
	3.83–15.1	Fl_D	

Water Gas (50% H_2, 50% CO)

Atm.	Limits	Exper. condn.	Lit.
Air..........	12.5–66.5		(19)
Air..........	12.4–66.8	E_{110}, Sat.	(23)
	12.3–	Fl_D, $Tb_{6.2}$	(23)

Water Gas (49.45% H_2, 47.90% CO, 2.65% air)

Atm.	Limits	Exper. condn.	Lit.
Air..........	12.4–66.2	E_{120}	(60)
O_2...........	12.6–92.1	E_{120}	(60)
$O_2:N_2$			
38.6:61.4....	12.5–81.3	E_{120}	(60)
52.7:47.3	12.6–86.1	E_{120}	

Mixtures of Combustible Gases (56)

$E_{15\,000}$, Fl_U

Vol. compn.			Limits
H_2	CO	CH_4	
100			4.1 –71.5
75	25		4.7 –
50	50		6.05–71.8
25	75		8.2 –
10	90		10.8 –
	100		12.5 –73.0
	90	10	11.0 –
	75	25	9.5 –
	50	50	7.7 –22.8
	40	60	7.2 –
	25	75	6.4 –
		100	5.6 –15.1
25		75	4.7 –
50		50	4.6 –
75		25	4.1 –
90		10	4.1 –
33	33	33	5.7–29.9
55	15	30	4.7 –
48.5		51.5	–33.6

Relative Limiting Igniting Pressures (39)

Below which, under the same sparking conditions, explosive mixtures would not ignite; *P* = limiting ignition pressure in mm Hg.

% H_2 in O_2	*P*	% CO in O_2	*P*
92.3	285	94.0	>400
91.7	341	93.9	75
88.9	212	92.5	108
85.7	183	91.0	99
80.0	149	88.9	81
75.0	123	85.7	78
66.7	103	80.0	55
50.0	66	75.0	50
40.0	53	66.7	50
36.7	53	50.0	30
33.3	45	40.0	26
25.0	52	37.5	24
16.7	54	35.3	27
11.8	57	33.3	32
9.1	72	25.0	74
8.8	68*	20.0	92
6.7	80*	18.4	106
		17.0	124
		16.0	135
		15.0	148
		14.3	340
		14.0*	
		13.8*	

* Incomplete combustion.

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(For a key to the periodicals see end of volume)

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(50) Burrell and Oberfell, *30*, No. **134**; 16. (51) Thornton, *3*, **33**: 190; 17. (52) Burrell and Ganger, *30*, No. **150**; 17. (53) Wheeler and Whitaker, *4*, **111**: 267; 17. (54) Payman, *54*, **37**: 406; 18. (55) Mason and Wheeler, *4*, **113**: 45; 18. (56) Coward, Carpenter and Payman, *4*, **115**: 27; 19. (57) White and Price, *4*, **115**: 1426; 19. (58) Payman, *4*, **115**: 1436; 19. (59) Satterly and Burton, *69*, **13**: 211; 19.

(60) Terres, *397*, **63**: 785, 805, 820, 836; 20. (61) Jorissen, *70*, **39**: 715; 20. (62) Chapman, *4*, **119**: 1677; 21. (63) Katz and Smith, *313*, No. **2400**: 11; 22. (64) White, *4*, **121**: 1244; 22. (65) White, *4*, **121**: 1688; 22. (66) White, *4*, **121**: 2561; 22. (67) Jorissen, *176*, **19**: 193; 22. (68) Boussu, *34*, **175**: 30; 22. (69) Asch, *97*, **4**: 468; 23.

(70) Builder, *136*, **47**: 435; 23. (71) Payman and Wheeler, *4*, **123**: 426; 23. (72) Jones, Yant and Berger, *45*, **16**: 353; 24. (73) Berl and Fischer, *9*, **30**: 29; 24. (74) White, *4*, **125**: 2387; 24. (75) Jorissen and Velisek, *70*, **43**: 80; 24. (76) Jorissen and Meuwissen, *70*, **43**: 591; 24. (77) White, *4*, **127**: 48; 25. (78) White, *4*, **127**: 672; 25. (79) Jorissen and Meuwissen, *70*, **44**: 132; 25.

(80) Crouch and Carver, *45*, **17**: 641; 25. (81) Jorissen and Valk, *70*, **44**: 810; 25. (82) Jorissen and Ongkiehong, *70*, **44**: 814; 25. (83) Jorissen, *70*, **44**: 1039; 25. (83a) Burgers and Wheeler, Safety in Mines Research Board, *Paper* No. **15**; 26. (83b) Coward and Hartwell, *Ibid.*, No. **19**; 26. (83c) Jorissen and Ongkiehong, *70*, **45**: 162, 224, 400; 26. (83d) Explosives in Mines Committee, *3rd Report*. London, H. M. Stationery Off., 1913.

Limiting Pressures

(84) Meyer and Seubert, *4*, **45**: 581; 84. (85) Dixon, *62*, **175**: 634; 84. (86) De Hemptinne, *186*, 761; 02. (87) Fischer and Wolf, *25*, **44**: 2956; 11. (88) Coward, Cooper and Warburton, *4*, **101**: 2278; 12. (89) Coward, Cooper and Jacobs, *4*, **105**: 1069; 14.

(90) Stavenhagen and Schuchard, *92*, **33**: 286; 20. (91) Stavenhagen and Schuchard, *92*, **34**: 114; 21.

Relative Inflammabilities

(92) Emich, *57*, **18**: 6; 97. (93) Emich, *57*, **19**: 299; 98.

PROPAGATION OF FLAME

The "Uniform Movement" and Attendant Phenomena

Given certain conditions, an initial "slow uniform flame movement" can usually be effected in a gaseous explosive medium; its velocity is, however, dependent upon (1) the composition of the mixture, (2) its temperature and pressure, (3) the nature and dimensions of the containing vessel (in case of a tube, the diameter being the important dimension) and (4) the source and character of ignition. It is usually determined experimentally by igniting each explosive mixture with the same type of flame at the open end of a tube which is closed at the other end.

The flame movement so initiated usually proceeds at uniform velocity for a certain short distance, and its termination is marked by a period of accelerated vibrational flame movement, which may in some cases give rise to detonation. In other cases, however, it seems to be succeeded abruptly by detonation.

Recently attempts have been made to establish a so-called "law of flame speeds" for complex combustible gaseous mixtures, *e.g.*, coal-gas and air, on the supposition that in such cases the observed flame speed is caused by the oxygen or combustible gas (whichever of the two is in defect) dividing itself during the combustion so as to form a series of explosive mixtures (of each single component combustible gas with oxygen) giving the same flame speed. This, however, seems a fundamentally wrong view of things.

Abbreviations and Units

Tb_x. A tube of diameter x cm was used in experiment. The values given in the tables are the velocities of propagation of flame in cm/sec for the mixtures noted. All gas percentages are in volume %.

H_2

Tb_1 (4) H_2 in air		(8) $2H_2+O_2+4N_2$		Tb_1 (7) $2H_2+O_2+4N_2$		$Tb_{2.5}$ (27) H_2 in O_2	
% H_2	cm/sec	Tb_1	350	20°	350	% H_2	cm/sec
20	200	$Tb_{0.6}$	323	100°	430	59.9	574
25	280	$Tb_{0.3}$	350			66.6	662
30*	340	$Tb_{0.09}$	172			75.2	515
35	410	$3H_2 + Cl_2$					
40	440	Tb_1	315				
50	380	$H_2 + 3Cl_2$					
60	230	Tb_1	600				

* Not propagated in $Tb_{0.09}$ or less.

H_2 in air (16). A, in $Tb_{0.9}$; B, in $Tb_{1.15}$; C, in $Tb_{2.5}$

% H_2	A	% H_2	B	% H_2	C
11.80	No	17.30	150	6.10	No
17.30	125	25.15	260	6.19	10
23.65	200	33.90	383	6.31	12
30.45	320	37.15	400	20.15	260
36.55	390	40.10	410	29.70	405
40.10	420	43.10	420	36.30	490
43.10	420	46.80	400	40.50	480
46.80	400	51.55	360	44.55	460
50.55	353	57.15	270	49.15	385
57.00	280	59.45	175	61.60	145
62.00	155			71.39	50
63.50	No			71.51	*

* Flame to open end only.

CO

$Tb_{2.5}$ (23) CO in air, saturated with H_2O at room temp. and $P = 1$ atm.		Effect of H_2 and H_2O on flame speeds of CO – air mixtures (34)				
% CO	cm/sec	t°	% CO	% H_2	% H_2O	cm/sec
		6	39.25	0.65	1.90	73.5
		28	38.00	0.65	3.70	103.5
		4	39.70	1.90	0.80	103.5
16.15	*	6	46.15	3.85	0.90	152.0
16.29	19.5	10	47.30	4.05	1.20	150.0
16.51	19.4	29	46.00	4.05	3.95	167.0
24.47	34.0	20	47.30	4.15	2.30	144.0
30.50	46.0	5	37.45	5.60	0.85	170.0
44.84	60.1	6	43.75	5.60	0.90	170.5
59.58	56.2	31	42.20	5.60	44.0	156.0
67.10	30.2	6	40.80	6.05	0.90	160.5
70.63	20.0	27	39.60	6.05	3.50	158.0
71.19	19.4	Tb_1 (7)				
71.31	†	$2CO + O_2$, 220 cm/sec				

* Flame tongue.
† Flame to 15 cm.

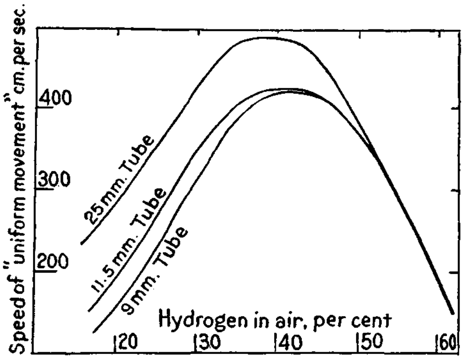

FIG. 5.—Influence of tube diameter on speed of "uniform movement" with mixtures of hydrogen and air (16).

Effect of H_2O on flame-speed (33). $Tb_{2.5}$. t° = temp. of saturation with H_2O

t°	% H_2O	cm/sec	t°	% H_2O	cm/sec	t°	% H_2O	cm/sec
2*	0.70	56	42*	8.00	118	27†	3.50	96
13*	1.45	76	4†	0.80	56	34†	5.20	107
27*	3.50	106	12†	1.35	68	39†	6.85	107
34*	5.20	120	20†	2.30	86			

* = 45 % CO in air.
† = 40 % CO in air.

CH_4 Methane

CH_4 in air (12); *cf.* (3, 6, 7, 8). A in glass $Tb_{2.65}$; B in lead $Tb_{2.64}$; C in copper $Tb_{2.3}$; D in iron $Tb_{2.72}$					CH_4 in air (13) Tb_5	
% CH_4	A	B	C	D	% CH_4	cm/sec
					5.4	36
5.99	21.7	19.4	18.3	21.2	6.8	55
6.83	33.4	32.5	32.7	34.1	8.8	100
7.6	45.6	43.5	42.4	43.8	9.45	110
7.95	48.6	48.2	45.2		10.6	109
8.94	63.66	58.7	59.4	63.3	11.5	84
10.0	69.8	65.0	63.2	67.3	13.0	42
10.98	61.1	53.9	54.1	57.5	14.3	36
11.3	53.3	45.4	47.7	50.6		
11.74	36.9	35.2	34.5	36.1		

"Uniform-movement" velocities in tubes of small diameter (20).
D = internal diam. of tube in mm; % = % CH_4 in air

D \ %	7.6	8.0	8.25	8.4	8.5	9.0	9.5	9.95	10.15
3.6	0	0	0	0	0	0	0	0	0
4.5	0	0	(20)	(18)	(20)	(20)	(20)	(33)	0
5.6	(25)	(20)	(27)		36.3	38.4	40.8	41.2	40.8
7.2	(37)	(30)	(30)	(30)	38.0	40.5	46.8	46.3	44.5
8.1	(45)	(30)	(35)	36.5	39.3	42.4	47.7	47.4	46.7
9.0	(55)	32.6	34.8		40.4	44.4	48.9	48.0	47.9

D \ %	10.5	10.65	10.8	11.0	11.5	11.6	11.65	12.0
3.6	0	0	0	0	0	0	0	0
4.5	0	0	0	0	0	0	0	0
5.6	38.4	0	0	0	0	0	0	0
7.2	42.9	(60)	(53)	(43)	0	0	0	0
8.1	44.0	42.2	41.0	(45)	(50)			(60)
9.0	46.5	45.5		42.5	36.9	35.3	(69)	(60)

Figures in parentheses denote distance travelled before flame died out.

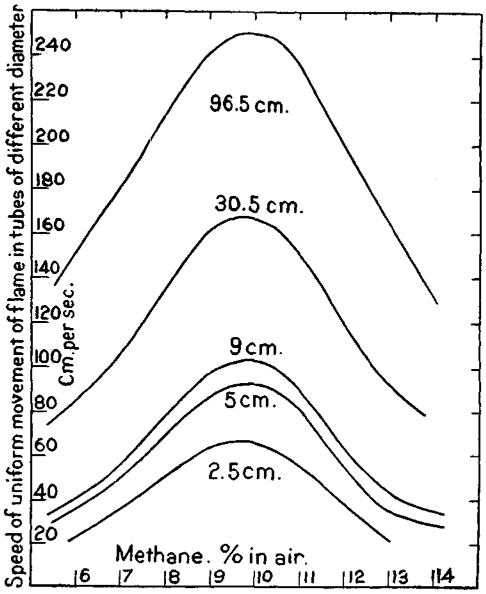

FIG. 6.—Influence of tube diameter on speed of "uniform movement" with mixtures of methane and air (19).

CH_4 in air, $Tb_{2\cdot5}$ (23)		CH_4 in O_2 (27)	
% CH_4	cm/sec	% CH_4	cm/sec
5.71	*	5.59	†
5.80	23.3	5.72	20
6.95	35.0	10.52	266
7.82	47.4	15.53	722
9.12	64.4	21.63	2300
9.96	66.2	26.95	3991
10.32	65.5	33.00	5502
11.10	57.0	40.00	3020
12.25	35.0	45.61	488
13.09	22.0	53.36	82
13.35	19.1	57.67	29
13.42	†	59.50	‡

* Flame to 15 cm.
† Flame to 5 cm.
‡ Flame to 30 cm.

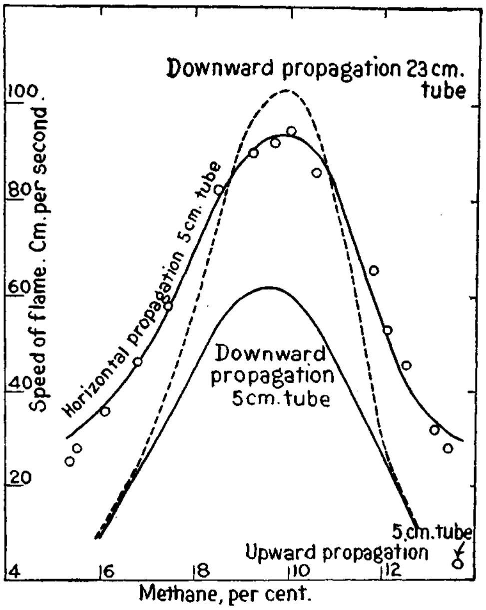

FIG. 7.—Influence of the direction of flame propagation on speed of "uniform movement" with mixtures of methane and air (28).

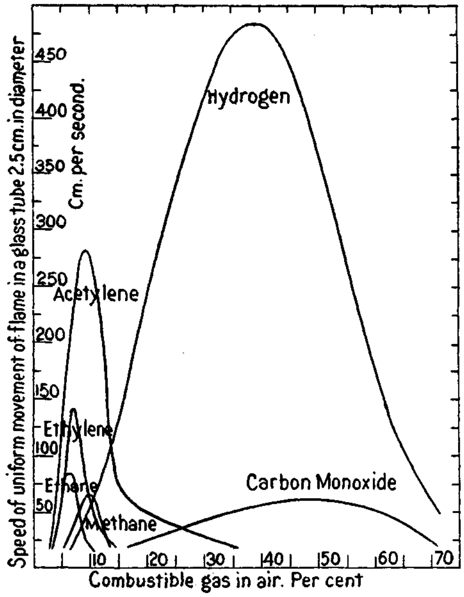

FIG. 8.—Comparison of the speeds of "uniform movement" of mixtures of various individual gases with air (29).

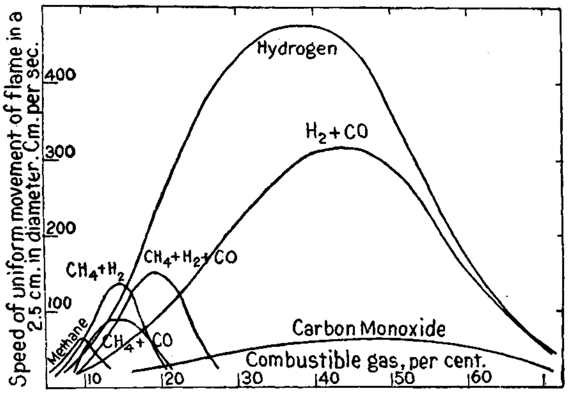

FIG. 9.—Speeds of "uniform movement" of mixtures of combustible gases with air (23).

C_2H_2 Acetylene

C_2H_2 in air		C_2H_2 in air		C_2H_2 in air (22)				
Tb_4 (9)		$Tb_{0.9}$ (17)		% C_2H_2	Diam. of tube in mm			
% C_2H_2	cm/sec	% C_2H_2	cm/sec		12.5	25	50	90
2.9*	10	4	45	2.75				40
8.0	500	6	147	3.45	25	41	60	
9.0–10.0	600	8	260	4.40				115
22.0	40	9	266	4.60	82	95	115	
64*	5	10	264	6.10	158	172	205	
		12	175	7.00				265
		14	114	8.15	258	270	303	
		16	75	9.45				335
		18	50	10.35	260	278	304	
		20	38	11.6	206	245	283	
				11.85				285
				13.25	115	145	175	220
				16.00	60	68	72	
				18.20			60	70

* Limit.

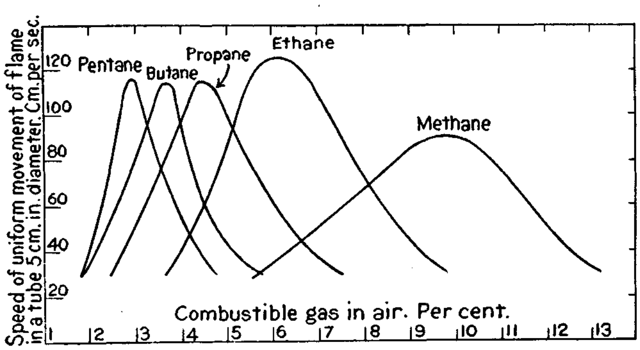

FIG. 10.—Speed of "uniform movement" of mixtures of the paraffin series with air (31).

C_2H_4 Ethylene		C_2H_6 Ethane		C_3H_8 Propane		C_4H_{10} Butane	
In air (29)		In air (23)		In air (23)		In air (22)	
$Tb_{2.5}$ % C_2H_4	cm/sec	$Tb_{2.5}$ % C_2H_6	cm/sec	$Tb_{2.5}$ % C_3H_8	cm/sec	$Tb_{2.5}$ % C_4H_{10}	cm/sec
3.55	25.8	3.16	*	2.30	‡	1.90	‡
4.00	41.3	3.30	18.1	2.37	20.8	1.95	20.1
6.10	108.4	3.58	25.6	2.58	26.0	2.05	23.3
6.50	129.9	4.47	52.7	2.80	31.4	2.57	49.1
7.20	142.4	4.90	65.0	3.50	48.2	3.01	67.9
8.10	120.6	5.57	80.5	4.28	72.8	3.40	80.2
9.45	72.6	6.08	82.5	4.39	79.1	3.66	82.6
13 35	23.5	6.53	85.6	4.71	82.1	4.05	75.0
14 00	22.2	7.07	81.3	4.84	80.2	4.34	61.9
		7.70	60.4	5.14	66.0	4.88	43.4
		8.23	45.8	5.90	41.2	5.50	27.7
		9.00	27.7	6.58	30.2	6.27	22.0
		9.50	23.1	7.10	23.0	6.53	20.3
		10.09	20.8	7.30	20.3	6.60	‖
		10.60	19.7	7.35	§		
		10.71	†				

* Flare only.
† Flame to 4 cm.
‡ Flame to 6 cm.
§ Flame to 15 cm.
‖ Flame to open end only.

C_5H_{12} Pentane				C_3H_6O Acetone		CS_2+3NO (7)	
In air (23). $Tb_{2.5}$				In air (17)		*Cf.* (5, 8)	
% C_5H_{12}	cm/sec	% C_5H_{12}	cm/sec	$Tb_{2.5}$			
1.52	*	3.85	48.0	% C_3H_6O	cm/sec		
1.61	20.2	4.00	44.0	2.70	55.0	Tb_3	125
1.98	40.1	4.32	33.0	3.85	69.0	Tb_2	124
2.35	60.2	4.56	28.7	5.05	93.8	Tb_1	75
2.63	74.3	4.87	25.8	6.40	68.5	$Tb_{0.4}$	
2.92	83.0	5.40	20.2	7.65	39.5		
3.00	82.1	5.50	†	8.20	30.5		
3.13	76.0						
3.35	65.9						
3.49	61.5						

* Flame to 6 cm. † Flame to open end only.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bunsen, *8*, **131**: 161; 67. (2) Mallard, *15*, **7**: 355; 75. (3) Fonseca Benevides, *407*, **7**: 166; 80. (4) Mallard and Le Châtelier, *34*, **93**: 145; 81. (5) Mallard and Le Chatelier, *34*, **95**: 599; 82. (6) Mallard, *185*, **15**: 268; 82. (7) Mallard and Le Chatelier, *51*, **1**: 173; 82. *27*, **39**: 369, 572; 83. (8) Mallard and Le Chatelier, *15*, **4**: 296; 83. (9) Le Chatelier, *34*, **121**: 1144; 95.

(10) Bunte, *25*, **31**: 19; 98. (11) Sellars and Campbell, *54*, **32**: 730; 13. (12) Parker and Rhead, *4*, **105**: 2150; 14. (13) Wheeler, *4*, **105**: 2606; 14. (14) Morgan, *115*, **99**: 39; 15. *67*, **26**: 172; 14. (15) Parker, *4*, **107**: 328; 15. (16) Haward and Otagawa, *4*, **109**: 83; 16. (17) Wheeler and Whitaker, *4*, **111**: 267; 17. (18) Haward and Sastry, *4*, **111**: 841; 17. (19) Mason and Wheeler, *4*, **111**: 1044; 17.

(20) Payman and Wheeler, *4*, **113**: 656; 18. (21) Payman and Wheeler, *4*, **115**: 36; 19. (22) Mason and Wheeler, *4*, **115**: 578; 19. (23) Payman, *4*, **115**: 1446, 1454; 19. (24) Morgan, *115*, **108**: 535; 19. (25) Nickolls, *Underwriters Labs. Special Investigation* No. 528; 19. (26) Mason and Wheeler, *4*, **117**: 36; 20. (27) Payman, *4*, **117**: 48; 20. (28) Mason and Wheeler, *4*, **117**: 1227; 20. (29) Chapman, *4*, **119**: 1677; 21.

(30) Payman and Wheeler, *4*, **121**: 363; 22. (31) Mason, *4*, **123**: 210; 23. (32) Payman, *4*, **123**: 412; 23. (33) Payman and Wheeler, *4*, **123**: 1251; 23. (34) Ellis, *4*, **123**: 1435; 23. (35) Campbell and Ellis, *4*, **125**: 1957; 24. (36) Ellis and Stubbs, *4*, **125**: 1960; 24. (37) Ellis and Robinson, *4*, **127**: 760; 25. (38) Ellis and Wheeler, *4*, **127**: 764; 25. (39) Gouy, *6*, **18**: 1; 79.

(40) Bunte, *25*, **31**: 19; 98. (41) Hofsass, *397*, **62**: 541; 19. (42) Payman and Wheeler, *83*, preprint, 1926.

THEORETICAL

(43) Vicaire, *6*, **19**: 118; 70. (44) Mallard and Le Chatelier, *15*, **4**: 296; 83. (45) Jouguet, *34*, **156**: 872; 13. (46) Nusselt, *98*, **59**: 872; 15. (47) Jouguet and Crussard, *34*, **168**: 820; 19.

DETONATION

The phenomenon of detonation, or "l'onde explosive" as it was originally known, in gaseous explosions was discovered by Berthelot and Vieille and by Mallard and Le Chatelier in the year 1881. It is set up when a sufficiently explosive mixture is ignited by means of a detonator (such as fulminate) or under circumstances such that the burning gases are exposed to the repeated effects of reflected compression waves. In the last named circumstance the initial uniform slow velocity is rapidly accelerated up to the point of detonation.

When once established its velocity is constant and within wide limits unaffected by the material and diameter of the tube employed, being solely dependent on the nature of the explosive mixture and on its temperature and pressure.

In the explosion wave the explosive mixture is fired adiabatically by compression so that the chemical reaction is more intense and of much shorter duration than in the case of normal combustion. In addition the pressure in the wave is much greater than in ordinary explosions, this being the cause of its shattering effect.

Abbreviations

Values not otherwise designated are detonation velocities in meters per second.

Composition of gas mixtures when given in percentages are in volume %.

The initial conditions of the detonating mixture are ordinary temperature and pressure unless otherwise stated.

H_2

Determinations in a lead pipe 100 m long × 6 mm diam. (8)
For $2H_2 + O_2$, normal conditions, 2821

At 10°				At 100°			
P_{mm}	m/sec	P_{mm}	m/sec	P_{mm}	m/sec	P_{mm}	m/sec
200	2627	760	2821	390	2697	1000	2828
300	2705	1100	2856	500	2738	1450	2842
500	2775	1500	2872	760	2790		

$2H_2 + O_2$	2821	$2H_2 + 8O_2$	1281	$2H_2 + O_2 + N_2$	2426
$2H_2 + 2O_2$	2328	$4H_2 + O_2$	3268	$2H_2 + O_2 + 3N_2$	2055
$2H_2 + 4O_2$	1927	$6H_2 + O_2$	3527	$2H_2 + O_2 + 5N_2$	1822
$2H_2 + 6O_2$	1707	$8H_2 + O_2$	3532	$2H_2 + 2O_2 + 2N_2$	2003

$H_2 + N_2O$, at $P_{mm} = 500$, 2094; $P_{mm} = 760$, 2307; $P_{mm} = 1000$, 2302

Determinations in a lead pipe 100 m long × 9 mm diam. (24)

% H_2	% O_2	m/sec	% H_2	% O_2	m/sec	% H_2	% O_2	m/sec
22.2	77.8	1600	50.0	50.0	2311	85.5	14.5	3527
25.0	75.0	1693	66.7	33.3	2817	88.9	11.1	3532
33.3	66.7	1917	80.0	20.0	3278			

% H_2	% O_2	% N_2	m/sec	% H_2	% O_2	% N_2	m/sec
25.0	50.0	25.0	1756	33.3	33.3	33.3	1990
33.3	44.4	22.3	1961	50.0	25.0	25.0	2388
50.0	33.3	16.7	2374	66.6	16.7	16.7	2767
66.6	22.2	11.2	2822	75.0	12.5	12.5	2846
75.0	16.7	8.3	3090	33.3	26.6	40.1	2016
80.0	13.3	6.7	3137	50.0	20.0	30.0	2383
				66.6	13.3	20.1	2655
				71.4	11.4	17.2	2671

In glass tubes (22)				(8)		$H_2 + Cl_2$ in dark, dry, 1795 wet, 1770 (6)
Tube diam. =	9	12.7	15			
$2H_2 + O_2$	2821		2828	$H_2 + Cl_2$	1729	
$2H_2 + 4O_2$	1927	1921		$2H_2 + Cl_2$	1849	
$2H_2 + O_2 + 3N_2$	2055		2089	$3H_2 + Cl_2$	1855	

Determinations in rubber tube 40 m long × 5 mm diam. (3)

$2H_2 + O_2$, normal conditions, 2810				%$(2H_2 + O_2)$		% H_2 in air	
P_{mm}	m/sec	P_{mm}	m/sec	In air		30	1439
560	2763	1260	2776	45	1439	26.7	1201
760	2800	1580	2744	40	1251	23.3	1205
$2H_2 + N_2O$		2284		35	1205	21.7	*
$2H_2 + N_2 + O_2$		2121		32.5	*		

* Detonation not propagated.

ClO_2

53.5% ClO_2, 46.5% O_2, 1065. 64.0% ClO_2, 36.0% O_2, 1126 (11)

CO

(3)			
$2CO + O_2$		$CO + N_2O$	1106
P_{mm}	m/sec	$2CO + O_2 + 2N_2$	(1000)
570	1120	30% CO in air not detonated	
760	1089		
834	1072		
1560	1132		

$2CO + O_2$ (13). In CO mixtures the speed may be influenced by nature of igniting charge.

Fired by
0.10 g chlorate powder...............1280*
0.05 g fulminate....1900†
0.75 g fulminate....1210‡

* Wave variable.
† Explosive.
‡ Undulatory.

$2CO + O_2$; influence of H_2O vapor (8); t° = saturation temp.

t°	% H_2O	P_{mm}	m/sec	t°	% H_2O	P_{mm}	m/sec
	Well-dried		1264	35	5.6	760	1738
	Dry		1305	35	5.6	1100	1782
10	1.2		1676	45	9.5	400	1570
20	2.3	400	1576	45	9.5	760	1693
20	2.3	760	1703	45	9.5	1100	1742
20	2.3	1100	1737	55	15.6		1666
28	3.7		1713	65	24.9		1526
35	5.6	400	1616	75	38.4		1266

CH_4 Methane

(8)				In O_2 (24)		(3)	
$CH_4 + 2O_2$		$CH_4 + 2O_2$	2146	% CH_4		$CH_4 + 2O_2$	2287
P_{mm}	m/sec	$CH_4 + 4O_2$	1963	11.1	1678	$CH_4 + 2N_2 + 4O_2$	1858
500	2280	$CH_4 + 1\frac{1}{2}O_2 + \frac{1}{2}N_2$	2349	20.0	1980	$CH_4 + 4N_2 + 2O_2$	1151
760	2322	$CH_4 + 1\frac{1}{2}O_2 + 1\frac{1}{2}N_2$	2154	25.0	2146	$CH_4 + 7.52\ N_2 + 2O_2$ gives no detonation.	
1000	2319	$CH_4 + 1\frac{1}{2}O_2 + 2\frac{1}{2}N_2$	1880	33.3	2337		
$CH_4 + 1\frac{1}{2}O_2$				40.0	2465		
500	2418			50.0	2513		
760	2470			53.3	2388		
1000	2488						

C_2H_2 Acetylene

(13)				(8)	
$2C_2H_2 + O_2$	2160	$C_2H_2 + 6O_2$	1950	$C_2H_2 + 2\frac{1}{2}O_2$	2391
$1\frac{1}{2}C_2H_2 + O_2$	2510	$C_2H_2 + 10O_2$	1850	$C_2H_2 + 1\frac{1}{2}O_2$	2716
$C_2H_2 + O_2$	2920	$C_2H_2 + 2N_2O$	2580	$C_2H_2 + 1\frac{1}{2}O_2 + N_2$	2414
$C_2H_2 + 3O_2$	2220	$C_2H_2 + 6N_2O$	2400	$C_2H_2 + O_2$	2961 (16)
$C_2H_2 + 4O_2$	2190	$C_2H_2 + 2NO$	2850	$C_2H_2 + 2\frac{1}{2}O_2$	2482 (3)
		$C_2H_2 + 6NO$	2800		

98% C_2H_2 (12). Determinations made in tube 1 m long × 3.5 mm diam. Since C_2H_2 is an endothermic compound, it can be detonated under pressure.

P = initial detonating pressure in kg/cm².

P................	5	10	12	15	20	30
Speed............	1050	1100	1280	1320	1500	1600

C_2H_4 Ethylene (8)

$C_2H_4 + 2O_2$*	2581	$C_2H_4 + 6O_2$	2118	$C_2H_4 + 2O_2 + 2N_2$	2211
$C_2H_4 + 2O_2$†	2538	$C_2H_4 + 8O_2$	1980		
$C_2H_4 + 3O_2$	2364	$C_2H_4 + 10O_2$	1856	$C_2H_4 + 2O_2 + 4N_2$	2024
$C_2H_4 + 4O_2$	2247	$C_2H_4 + 2O_2 + N_2$	2413		
(3)				$C_2H_4 + 2O_2 + 6N_2$	1878
$C_2H_4 + 3O_2$	2209			$C_2H_4 + 2O_2 + 8N_2$	1734

* 10°.
† 100°.

C_2H_6 Ethane

$C_2H_6 + 3\frac{1}{2}O_2$, 2363 (3)

C_2N_2 Cyanogen

(3)		(8)			(22)	
$C_2N_2 + 4N_2O$	2035	P_{mm}	$C_2N_2 + O_2$	$C_2N_2 + 2O_2$, 2321	$C_2N_2 + O_2 + 2N_2$	
$C_2N_2 + 2O_2$	2043	500	2536	$C_2N_2 + 3O_2$, 2110	Diam. of tube	m/sec
$C_2N_2 + 2N_2 + 2O_2$	1203	760	2677	$C_2N_2 + O_2 + N_2$, 2398	6 mm	2161
$C_2N_2 + 4N_2 + 2O_2$	*	1000	2671	$C_2N_2 + O_2 + N_2$, 2165	9 mm	2230
P_{mm}	$C_2N_2 + 2O_2$	t°			12.7 mm	2230
388	2171	10	2728			
758	2195	100	2711			
878	2052					

* Detonation not propagated.

MIXTURES OF COMBUSTIBLE GASES

(23)

$2(xH_2 + yCO) + O_2$			$4(xH_2 + yCO) + O_2$		
x	y	m/sec	x	y	m/sec
0.75	99.25	1754	1	99	1747
1.5	98.5	1758	2	98	1755
7.5	92.5	1796	5	95	1776
15	85	1858	25	75	1952
37.5	62.5	2020	50	50	2212
50	50	2130	75	25	2614
75	25	2391	85	15	2819
85	15	2507	92.5	7.5	3015
92.5	7.5	2643	100	0	3284
100	0	2810			

$H_2 + CH_4$ (24). M = % mixture in O_2

$H_2 + CH_4$		$2H_2 + CH_4$		$H_2 + 2CH_4$	
M	m/sec	M	m/sec	M	m/sec
13.8	1532	14.3	1449	14.3	1728
21.0	1875	15.8	1582	25.0	2050
44.4	2464	16.7	1666	40.0	2444
50.0	2561	20.0	1764	46.1	2546
57.1	2697	33.3	2094	50.0	2605
66.7	2604	50.0	2474	54.5	2679
		54.5	2572	60.0	2600
		66.7	2782		

(8)	
$2H_2 + O_2 + 2CO$	2455
$2H_2 + O_2 + 6CO$	2080
$H_2 + O_2 + 2CO$	2143
(3)	
$H_2 + O_2 + CO$	2008
$3H_2 + 2\frac{1}{2}O_2 + 2CO$	2170
$H_2 + C_2H_4 + 3\frac{1}{3}O_2$	2417
$2H_2 + C_2H_4 + 4O_2$	2579
$H_2 + C_2H_6 + 4O_2$	2250

LIMITING DILUTIONS OF EXPLOSIVE MIXTURES FOR THE INITIATION OF DETONATION

Detonation cannot be propagated in mixtures diluted beyond the limits given

	Limits	Speed	Lit.
H_2 and air............	Lower 23.3% H_2	1205	(3)
	Between 21.7% H_2	*	
CO..................	$4CO + 2N_2 + O_2$	*	(3)
	$2CO + N_2 + O_2$	*	(3)
CH_4 Methane.........	$CH_4 + O_2$		
	Lower 11.1% CH_4	1678	(24)
	Upper 53.3% CH_4	2388	
	$CH_4 + 4N_2 + 2O_2$	1151	(3)
	$CH_4 + 7.5N_2 + 2O_2$	*	(3)
	9.5% CH_4 in air	*	(3)
C_2H_2 Acetylene.......	$C_2H_2 + 10O_2$	1850	(13)
	$C_2H_2 + 6NO$	2800	(13)
C_2N_2 Cyanogen.......	$C_2N_2 + 2N_2 + 2O_2$	1203	(3)
	$C_2N_2 + 4N_2 + 2O_2$	*	(3)
	$C_2N_2 + 4N_2O$	2035†	(3)
	$C_2N_2 + 4NO$	*	(3)

* Detonation not propagated.

† Sometimes propagated.

Mean flame velocity before a uniform detonation speed ensues (3). $2H_2 + O_2$, in rubber tube 5 mm diam.; *D* = distance from initiating explosive in m; *S* = time in sec; *V* = mean vel. from origin in m/sec; $V_{int.}$ = mean vel. in each interval.

D	*S*	*V*	$V_{int.}$
0.020	0.000275	72.72	72.7
0.050	0.000342	146.2	448.0
0.500	0.000541	924.4	2261
5.250	0.002108	2491.0	3031
20.190	0.007620	2649.0	2710
40.430	0.015100	2679.0	2706

Distance in inches from spark at which detonation occurs = D_0 for spark at end of tube and D_3 for spark 3 in. from end (16).

Mixture	D_0	D_3
$2H_2 + O_2$	48	12
$2H_2 + 2\frac{1}{2}O_2$		48
$6H_2 + O_2$		192
$C_2N_2 + O_2$	$8\frac{1}{2}$	4
$C_2N_2 + 2O_2$	12	10
$2C_2H_2 + 3O_2$	$4\frac{1}{2}$	$2\frac{1}{2}$
$C_2H_4 + 2O_2$	9	5

Distance before detonation wave is established = *D* cm (13). Glass tube, 10 mm diam. Spark at end of tube

Mixture	*D*
$2C_2H_2 + O_2$	100
$C_2H_2 + O_2$	5
$C_2H_2 + 6O_2$	15
$C_2H_2 + 10O_2$	80
$C_2H_2 + 2NO$	20
$C_2H_2 + 6NO$	50
$C_2H_2 + 2N_2O$	100
$C_2H_2 + 6N_2O$	10

Influence of tube diameter on the distance from the firing source at which detonation occurs (25). Mixture = $CS_2 + 3O_2$. Spark at end of tube. D_{cm} = cm travelled by flame before detonation.

Tube diam., mm	D_{cm}
6.5–7	48
10	50
24–25	58
34–35	84
43–44	103
53–54	131

Distance required for the re-establishment of detonation waves after they are damped out by passing from one tube to another of larger diameter (26). Diam. of first tube = 7 mm. Distance in cm travelled by flame in second tube prior to detonation = *D*.

Diam. mm second tube......	13	16	23–24	33–34	44–45
D ($CS_2 + 3O_2$)..............	8	10	15	50	100
D ($2H_2 + O_2$)..............			3	62	

WAVE VELOCITIES (14)

	$C_2H_2 + O_2$	$C_2H_2 + 2NO$	$2CO + O_2$
L'onde explosive (détonation wave)..........	2990	2850	1900
L'onde rétrograde (retonation wave)*.........	2300	1140	
L'onde réfléchie (reflexion wave)†...........	2250	1350	1000
L'onde prolongée (collision wave)‡..........	2050		

* A "retonation" wave is thrown back into the burnt gases when the detonation wave is set up.

† The wave reflected through the burnt gases after a detonation wave has reached the walls of the vessel in which the explosion occurs.

‡ Collision waves occur when two detonation waves meet.

REFLECTED WAVES IN A $C_2H_2 + O_2$ MIXTURE

Initial speed...........	2300	After first crossing......	1080
After reflection.........	1350	After second crossing...	980

Ratio of Wave Velocities ([16])

Mixture	Detonation wave velocity	Reflection wave velocity	Ratio of velocities
$2H_2 + O_2$	2820	1538	1.83
$H_2 + N_2O$	2305	1383	1.67
$2CO + O_2$	1676	1078	1.56
$C_2N_2 + O_2$	2728	1230	2.22
$C_2N_2 + 2O_2$	2321	1129	2.06
$2C_2N_2 + 5O_2$	2391	1133	2.11

Two equations of importance have been deduced whereby velocities of detonation agreeing closely with experimental values may be calculated ([34, 35]).

$$V^2 = \frac{2RJ}{\mu C_v^2}[\{(m-n)C_p + mC_v\}C_pT_o + (C_p + C_v)h] \text{ where}$$

V	Velocity of wave.
R	Gas constant.
J	Dynamical equivalent of heat (42 × 10^6 ergs).
μ	Gram equivalents of the mixture exploded.
n and m	Number of molecules before and after the chemical change in the wave.
C_p and C_v	Mean specific heats of the products at constant pressure and volume, respectively.
h	Total heat generated in the wave.
T_o	Initial temperature (abs.) of the mixture exploded.

$$\left(\frac{dP}{dl}\right)^2 = \mu^2\frac{Rk_2T_2}{M}\left(1 + \frac{k_2R}{MC_2}\right), \text{ where}$$

$\left(\frac{dP}{dt}\right)$	Velocity of the wave.
R	Gas constant.
M	Molecular mass of the gas taken.
T_2	Temperature of the flame.
μ	$\frac{d_2}{d_1}$ (ratio of the final and initial densities).
C_2	Mean specific heat at constant volume of the explosion products.
k_2	Number of molecules in the explosion products.

LITERATURE

(For a key to the periodicals see end of volume)

Experimental

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Theoretical

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EXPLOSIONS IN CLOSED VESSELS

Much of the experimental determination of explosion times and pressures using gaseous mixtures has been carried out with coal gas—air mixtures. Owing to the variable composition and heat of combustion of the samples of coal gas so employed, it has not been found possible to tabulate such data except in so far as they may have a general bearing on the subject of gaseous explosions—and more particularly where data relative to the simpler combustible gases are lacking.

All maximum pressures have been expressed as a ratio, $\frac{\text{maximum pressure}}{\text{initial pressure}}$, thus giving a better basis of comparison. In most cases the published figures for initial pressures refer to room temperatures. Where this has been found to be otherwise, the initial pressures have been adjusted to correspond to a temperature of 15°C, and a corresponding correction applied to maximum pressures.

No attempt has been made to tabulate investigators' estimates of their explosion temperatures because (*a*) an arbitrary correction must necessarily be applied for cooling loss during the explosion period—this being dependent on the explosion vessel employed and (*b*) allowances must be made for dissociation. An approximate value of the temperature attained may be calculated from the formula

$$T_{(\text{max.})\text{ abs.}} = \frac{P_{\text{max.}}}{P_{\text{init.}}} \times T_{(\text{init.})\text{ abs.}} \times \frac{m}{n}$$

where m/n represents the molecular change.

Few direct determinations of explosion temperatures have been possible owing to the very high temperatures developed.

In comparing explosion times, consideration must be given to the dimensions of the explosion vessels concerned—on which they are solely dependent.

In the following tables all results may be considered to refer to explosions of gaseous mixtures at atmospheric pressure and temperature unless specially stated otherwise.

Abbreviations

$\frac{P_{\text{max.}}}{P_{\text{init.}}}$	Ratio of maximum pressure developed to initial pressure.
$P_{\text{init.}}$	Initial pressure in atmospheres.
$T_{\text{init.}}$	Initial temperature in °C.
V_x	Vessel whose capacity is x cm^3, unless otherwise stated.
Cyl.	Cylindrical.
Con.	Conical.
Sphere	Spherical.
Exper. condn.	Experimental conditions.
Milli-sec	Time in milli-seconds to attain maximum pressure.

H_2

Mixture	$\frac{P_{\text{max.}}}{P_{\text{init.}}}$	Milli-sec	Exper. condn.	Lit.
$2H_2$				
$+O_2$	9.5		Cyl., V_{18}	(2)
$+O_2 + 4N_2$	6.5	10	Cyl., V*	(6)
$+O_2$	9.25		Cyl., V_{4000}	(9)
$+O_2 + 2H_2$	8.34			
$+O_2 + 4H_2$	7.58			
$+O_2 + 6H_2$	6.67			
$+O_2 + 2O_2$	8.2			
$+O_2 + 6O_2$	6.4			
$+O_2 + N_2$	8.65			
$+O_2 + 2N_2$	8.26			
$+O_2 + 4N_2$	7.5			
$+O_2 + 6N_2$	6.5			

H_2.—(*Continued*)

Mixture	Pmax./Pinit.	Millisec	Exper. condn.	Lit.
$+2N_2O$	12.85		Cyl.., V_{4000}	(9)
$+2N_2O + 2N_2$	10.47			
$+O_2$	7.41	1.04	Cyl., V_{300}	(11, 15)
$+O_2$	9.69	2.14	Cyl., V_{4000}	(11, 15)
$+O_2 + \frac{1}{20} H_2$		2.27	Cyl., V_{4000}	(11, 15)
$+O_2 + \frac{1}{10} H_2$		2.53		
$+O_2 + \frac{1}{5} H_2$		2.41		
$+O_2 + H_2$		2.82		
$+O_2 + 2H_2$		1.67	Cyl., V_{300}	(11, 15)
$+O_2 + 2H_2$		4.22	Cyl., V_{4000}	(11, 15)
$+O_2 + 3H_2$		5.95		
$+O_2 + 4H_2$		9.67		
$+O_2 + 2O_2$		8.16		
$+O_2 + 6O_2$		16.04		
$+O_2 + N_2$		2.86		
$+O_2 + \frac{1}{2}N_2$		3.55		
$+O_2 + 2N_2$	8.63	6.87		
$+O_2 + 2N_2$	7.60	2.67	Cyl., V_{300}	(11, 15)
$+O_2 + 4N_2$	7.55	11.98	Cyl., V_{4000}	(11, 15)
$+O_2 + 4N_2$	7.34		Cyl., V_{300}	(11, 15)
$+O_2 + 6N_2$	6.64	24.45	Cyl., V_{4000}	(11, 15)
$+O_2 + 6N_2$	6.12		Cyl., V_{300}	(11, 15)
$+O_2 + 8N_2$		36.35	Cyl., V_{300}	(11, 15)
$+O_2$	8.48		Cyl., V_{4000}	(13). *Cf.* (5, 7)
$+O_2 + \frac{1}{2}O_2$	8.37			
$+O_2 + 3O_2$	7.94			
$+O_2 + 6O_2$	7.0			
$+O_2 + 3H_2$	8.02			
$+O_2 + 4N_2$	6.8	9.5	Con., V_{115} in.³, ignit. at vertex	(68)
$+O_2 + 4N_2$	7.54†	8.4	1.15 Pinit. atm. Cyl., V* Tinit. = 54°C	(75)
$+O_2 + 4N_2$	7.96†	6.9	3.0	
$+O_2 + 4N_2$	8.14†	6.1	5.5	
$+O_2 + 4N_2$	7.98	5.5	Tinit. = 15°C Pinit. = 2 atm. Cyl., V*	(75)
$+O_2 + 2N_2$	8.28	2.2		
$+O_2 + 4H_2$	8.1	1.0		
$+O_2 + 2H_2$	9.13	1.0		
$+O_2$	9.3	0.7		
$+O_2 + 4O_2$	7.7	2.9		
$+O_2 + 2O_2$	8.8	1.5		
$+O_2 + 4CO_2$	5.65	25.5		
$+O_2 + 2CO_2$	7.10	4.6		
$+O_2 + 4N_2$	7.7	5 or less, decreasing at higher Pinit.	3 Pinit. Sphere, V_{240} Tinit. = 17°C	(79)
	7.8		10	
	8.0		25	
	8.1		50	
	8.33		75	
	8.50		100	
	8.64		125	
	8.67		150	
	8.80		175	
$+O_2 + 4N_2$	7.7		Same as above except Pmax./Pinit. has been corrected: Pmax. for cooling losses during combustion period; Pinit. for deviation from Boyle's law.	(79)
	7.84			
	8.05			
	8.16			
	8.43			
	8.63			
	8.79			
	8.82			
	8.98			
H_2				
$+N_2O$		2.06	Cyl., V_{300}	(11, 15)
$+Cl_2 + 3.6H_2$	6.88		Cyl., V_{4000}	(13) *cf.* (5, 7)
% H_2 in air	Values calculated from published temp. estimates			
25.4	7.23		Cyl., V 30 cm diam., 30 cm deep	(61)
15.3	5.03			
10.0	4.03			

CO

Mixture	Pmax./Pinit.	Millisec	Exper. condn.	Lit.
2CO				
$+O_2$	10.1		Cyl., V_{18}	(2)
$+O_2 + 4N_2$	7.3		Cyl., V_{18}	(2)

* Diam. 7 in., depth 8 in.

† Calculated to Tinit. = 15°.

CO.—(*Continued*)

Mixture	Pmax./Pinit.	Millisec	Exper. condn.	Lit.
$+O_2$	9.56		Cyl., V_{4000}	(9)
$+O_2 + N_2$	8.82			
$+O_2 + 2N_2$	8.28			
$+O_2 + 5N_2$	6.66			
$+O_2$	9.42		Cyl., V_{4000}	(13) *cf.* (5, 7)
$+O_2 + 1\frac{1}{2}CO_2$	7.50			
$+O_2 + 3CO_2$	6.50			
$+O_2 + 4\frac{1}{2}CO_2$	4.8			
$+O_2 + 1\frac{1}{2}CO$	8.33			
$+O_2 + 6CO$	7.01			
$+O_2 + 1\frac{1}{2}O_2$	8.52			
$+O_2 + 6O_2$	6.40			
$+O_2 + 3\frac{3}{4}N_2$	7.24			
$+O_2 + 7\frac{1}{2}N_2$	5.98			
$+O_2$	9.29	12.86	Cyl., V_{300}	(11, 15)
$+O_2$	9.93	15.51	Cyl., V_{4000}	(11, 15)
$+O_2 + N_2$		17.78	Cyl., V_{300}	(11, 15)
$+O_2 + 2N_2$		26.49	Cyl., V_{300}	(11, 15)
$+O_2 + CO_2$		27.18	Cyl., V_{300}	(11, 15)
$+O_2 + 2CO_2$		35.80	Cyl., V_{300}	(11, 15)
$+O_2$	10.0	12.5	4.3 Sphere, V_{240} Pinit. Tinit. = 17°C.	(73)
$+O_2$	11.5	5.0	21.4	
$+O_2$	12.1	5.0	50.0	
$+O_2 + 2A$	10.6	10	Sphere, V_{240} Pinit. = 35.7 Tinit. = 17°C	(69)
$+O_2 + 2O_2$	10.3	5		
$+O_2 + 2CO$	10.01	5		
$+O_2 + 2N_2$	9.55	40		
$+O_2 + 4A$	10.20	25	Sphere, V_{240} Pinit. = 50 Tinit. = 17°C	(69)
$+O_2 + 4O_2$	9.20	5		
$+O_2 + 4CO$	9.00	10		
$+O_2 + 4N_2$	8.30	190		
$+O_2 + 6A$	9.7	140	Sphere, V_{240} Pinit. = 64.3 Tinit. = 17°C	(69)
$+O_2 + 6CO$	7.9	130		
$+O_2 + 6N_2$	6.4	1100		
$+O_2 + 4A$	8.5	35	3.0 Sphere, V_{240} Pinit. Tinit. = 17°C	(79)
	8.9	50	10.0	
	10.2	25	50.0	
	10.53	15	75.0	
	10.63	10	100.0	
	11.2	10	125.0	
	11.66	10	150.0	
$+O_2 + 4A$	8.65		Same as above except Pmax./Pinit. has been corrected: Pmax. for cooling loss during combustion period; Pinit. for deviation from Boyle's law.	(79)
	9.1			
	10.1			
	10.3			
	10.33			
	10.84			
	11.4			
$+O_2 + 4O_2$	7.6	60	3.0 Sphere, V_{240} Pinit. Tinit. = 17°C	(73)
	7.7	45	10.0	
	8.6	10	25.0	
	9.2	5	50.0	
	10.1	5	75.0	
$+O_2 + 4CO$	9.6	10	75.0 Sphere, V_{240} Pinit. Tinit. = 17°C	(79)
	9.8	5	100.0	
	10.0	5	125.0	
	10.13	5	150.0	
$+O_2 + 4CO$	9.48		Same as above except Pmax./Pinit. corrected for combustion period loss and deviation from Boyle's law.	(79)
	9.68			
	9.95			
	10.16			
$+O_2 + 4N_2$	7.13	70	3.0 Sphere, V_{240} Pinit. Tinit. = 17°C	(79)
	7.5	100	10.0	
	7.72	150	25.0	
	8.20	190	50.0	
	8.47	320	75.0	
	8.80	400	100.0	
	8.88	470	125.0	
	9.03	530	150.0	
	9.23	560	175.0	
$+O_2 + 4N_2$	7.80		Same as above except Pmax./Pinit. corrected for combustion loss and deviation from Boyle's law.	(79)
	8.00			
	8.30			
	8.65			
	9.14			
	9.37			
	9.45			
	9.76			
	10.17			

Continued on p. 190.

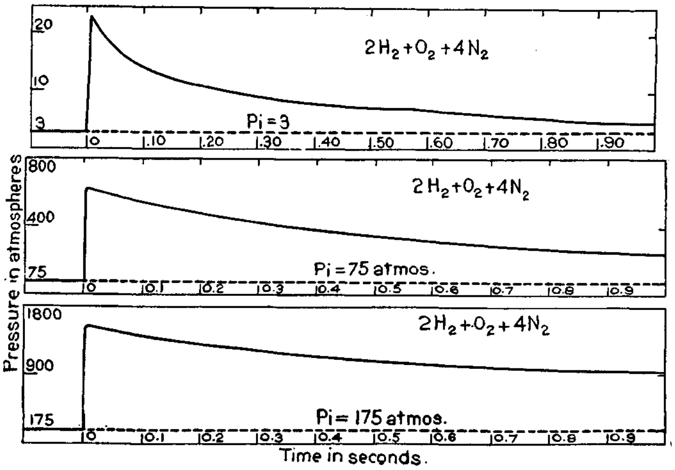

FIG. 11.—Time-pressure curves of $2H_2 + O_2 + 4N_2$ explosions at initial pressures of 3, 75 and 175 atm. (73, 79). Spherical vessel, 2400 cc capacity.

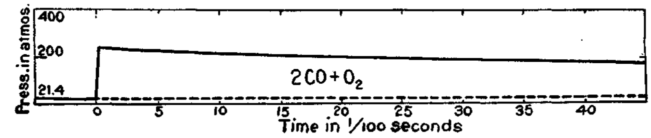

FIG. 12.—Time-pressure curve of $2CO + O_2$ explosion at an initial pressure of 21.4 atm. (69). Spherical vessel, 240 cc capacity.

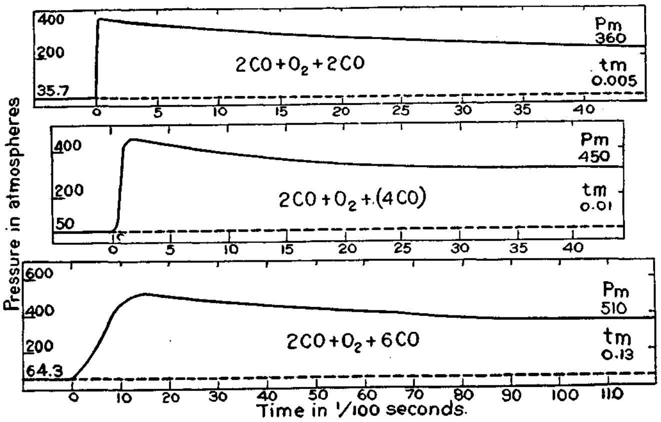

FIG. 13.—Time-pressure curves of $2CO + O_2 + (2CO, 4CO, 6CO)$ explosions at initial pressures of 35.7, 50 and 64.3 atm. respt. (69).

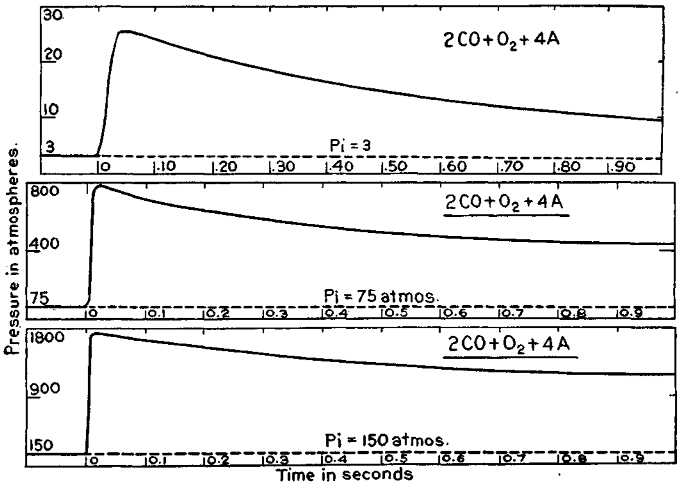

FIG. 15.—Time pressure curves of $2CO + O_2 + 4A$ explosions at initial pressures of 3.75 (73) and 175 atm. (79). Spherical vessel, 240 cc capacity.

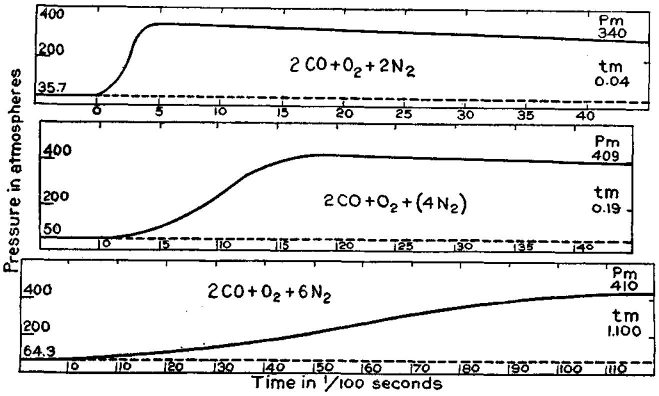

FIG. 14.—Time-pressure curves of $2CO + O_2 + (2N_2, 4N_2, 6N_2)$ explosions at initial pressures of 35.7, 50, and 64.3 atm. respt. (69).

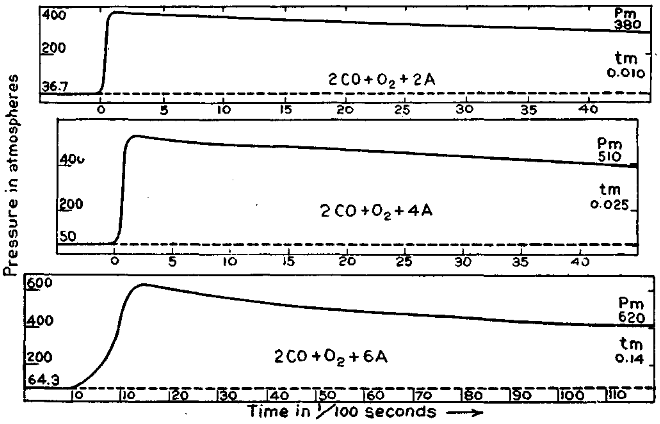

FIG. 16.—Time-pressure curves of $2CO + O_2 + (2A, 4A, 6A)$ explosions at initial pressures of 35.7, 50 and 64.3 atm. (69).

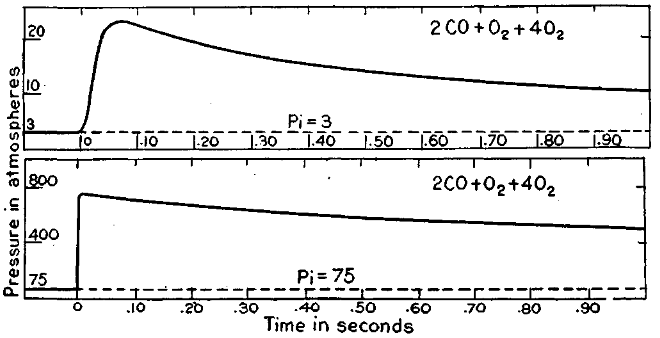

FIG. 17.—Time-temperature curves of $2CO + O_2 + 4O_2$ explosions at initial pressures of 3 and 75 atm. (73). Spherical vessel, 240 cc capacity.

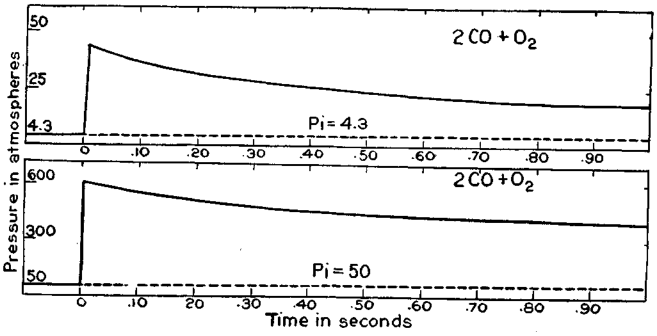

FIG. 18.—Time-pressure curves of $2CO + O_2$ explosions at initial pressures of 4 and 50 atm. (73). Spherical vessel, 240 cc capacity.

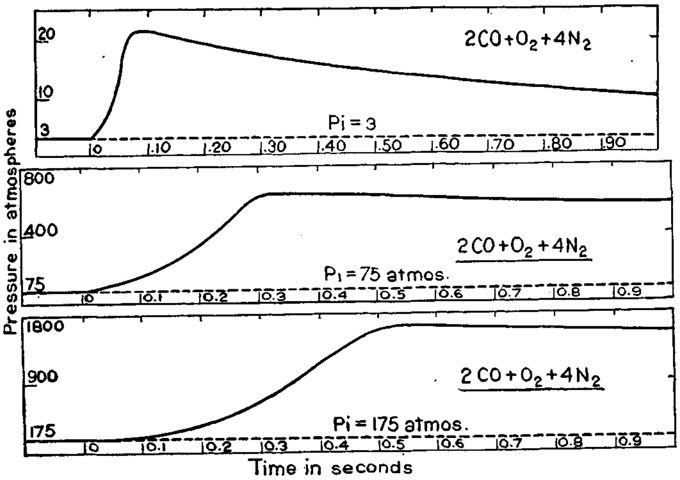

FIG. 19.—Time-pressure curves of $2CO + O_2 + 4N_2$ explosions at initial pressures of 3 (79), 75 and 175 atm. (73). Spherical vessel, 240 cc capacity.

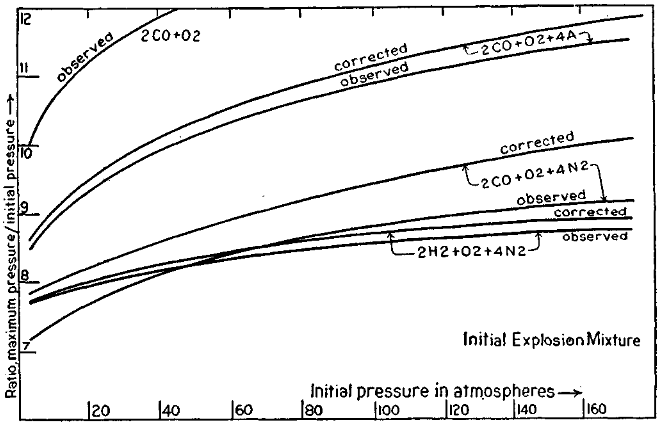

FIG. 20.—Influence of initial pressure on the ratio maximum pressure/initial pressure (79). Spherical bomb, capacity 240 cc. The corrected curve gives maximum pressure (corrected for cooling loss during combustion period)/initial pressure (corrected for deviation from Boyle's law).

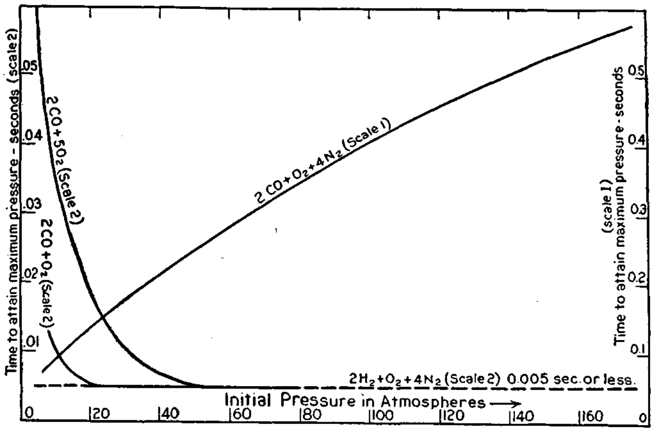

FIG. 21.—Influence of initial pressure on the time taken for the attainment of maximum pressure (79). Spherical bomb. capacity 240 cc.

CO.—(*Continued*)

Mixture	*P*max. / *P*init.	Millisec	Exper. condn.	Lit.
CO				
$+N_2O$	10.78		Cyl., V_{4000}	(9)
$+N_2O$		15.40	V_{300}	(11, 15)
% CO (97.5 %) in air				
20	5.77	800	*P*init. = 2 Sphere *V*, 16 in. diam.; silver plated interior; central ignition; gas saturated with water vapor at room temperature	(76)
25	7.12	385		
30	7.86	231		
35	8.16	211		
40	8.27	175		
45	8.25	170		
50	7.65	189		
55	7.10	251		
60	6.05	390		
65	4.87	920		
25	6.39	280	1	(76)
	7.12	385	2	
	7.10	482	3	
	7.22	550	4 *P*init.	
	7.39	668	5	
	7.24	990	6	
	7.47	1010	7	
30	7.86	231	2	(76)
	8.25	335	4 *P*init.	
	8.85	560	6	

Influence of the amount of water vapor present. 29.3 % CO in air

Vol. H_2O vapor + 100 of mixture				
0	7.72*	290.2	Cyl. *V*, 7 in. diam., 8 in. deep *T*init. = 50°C *P*init. = 5	(83)
2.56	7.93*	90.1		
1.68	7.94*	97.0		
1.67	7.94*	92.0		
1.24	7.96*	101.5		
1.21	7.96*	101.0		
0.60	7.94*	125.9		
0.30	7.89*	166.3		

* Calcd. to *T*init. = 15°.

Mixtures of H_2 and CO

2CO				
$+H_2 + 1\frac{1}{2}O_2$	9.28		Cyl., V_{4000}	(9, 15)
$+H_2 + 4O_2$	8.3			
$+3H_2 + 1\frac{1}{2}O_2$	8.92			
$+4H_2 + 3O_2$	9.08			
$2H_2 + O_2$		1.04	Cyl., V_{300}	(11)
$2CO + O_2$		12.86	Cyl., V_{300}	(11)
$2H_2$				
$+CO + 1\frac{1}{2}O_2$		2.57	Cyl., V_{300}	(11)
$+CO + O_2$		1.39	Cyl., V_{300}	(11)
H_2				
$+CO + O_2$		3.88	Cyl., V_{300}	(11)
$+2CO + 1\frac{1}{2}O_2$		4.14	Cyl., V_{300}	(11)
$2(xH_2 + yCO) + O_2 + 4N_2$				
x y				
100 0	8.10*	7.5	Cyl. *V*, 7 in. diam., 8 in. deep *P*init. = 5 *T*init. = 50°C	(83)
49.7 50.3	8.10*	15.5		
24.8 75.2	8.10*	29.3		
11.9 88.1	8.10*	46.5		
8.0 92.0	8.10*	56.6		
4.1 95.9	8.05*	75.9		
0.2 99.8	7.79*	245.9		
$2(xH_2 + yCO) + O_2 + 4N_2$				
100 0	7.82	5	Sphere, V_{240} *T*init. = 17°C *P*init. = 50	(67)
50 50	7.98	15		
25 75	8.2	15		
12.5 87.5	8.2	25		
8 92	8.5	25–30		
4 96	8.5	30		
0 100	8.4	180		

* Calcd. to *T*init. = 15°.

C_2H_2 Acetylene

Mixture	$\frac{P\text{max.}}{P\text{init.}}$	Milli-sec	Exper. condn.	Lit.
$C_2H_2 + 2\frac{1}{2}O_2$	14.45		Cyl., V_{4000}	(9, 15)
$C_2H_2 + 2\frac{1}{2}O_2$		1.94	Cyl., V_{300}	(11)

C_2H_4 Ethylene

$C_2H_4 + 3O_2$	15.25		Cyl., V_{4000}	(9, 15)
$C_2H_4 + 3O_2$	14.18	2.86	Cyl., V_{300}	(11, 14)
$C_2H_4 + 3O_2$	15.73	2.23	Cyl., V_{4000}	(11, 14)

C_2H_6 Ethane

Mixture	$\frac{P\text{max.}}{P\text{init.}}$	Milli-sec	Exper. condn.	Lit.
$C_2H_6 + 3\frac{1}{2}O_2$	15.30		Cyl., V_{4000}	(9)
$C_2H_6 + 3\frac{1}{2}O_2$		0.83	Cyl., V_{300}	(11)
% C_2H_6 in air				
3.05	3.8		Deduced from a published curve	(56)
3.3	4.9			
3.6	5.75			
4.05	6.85			
4.8	7.8			
5.6	8.3			
6.7	8.75			

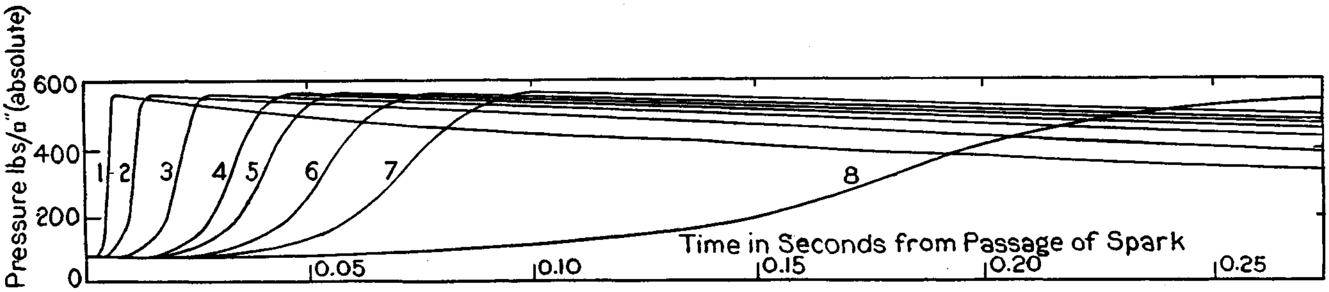

FIG. 22.—Time-pressure curves obtained from the explosion of $2(xH_2 + yCO) + O_2 + N_2$ mixtures. Initial pressure, 5 atm. Initial temperature, 50°C. Cylindrical vessels 7″ in diam., 8″ deep (83)

Curve	1	2	3	4	5	6	7	8
H_2	100	50	25	12	8	4	2.2	0.2
CO	0	50	75	88	92	96	97.8	99.8

CH_4 Methane

CH_4				
$+1.84O_2$	14.35		Cyl., V_{4000}	(13)
$+2.8O_2 + 10.5N_2$	7.9			
$+1.92O_2 + 7.24N_2$	8.95			
$+1.44O_2 + 5.41N_2$	7.98			
$+2O_2$	15.44		Cyl., V_{4000}	(9, 15)
$+2O_2$	13.94	1.24	Cyl., V_{300}	(11, 14)
$+2O_2$	14.81		Cyl., V_{4000}	(11, 14)
$+O_2 + 4N_2$	5.6	80	Sphere, V_{240}; Pinit. = 50 Tinit. = 17°C	(53)
% CH_4 in air				
6.30	4.20		Sphere, V_{4000}; highly polished interior surface	(54)
6.80	6.10			
7.45	6.64			
7.95	7.09			
8.45	7.40			
9.20	7.73			
9.40	7.80			
9.65	7.90			
10.10	7.97			
10.25	7.97			
10.75	7.87			
11.40	7.73			
12.10	7.36			
12.90	6.78			
13.40	4.80			
13.90	3.50			
6.05	3.86		Sphere, $V_{16\,000}$; highly polished interior surface	(54)
6.85	5.35			
7.80	6.85			
8.80	7.66			
9.80	7.94			
10.80	7.80			
11.90	7.40			
12.80	6.78			
12.1	8.15*	275.9	Tinit. = 100°C Cyl., V, 7 in. diam., 8 in. deep Pinit. = 6.5	(83)
11.0	8.56*	140.6		
10.5	8.69*	119.3		
9.9	8.70*	105.8		
9.7	8.77*	106.5		
8.5	8.19*	128.8		
7.3	7.20*	225.9		

* Calcd. to Tinit. = 15°. *See also* p. 177.

C_2H_6O Methyl Ether

$C_2H_6O + 3O_2$	18.82		Cyl., V_{4000}	(9)

$C_4H_{10}O$ Ethyl Ether

$C_4H_{10}O + 6O_2$	15.42		Cyl., V_{4000}	(9)

C_2N_2 Cyanogen

C_2N_2				
$+ O_2 + 4N_2$	10.95		Cyl., V_{18}	(2)
$+2O_2$	19.80		Cyl., V_{4000}	(9, 15) *Cf.* (5, 13)
$+N_2 + 2O_2$	16.72			
$+2N_2 + 2O_2$	13.93			
$+4N_2 + 2O_2$	11.66			
$+O_2$	23.72			
$+\frac{3}{4}N_2 + O_2$	19.52			
$+2N_2 + O_2$	14.42			
$+4N_2 + O_2$	11.14			
$+4NO$	16.00			
$+N_2O$	21.40			
$+2NO$	22.08			
$+2N_2O$	24.6			
$+O_2$		1.06	Cyl., V_{300}	(11)
$+2O_2$		1.55	Cyl., V_{300}	(11)
$+2O_2$		4.50	Sphere, V_{1500}	(11)
$+2O_2 + 2N_2$		15.4	Cyl., V_{300}	(11)
$+2O_2 + N_2$		6.09	Cyl., V_{300}	(11)
$+O_2 + \frac{3}{4}N_2$	18.65	3.20	Cyl., V_{300}	(11)
$+O_2 + \frac{3}{4}N_2$	21.09	2.74	Sphere, V_{1500}	(11)
$+O_2 + 3N_2$	13.88	10.35	Cyl., V_{300}	(11)
$+O_2 + 3N_2$	15.56	15.12	Sphere, V_{1500}	(11)
$+O_2 + 3N_2$		23.63	Cyl., V_{300}	(11)
$+O_2 + 4N_2$	10.6	29.78	Cyl., V_{300}	(11)
$+4N_2O$		4.53	Cyl., V_{300}	(11)
$+4N_2O$	12.02		Sphere, V_{1500}	(11)

C_6H_6 Benzene (82)

Mixture	$\frac{P_{\text{max.}}}{P_{\text{init.}}}$	Milli-sec	Exper. condn.
16.84	8.28	105.1	$T_{\text{init.}}$ = 100°C $P_{\text{init.}}$ = 95 lbs./in.^{2} Cyl., V, 7 in. diam., 8 in. deep
14.76	9.00	73.5	
13.24	9.50	59.7	
13.16	9.50	59.8	
12.06	9.74	55.1	
10.7	9.78	49.0	
9.15	Loud metallic knock		

C_6H_{14} Hexane (82)

Mixture	$\frac{P_{max.}}{P_{init.}}$	Milli-sec	Exper. condn.
16.91	8.86	91.2	$T_{init.}$ = 100°C
14.80	9.48	69.5	$P_{init.}$ = 95 lbs./in.^{2}
13.97	9.56	64.0	Cyl., *V*, 7 in. diam.,
13.20	9.50	58.6	8 in. deep
10.72	Violent explosion		

Petrol (82)

Ratio air/fuel by wt.	$\frac{P_{max.}}{P_{init.}}$*	Milli-sec	Exper. condn. $P_{init.}$ lbs./in.^{2}	
19.2	7.74	175.2	95.2	
16.9	8.58	109.6	95.5	$T_{init.}$ = 100°C
	8.52	110.8	142.5	Cyl., *V*,
14.8	9.33	78.4	95.5	7 in. diam.,
13.0	9.71	67.1	95.7	8 in. deep
10.7	Loud metallic knock		95.3	

* Calcd. to $T_{init.}$ = 15°C.

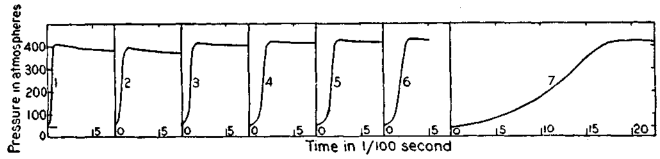

FIG. 23.—Time-pressure curve obtained from the explosion of $2(xH_2 + yCO) + O_2 + 4N_2$ mixtures. Initial pressure, 50 atm., room temperature. Spherical vessel, 240 cc capacity (67, 71).

Curve	1	2	3	4	5	6	7
H_2	100	50	25	12.5	8	4	0
CO	0	50	75	87.5	92	96	100

INFLUENCE OF TEMPERATURE AND PRESSURE

Mixture: 9.9 % CH_4 in air. Cyl. *V*, 7 in. diam., 8 in. deep

$T_{init.}$ °C	$P_{init.}$ lb./in.^{2}	$\frac{P_{max.}}{P_{init.}}$	$\frac{P_{max.}}{P_{init.}}$	Milli-sec
24.7	30.3	8.32	8.57*	99.7
24.7	53.0	8.41	8.65*	11.63
100	38.1	6.79	8.51*	79.8
100	66.7	6.79	8.52*	104.7
100	95.0	6.95	8.71*	109.0
200	48.2	5.60	8.57*	68.2
200	84.4	5.65	8.64*	75.0
200	120.6	5.66	8.69*	83.8
300	58.2	4.68	8.36*	49.6
300	102.3	4.75	8.48*	59.7
300	145.9	4.80	8.57*	67.1
400	68.5	4.12	8.30*	41.0
400	120.1	4.12	8.30*	47.3
400	171.5	4.19	8.56*	54.8

* Calcd. to $T_{init.}$ = 15°C.

EFFECT OF INITIAL TEMPERATURE AND PRESSURE

Petrol, Hexane and Benzene (82)

$T_{init.}$ °C	$P_{init.}$ lbs./in.^{2}	Pressure rise (lbs./in.^{2}) ratio air/fuel by wt. Petrol	Hexane	Benzene
		13	14	12
100	100	660	668	680
	50	321	324	327
200	100	519	520	523
	50	250	250	248

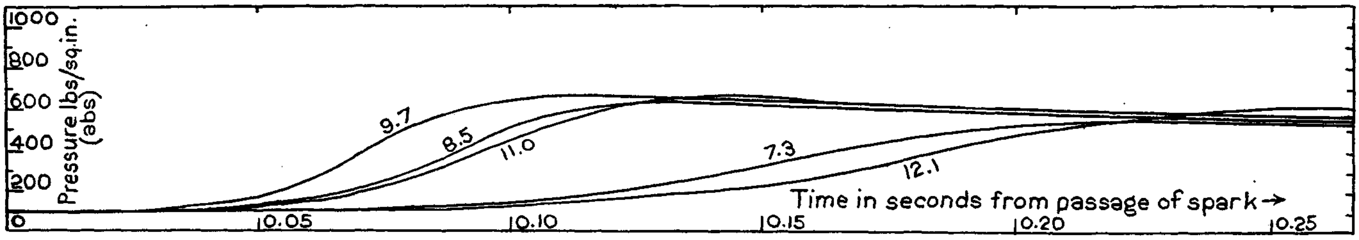

FIG. 24.—Time-pressure curves obtained from the explosion of methane-air mixtures. Initial pressure, 95.1 lb./in.^{2} Initial temperature, 100°C (83).

EFFECT OF INITIAL TEMPERATURE AND PRESSURE

C_6H_6 Benzene (82)

$T_{init.}$ °C	$P_{init.}$ lbs./in.^{2}	Maximum pressure rise (lbs./in.^{2}) ratio air/fuel by wt. 12.0	10.7	9.15
100	95.0	645	644	
	67.0	447	449	
	38.0	242	248	241
200	120.5	636		646
	84.5	438		442
	48.2	238		240
300	146.0	614		633
	102.0	420		434
	58.0	226		237

MEASUREMENTS OF EXPLOSION TEMPERATURES

Temperature Distribution at Moment of Maximum Pressure

Ten per cent coal gas (680 BTU/ft.^{3}) (31). Vessel (Fig. 25): Capacity 6.2 ft.^{3}

Mean temperature (inferred from pressure)	1600°C
(*a*) Temperature at center near spark (*B*)	1900°C
(*b*) Temperature 10 cm within wall (*C*)	1700°C
(*c*) Temperature 1 cm from wall (*D*)	1100°–1300°C
(*d*) Temperature 1 cm from wall (at the side)	850°C

Temperature Distribution 0.5 sec after Maximum Pressure

Mean temperature throughout the gas	1100°C
Mean temperature of gas excluding a layer 1 cm thick in contact with the walls	1160°C

DIRECT MEASUREMENT OF THE TEMPERATURE-CYCLE IN A GAS ENGINE (47); *cf.* (18, 20, 38)

Coal gas (460 BTU/ft.^{3}); cylinder 7 in. diameter; stroke 15 in.; working volume 577 in.^{3}; thermocouple: 10% alloys of Pt-Rh and Pt-Ir (0.0005–0.0008 in. thick).

No............	1	2	3	4	5
Ratio Air/ Gas..	7.35/1	7.08/1	7.13/1	6.71/1	5.66/1
Jacket outlet, °C	35.6	37.2	81.4	40.6	52.8
Angle of crank	Temp., °C	Temp., °C	Temp., °C	Temp., °C	Temp., °C
360	569	568	582	705	636
300	496	503	515	624	540
240	349	348	371	517	431
180	256	269	317	422	371
120	217	223	262	365	330
60	228	241	273	326	337
30	267	275	330	339	442
720					2249
710				1947	
709					
708				1889	
705		1848	1871		1918
697	1836				
690	1546	1551	1532	1579	1721
675	1423	1418	1397	1437	1586
660	1154	1147	1269	1247	1417
645	1159	1124	1139	1193	1275
630	1041	1052	1018	1098	1192
615	1022	1007	1017	1058	1124
600	1017	975	975	982	1068
540	856	843	816	895	889
480	726	708	704	794	764
420	648	646	637	751	705

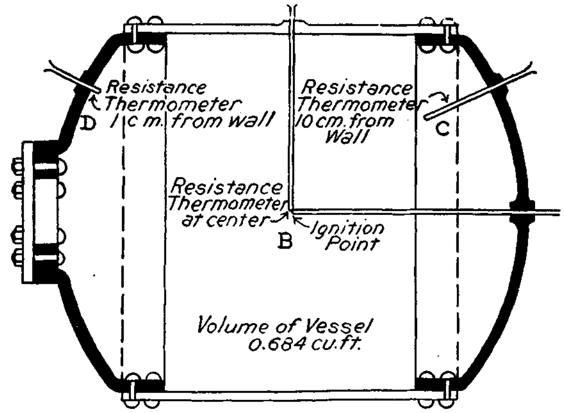

FIG. 25.—Explosion vessel.

RADIATION LOSSES

Pressure-time curves obtained from the explosion of a 15% coal gas (675 BTU/ft.^{3})—air mixture in an explosion vessel: (*a*) with a highly polished, (*b*) with a blackened interior surface (44); volume of vessel 0.788 ft.^{3}; area of interior surface 4380 cm^2.

Maximum pressure for initial pressure 1 atmosphere	Pressure lb./in.^{2} for seconds after ignition			
	0.15	0.25	0.35	0.45
(*a*) 114.0 lb./in.^{2}.........	98.7	84.2	73.5	64.9
(*b*) 110.8 lb./in.^{2}.........	89.2	73.1	61.3	53.5

Same for 9.8% coal gas (575 BTU/ft.^{3}) (45). Vessel as above

Time from ignition	Mean temperature °K, inferred from pressure	Mean radiation received per cm^2 of wall	Total loss of heat by radiation, % heat of combustion
0.15	1600	0.12	5.0
0.18	1700*	0.17	7.0
0.20	1680	0.21	8.7
0.25	1600	0.28	11.6
0.50	1280	0.46	19.0
0.75	1085	0.54	22.3
1.00	950	0.57	23.6

* Maximum temperature.

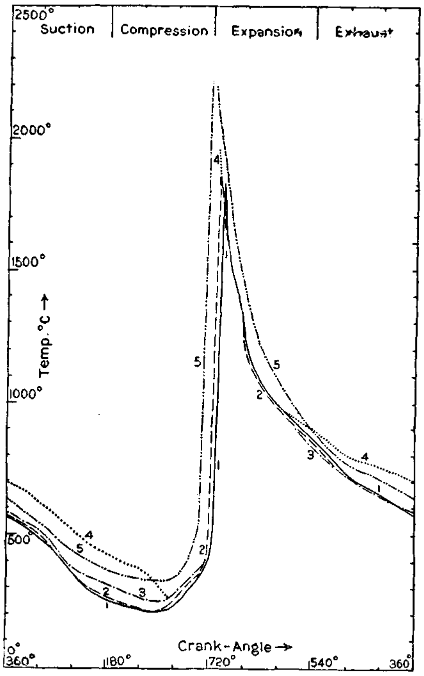

FIG. 26.—Direct measurement of temperature-cycle in a gas engine (47).

INFLUENCE OF DENSITY OF GAS ON RADIATION LOSS

Fifteen per cent coal gas (575 BTU/ft.^{3})—air mixture (45)

Time from ignition, sec	Mean temperature °K, of gas (inferred from pressure)		Mean radiation received per cm^2 of wall		Total heat loss by radiation, % heat of combustion	
	$P_i = \frac{1}{2}$ at.	$P_i = 1\frac{1}{2}$ at.	$P_i = \frac{1}{2}$ at.	$P_i = 1\frac{1}{2}$ at.	$P_i = \frac{1}{2}$ at.	$P_i = 1\frac{1}{2}$ at.
0.05	2270	2400	0.061	0.14	3.3	2.5
0.10	2020	2210	0.2	0.425	11.0	7.7
0.15	1790	2040	0.29	0.615	15.9	11.3
0.20	1600	1890	0.35	0.75	19.2	13.6
0.25	1440	1765	0.39	0.843	21.4	15.3
0.50	1030	1350	0.47	1.065	25.7	19.3
0.75	810	1140	0.49	1.143	26.8	20.7
1.00	700	1010	0.492	1.158	26.9	21.0

HYDROGEN—AIR MIXTURES (61)

Strength of mixture	Maximum temperature °K, developed (inferred from pressure)	Time of explosion (sec)	Total radiation received per cm² of wall	% heat of combustion lost by radiation up to max. pressure	Total heat loss by radiation, % heat of combustion
25.4	2400	0.017	0.60	0.5	16.1
15.3	1580	0.065	0.245	1.3	11.0
10.0	1230	0.240	0.12	1.4	8.2
Compared with coal gas					
15.0	2410	0.05	0.98	3.3	26.1
13.0	2170	0.07	0.81	3.7	25.0
9.8	1700	0.18	0.57	7.0	23.6

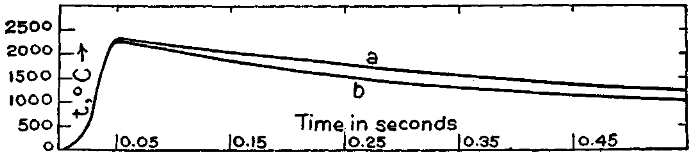

FIG. 27.—Pressure-time curves obtained from the explosion of a 15 % coal gas air mixture (44).

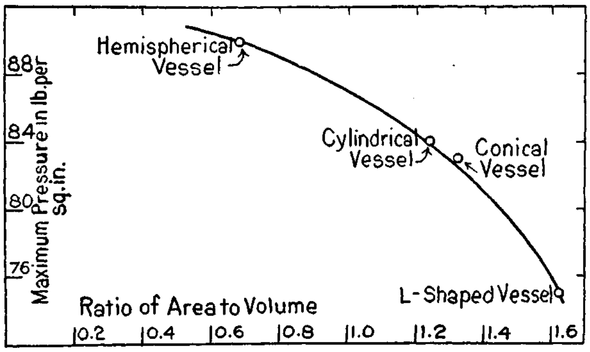

FIG. 28.—Influence of shape of explosion vessels having the same initial capacity on the maximum pressure developed (68).

HEAT LOSS

Mixture of 15% coal gas (570 BTU/ft.³) in air (64)

Sec*	Mean† gas temperature, °K	Heat loss/cm², % heat of combustion of the coal gas		
		Conduction	Radiation	Total
0.05	2440‡	5.1	3.8	8.9
0.1	2220	14.4	10.4	24.8
0.15	2020	20.3	15.0	35.3
0.2	1840	24.5	17.9	42.4
0.25	1710	27.7	20.3	48.0
0.3	1600	30.0	22.2	52.2
0.4	1430	34.4	24.3	58.7
0.5	1300	37.6	25.6	63.2

* Time after ignition in seconds.
† Inferred from pressure.
‡ Maximum temperature.

Various Formulae for Approximate Estimation of Cooling Losses in Explosions of Coal Gas—Air Mixtures

General formula for radiation loss in coal gas—air explosions (59)

$$R_T = 0.0001\ (T_{\text{max.}} - 700\sqrt{D \times L})$$

where

R_T = Total radiation registered
$T_{\text{max.}}$ = Maximum temperature (mean, °K)
D = Density of the gaseous mixture in atmospheres
L = Length of the explosion cylinder in cm

Rate of loss of heat by radiation, cm² of wall surface/sec (R_L) (64)

$$R_L = 1.75 \times 10^{-14}\theta^4$$

where

θ = mean absolute temperature.

For a cylindrical vessel (h cm diam. × h cm deep):

$$R_L = 0.32 \times 10^{-14}\theta^4\sqrt{h}.$$

Rate of loss of heat by conduction, cm² of wall surface/sec (R_L) (64):

$$R_c = 4 \times 10^{-13}\ (t - t_w)^4$$

for temperatures above 2000°K;

$$R_c = 7 \times 10^{-10}\ (t - t_w)^3$$

for temperatures below 2000°K where $(t - t_w)$ is the temperature difference, °C, between the hot gases and the walls of the explosion vessel.

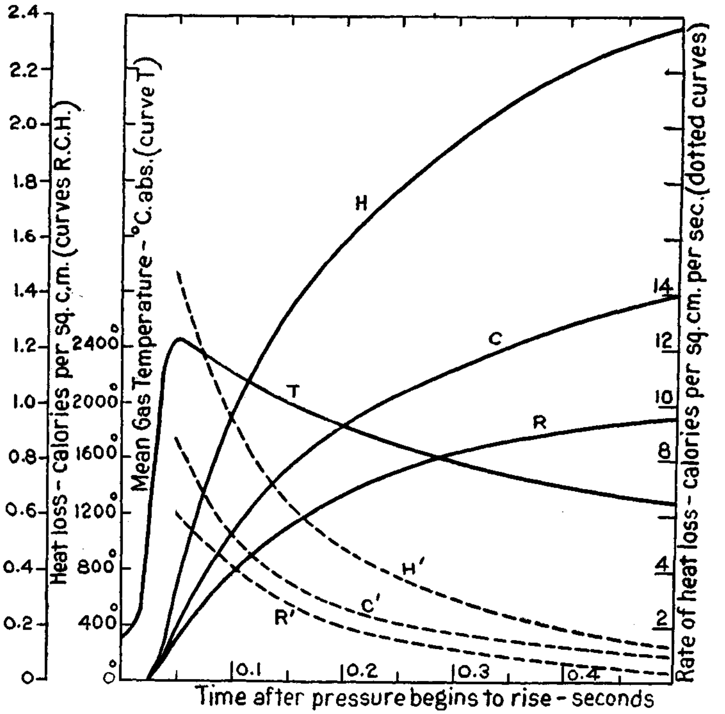

FIG. 29.—Heat loss from 15 % mixture of coal gas and air (64, 74). R = mean loss of heat by radiator per cm² of wall surface. C = mean loss of heat by conductor per cm² of wall surface. H = total heat loss. R′, C′ and H′ give the *rate* of heat loss by radiation, conduction and total loss, respectively. T = mean gas temperature (deduced from the pressure).

Rate of total heat loss, cm² of wall surface/sec (H_T) in a cylinder (h cm diam. × h cm deep) (64):

$$H_T = 4 \times 10^{-13}\ (T - T_w)^4 + 0.32 \times 10^{-14}\ T^4\sqrt{h}$$

for temperatures above 2000°K;

$$H_T = 7 \times 10^{-10}\ (T - T_u)^3 + 0.32 \times 10^{-14}\ T^1\sqrt{h}$$

for temperatures below 2000°K.

Total heat loss to walls of cylindrical explosion vessel (30 cm × 30 cm up to moment of maximum pressure (64) (coal gas—air explosions) at atmospheric density:

$$H_{\text{max.}} = 2.15 \times 10^{-8}\theta^{2\cdot5}_{\text{max.}} \times t_e$$

or expressed as a proportion of the heat of combustion

$$H_{c\ \text{max.}} = 1.43 \times 10^{-5}\theta^{1\cdot5}_{\text{max.}} \times t_e$$

where t_e is the explosion time.

Total heat loss per unit area in similar engines working under similar conditions may be given by the equation (74):

$$H = C + R\sqrt{d}$$

where

C = conduction loss per unit area
$R\sqrt{d}$ = radiation loss per unit area in an engine of diameter d.

INFLUENCE OF TURBULENCE

Explosions of coal gas—air mixtures in conical vessel, capacity 115 in.^{3} (ignition at vertex) (68); *cf.* (**7, 31, 39, 56, 75**)

Ratio air/coal gas	$\frac{P_{max.}}{P_{init.}}$		Milli-sec	
	With turbulence	Quiescent	With turbulence	Quiescent
2.08	6.92		70.0	
2.61	7.23	6.44	28.0	95.0
3.13	7.48	6.68	39.0	71.0
3.65	7.24		38.0	
4.17	6.70	6.30	51.6	83.0
5.21	6.13	5.52	49.6	139.0
6.25	5.53	4.70	81.0	329.0
7.29	4.84	3.76	136.0	942.0
8.33	4.15		344.0	

Ethane, C_2H_6, and air mixtures in spherical vessel, capacity 4000 cm^3 (sparked at center) (56)

% C_2H_6 in air	Milli-sec	
	Quiescent	Turbulence
3.30		176
3.45		96
3.60	332	
3.80	152	
3.85	146	45
4.05	124	36
4.30		33
4.35	94	
4.60		26
4.65	73	
4.70		29
4.80	70	
5.00	63	24
5.25		21
5.35	54	20
5.60	52	
5.95		19
6.00	46.5	
6.40		19
6.45	46	
6.75	46.5	19
7.05	50	20
7.15	52	

Distribution of Energy at the Moment of Maximum Pressure

Coal gas—air explosions (64)

Internal Thermal Energy.—From 72% of the heat of combustion in a 9.7% coal gas—air mixture to 80% in a 15% mixture.

Available Chemical Energy.—About 10% in each case.

Heat Loss to Walls of Vessel.—From about 10% in a 15% mixture to about 18% in a 9.7% mixture.

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ANIMAL AND VEGETABLE OILS, FATS AND WAXES

C. Ainsworth Mitchell

INTRODUCTION

The General Property Table.—In Table 2, the oils and fats are first classified according to the Alder Wright system. Under each class, the individuals are arranged in alphabetical order of their generic names; and each individual is given a *General Index No.* by means of which it is identified in all subsequent tables. Where only one series of values is given, the data are usually those recorded for a single specimen of the particular oil. Table 2 serves therefore as a general finding table based upon the scientific names. If the scientific name is not known to the reader, he should first consult Table 1 and obtain the General Index No.

Supplementary Tables.—Properties not covered by Table 2 are set forth in Tables 3 to 17 inclusive.

Property-Substance Tables.—In these tables (Tables 18 to 27, inclusive) the individuals are arranged by index number in ascending order of the value of the property, the intervals on the scale of property values being indicated in bold-face type. These property-substance tables may be used (1) to select an individual having any desired value of a given property, or (2) to identify (in some cases at least) an individual by means of its properties. For the latter purpose, the properties cited in the following example are most useful.

Example; An oil is found by test to have the following properties: Congealing point, 0°; saponification, 190; iodine, 82; acetyl,

INTRODUCTION

Table des propriétés générales.—Dans la Table 2, les huiles et les graisses sont d'abord classées suivant le système d'Alder Wright. Dans chaque classe, les huiles et graisses sont rangées suivant l'ordre alphabétique de leurs noms génériques et on leur a attribué un "numéro index général" au moyen duquel elles seront identifiées dans toutes les tables suivantes. Où on a donné seulement une serie de valeurs, les données sont généralement ceux d'un seul échantillon de l'huile particulière. La Table 2 est donc une table de recherche générale, basée sur les noms scientifiques. Si le nom scientifique n'est pas connu du lecteur, il devra d'abord consulter la Table 1 afin d'obtenir le "numéro index général."

Tables supplémentaires.—Les propriétés qui ne sont pas mentionnées dans la Table 2 sont contenues dans les Tables 3 à 17 inclusivement.

Tables des propriétés des substances.—Dans ces tables (Tables 18 à 27 inclusivement), les huiles et graisses représentées par leur nombre index sont arrangées suivant l'ordre ascendant de la valeur de la propriété, les intervalles de l'échelle des valeurs de la propriété étant indiqués en caractères gras. Ces tables des propriétés des substances peuvent être utilisées: 1) pour choisir une huile ou graisse possédant une valeur désirée d'une propriété donnée, ou 2) pour identifier (au moins dans quelques cas) une huile ou graisse au moyen de ses propriétés. On se servira alors de

11; unsaponifiables, 0.6; fatty acids, M. P., 28°; "titer," 21°; n_D^{25}, 1.466. From each of Tables 20, 23, 22, 21, 26, 27 and 16*B*, write down a list of the General Index Nos. lying in the neighborhood of the experimental value and arrange each list in ascending order of these numbers. Determine the number of times each Index No. occurs in this set of lists. For the present example, this gives the following result: 8 times, No. 8; 7 times, No. 31; 4 times, Nos. 3, 5, 26, 47, 62, 91; 3 times, Nos. 13, 20, 29, 33, 54, 61, 67, 83, 84, 92.

By turning to Table 2 and examining the properties there recorded for these oils, all but Nos. 8 and 31 are definitely eliminated. The oil under examination must, therefore, be either olive oil or neat's foot oil, or some oil closely resembling these but not included in Table 2. A further comparison of Nos. 8 and 31 results in the elimination of No. 31 on the basis of the acetyl and iodine values, but additional confirmatory tests are necessary.

Definitions.—*v.* p. viii.

EINLEITUNG

Die Haupteigenschafts Tafel.—In der Tafel 2 werden die Öle und Fette zuerst entsprechend dem Alder Wright System klassifiziert. In jeder Klasse sind die einzelnen Fette und Öle in alphabetischer Ordnung mit deren Gattungsnamen angeordnet, wobei jedem eine "General Index No." zu geordnet ist mit der es in den folgenden Tafeln erkannt werden kann. Ist nur eine Serie von Werten angegeben, so beziehen sich diese gewöhnlich auf eine einzelne Probe des bezeichneten Öles. Tafel 2 dient daher allgemein zum Nachschlagen, mit den wissenschaftlichen Namen als Grundlage. Ist dem Leser der wissenschaftliche Name nicht bekannt, so wäre zuerst die Tafel 1 heranzuziehen, wo die General Index No. erhalten wird.

Ergänzende Tafeln.—Eigenschaften die sich nicht in der Tafel 2 vorfinden, sind in den Tafeln 3 bis einschliesslich 17 enthalten.

Eigenschafts Tafeln.—In diesen (Tafel 18 bis einschliesslich 27) sind die einzelnen Öle und Fette nach ihren Index Nummern in aufsteigender Ordnung ihrer Eigenschaftswerte gereiht, wobei die Intervalle an der Skale der Eigenschaftswerte durch hervorgehobene Schrift angezeigt werden. Diese Eigenschafts Tafeln wären zu benützen:1) Um ein besonderes Öl oder Fett heranzuziehen, welches ihrgend einen gewünschten Wert einer gegebenen Eigenschaft hat. 2) Zur Erkennung (wenigstens in einigen Fällen) eines besonderen Öles oder Fettes auf Grund seiner Eigenschaften. In diesem zweiten Falle ist es am nützlichsten die Eigenschaften in der Art des folgenden Beispieles festzulegen.

Beispiel: Von einem Öl wurden durch Untersuchung folgende Eigenschaften gefunden: Erstarrungspunkt 0°; Verseifungszahl 190; Jodzahl 82; Azetylzahl 11; Unverseifbares 0,6; Fettsäure: Sm. P. 28°; Erstarrungs-Punkt 21°; $n_D^{25} = 1{,}466$. Aus jeder der Tafeln, 20, 23, 22, 21, 26, 27; und 16*B* schreibe man eine Liste der General Index Nummern heraus, welche in der Nähe der experimentell bestimmten Grösse liegen, wobei in der Liste die Nummern in aufsteigender Reihenfolge anzuordnen sind. Dann bestimmt man wie oft jede einzelne Index Nummer in der Liste anzutreffen ist. Für das vorliegende Beispiel bekommt man als Ergebnis: 8 mal No. 8, 7 mal No. 31, 4 mal No. 3, 5, 26, 47, 62, 91, 3 mal No. 13, 20, 29, 33, 54, 61, 67, 83, 84, 92.

Verwendet man die Tafel 2 und prüft die für diese Öle hier angegebenen Eigenschaften, so findet man, dass bis auf No. 8 und No. 31, alle anderen ausscheiden. Das gesuchte Öl ist daher entweder Olivenöl oder Klauenöl, oder ihrgend ein Öl, welches den genannten zwei sehr eng verwandt sein muss und nicht in der Tafel 2 enthalten ist. Ein weiterer Vergleich von No. 8 und No. 31 gibt, dass No. 31 auf Grund der Azetyl- und Jodzahl wegfällt. Besondere bestätigende Untersuchungen sind jedoch notwendig.

Definitionen.—*v.* p. viii.

préférence des propriétés citées dans l'exemple suivant, qui sont les plus utiles pour atteindre ce but.

Exemple: On a trouvé expérimentalement qu'une huile possède les propriétés suivantes: point de congélation 0°; indice de saponification, 190; indice d'iode, 82; indice d'acétyle, 11; insaponifiable 0,6; acides gras Pt. F., 28°, Pt. S., 21°;n_D^{25}, 1,466. On consulte alors les Tables 20, 23, 22, 21, 26, 27 et 16*B* et on dresse pour chacune des tables la liste des "numéros index général" qui se trouvent dans le voisinage de la valeur expérimentale, en disposant dans chaque liste ces numéros dans l'ordre ascendant. Ensuite on détermine combien de fois chaque numéro index se trouve dans l'ensemble des différentes listes. Pour l'exemple indiqué, on obtient les résultats suivants: 8 fois le No. 8; 7 fois le No. 31; 4 fois les Nos. 3, 5, 26, 47, 62, 91; 3 fois les numéros 13, 20, 29, 33, 54, 61, 67, 83, 84 et 92.

En se référant à la Table 2 et en examinant les propriétés qui y sont mentionnées relativement à ces huiles, on peut éliminer tous les numéros à l'exception des Nos. 8 et 31. L'huile à déterminer doit donc être ou de l'huile d'olive, ou de l'huile de pied de boeuf, ou une huile présentant une ressemblance étroite avec celles-ci, mais non mentionnée dans la Table 2. D'une comparaison ultérieure des Nos. 8 et 31, il résulte l'élimination du No. 31, sur la base les indices d'acétyle et d'iode, mais des essais supplémentaires confirmant la chose sont nécessaires.

INTRODUZIONE

Tabella delle proprietà principali.—Nella Tabella 2 gli olii ed i grassi sono anzitutto classificati secondo il sistema di Alder Wright. In ogni classe essi sono disposti in ordine alfabetico in base al nome comune, e ad ognuno è assegnato un numero indice che serve a riconoscerlo nelle tabell successive. Data una sola serie di valori, questi sono in generale quelli di uno solo campione del olio particolare. La Tabella 2 serve perciò come tabella generale di riscontri in base ai nomi scientifici. Se il lettore non conosce il nome scientifico, deve consultare prima la Tabella 1 dove trova il numero indice.

Tabelle supplementari.—Le proprietà che non si trovano nella Tabella 2, sono contenute nelle tabelle da 3 a 17 inclusa.

Tabelle delle proprietà.—In queste (da 18 a 27 inclusa) i singoli olii e grassi sono disposti nell'ordine crescente delle loro proprietà in base ai numeri indici: gli intervalli nella scala dei valori delle proprietà sono indicati con caratteri in grassetto.

Queste tabelle di proprietà possono servire: 1) per scegliere una sostanza che abbia un determinato valore di una certa proprietà, oppure, 2) per identificare (in alcuni casi almeno) una sostanza in base alle sue proprietà. A questo ultimo scopo sono sopratutto utili le proprietà citate nel seguente esempio.

Esempio.—Si sia trovato che un olio ha le seguenti proprietà: Punto di congelamento 0°; numero di saponificazione 190; numero di iodio 82; numero di acetile 11; insaponificabile 0,6; punto di fusione degli acidi grassi 28°, punto di solidificazione 21°; n_D^{25}, 1,466.

Da ognuna delle Tabelle 20, 23, 22, 21, 26, 27 e 16*B* si ricava allora una lista di numeri indici con valori delle proprietà vicini a quelli sperimentali e si dispone ogni lista con questi valori in ordine crescente. Si osserva quindi quante volte ogni numero indice figura in questa serie di elenchi. Nel caso presente si ha: 8 volte il numero 8; 7 volte il numero 31; 4 volte i numeri 3, 5, 26, 47, 62, 91; 3 volte i numeri 13, 20, 29, 33, 54, 61, 67, 83, 84, 92.

Se ora si considera la Tabella 2 e si esaminano le proprietà ivi riportate per questi olii, essi vengono ad essere tutti scartati tranne i numeri 8 e 31. L'olio in esame perciò deve essere olio di oliva, oppure olio di piede di bue, o un olio che rassomiglia molto a questi due, ma che non è compreso nella Tabella 2.

Confrontando ancora i numeri 8 e 31, si scarta pure il 31 in base ai numeri di acetile e di iodio.

E' necessario però confermare ulteriormente questo risultato.

1. INDEX OF COMMON NAMES

English

(In the following index the word "oil" has been omitted. The various entries are oils unless specifically classified as "fats," "waxes," etc.)

French

(Dans la table suivante, le mot "huile" n'est pas mentionné. Les diverses références sont des huiles à moins qu'elles ne soient spécifiées comm "graisses" "cires," etc.)

German

(In dem folgenden Index wird das Wort "Öl" meistens ausgelassen. Die verschiedenen Bezeichnungen gelten Ölen, wenn sie nicht besonders mit den Namen "Fette," "Wachse," etc. bezeichnet sind)

Italian

(Nell'indice seguente è stata omessa la parola "olio." I diversi prodotti sono olii, tranne che non sia esplicitamente dichiarato che si tratta di "grassi," "cere," ecc.)

2. SCIENTIFIC NAMES AND COMMON PROPERTIES

Non-drying Vegetable Oils of the Olive Oil Type

F = fruit pulp; G = whole grain; Gm = germ; K = kernel; N = nut; S = seed; R = rhizome; *n* = refractive index

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value *v.* p. viii	Saponification value *v.* p. viii	Iodine value *v.* p. viii	Acetyl value *v.* p. viii	Hehner value *v.* p. viii	Reichert-Meissl value *v.* p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C *v.* p. viii	*n* Finding No. *v.* p. 212
0.5	*Abelmoschus moschatus* (S)	0.917–0.918			195	95		96		0.3			
1	*Amygdalus Persica* (S)	0.918–0.925	−20	1–1.5	191–193	92–99.7	6.5	94–96				13–13.5	69
2	*Anacardium occidentale* (S)	0.918		1.45	194–200	79.5			0.6	1.5			61
3	*Arachis hypogaea* (S)	0.917–0.926	3	0.8	186–194	88–98	3.5	95	0.4	0.5–0.9		30.5–39	66
3.5	*Camellia oleifera* (S)	0.916–0.9227	−12		180–196	80–90		93–96	0.8–1		21–30		
4	*Carapa Guianensis* (S)	0.912–0.923	4.5		188–195.6	58–65		92–93.7	2.5–3.3		38.8		43
5	*Corylus avellana* (S)	0.917	−17 to −18		191–197	87	3.2	95.5	0.99	0.5	22–25	19–20	52
5.5	*Cyperus esculentus* (R)	0.924	below 0		225	62–76							
6	*Lecythis zabucajo* (S)	0.895	4	3.19	173.6	76.6	44.8				37.6		77
7	*Moringa oleifera* (S)	0.912–0.920	7–8		185–189	109–112.6		95	0.5			37.8	60
8	*Olea Europaea sativa* (F)	0.915–0.920 *Cf.* Table 10	+2 turbid −6 deposit	0.3–1.0	185–196	79–88	10.5	95	0.6–1.5	0.4–1.0	26–30	16.9–26.4	63
9	*Olea Europaea sativa* (S)	0.918–0.919		1–1.8	182–186	88							65
10	*Oriza sativa* (S)	0.920–0.927	−10	43–77.2	192–195.8	96.4–99.9		95.2		3			85
11	*Phoenix dactylifera* (S)		18.1		211	52.3		95.2	0.88				37
12	*Pistacia vera* (S)	0.913–0.919	−5 to −10		191	83–87		96			17–20	13–14	57
13	*Prunus amygdalus* (S)	0.914–0.921	−15 to −20	0.5–3.5	183.3–207.6	93–103.4	9.6	96.0	0.5	0.75	13–14	9.5–11.8	58
14	*Prunus Armeniaca* (S)	0.915–0.926	−17	3.5	191.4–198.2	100–108.7	12.2		0.2		2.3–4.5		70
15	*Prunus cerasus* (S)	0.918–0.929	−19 to −20	1.1	193.3–195	110–114.3					19–21	13–15	38
16	*Prunus domestica* and *P. damascena* (S)	0.912–0.913	−5 to −8	0.55	191–193	100–103.6					12.4–18		68
16.5	*Sterculia foetida* (F, S)	0.926			188–199	76–83		95–96	1.0			31–32	81.5
16.6	*Strophanthus hispidus* (S)	0.9249–0.9254	−6		188–195	96–102		92–95	0.5–0.9		32.2		
16.7	*Terminalia catappa* (S)	0.917–0.920	3–4		175–196	84–89		91–92			42–44		48.5
17	*Thea sasanqua* (S)	0.920	−5 to −12		190–194	91		91.5	0.1				54, 55
18	*Ungnadia speciosa* (S)	0.912	−12		191–192	81–82		94			19	10	

Non-drying Vegetable Oils of the Rape Oil Type

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value *v.* p. viii	Saponification value *v.* p. viii	Iodine value *v.* p. viii	Acetyl value *v.* p. viii	Hehner value *v.* p. viii	Reichert-Meissl value *v.* p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C *v.* p. viii	*n* Finding No. *v.* p. 212
19	*Brassica juncea* (S)	0.916–0.921		3.7–7.2	172–180	102–108		95.5	0.33–0.89				78
20	*Brassica campestris* (S)	0.913–0.917	−10	0.36–1.0	168–179	94–105	14.75	94.5–96.3	0–0.79	1.48	18.5–20	11.7–13.6	82
21	*Brassica* (varieties of) (S)	0.916–0.919	−8		177–181	109–122				1.4–1.7		13.5–16.5	94
22	*Eruca sativa* (S)	0.916–0.919		2.5–3.7	169–174	97.5–102		95.5	0.75				80
23	*Raphanus sativa* (S)	0.916–0.918	−10 to −18		174–178			95.9	0.33		20	13–15	71
24	*Sinapis alba* (S)	0.912–0.916	−8 to −16	5.4	171–174	94–98.4		96–97			15–16		75
25	*Sinapis nigra* (S)	0.915–0.919		5.7–7.3	173–175	99–110		96		3.3	16–17	13.4–13.7	88
25.1	*Sinapis nigra* (Russian)	0.920			181–182	115–120							

Non-drying Vegetable Oils of the Castor Oil Type

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value *v.* p. viii	Saponification value *v.* p. viii	Iodine value *v.* p. viii	Acetyl value *v.* p. viii	Hehner value *v.* p. viii	Reichert-Meissl value *v.* p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C *v.* p. viii	*n* Finding No. *v.* p. 212
26	*Jatropha curcas* (S)	0.919–0.924	4.4 turbid 2.8–2.9 solid	0.5–5.0	192.5–210	98–110	9–25.3	95.2	0.28–0.48		24–30		67
27	*Ricinus communis* (S)	0.960–0.967	−12 turbid −17 to −18 solid	0.12–0.8	175–183	84	146–150.5		1.4	0.6	13		110
28	*Vites vinifera* (S)	0.917–0.933	−10 to −17	0.75	171–191	94.3–135	13.5–14.5	92	0.46	1.6	23–25		89

Non-drying Animal Oils

L = lard; T = tallow; F = foot

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value *v.* p. viii	Saponification value *v.* p. viii	Iodine value *v.* p. viii	Acetyl value *v.* p. viii	Hehner value *v.* p. viii	Reichert-Meissl value *v.* p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C *v.* p. viii	*n* Finding No. *v.* p. 212
29	*Oleum adipis* (L)	0.913–0.915	−2 to +4	1.56 (0.1–2.5)	193–198	62.5–79		97		0.6	33–38.4	27–33	45
30	*Oleum adipis bovis* (T)	0.914–0.919	2 to 7.5	0.2–0.25	193.5–199	56–60.5						35–37.5	
31	*Oleum pedis bovis* (F)	0.913–0.918	−2 to +10	0.1–0.6	193–199	57.5–75	7.7–9.3	94.8–95.9	0.9–1.2	0.12–0.65	29–41	16–26.5	47

Vegetable Semi-drying Oils

F = fruit pulp; G = whole grain; Gm = germ; K = kernel; N = nut; S = seed

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value *v.* p. viii	Saponification value *v.* p. viii	Iodine value *v.* p. viii	Acetyl value *v.* p. viii	Hehner value *v.* p. viii	Reichert-Meissl value *v.* p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C *v.* p. viii	*n* Finding No. *v.* p. 212
32	*Avena sativa* (G)	0.925		34.7–35.3	189.8–192.4	114.2		94.9		1.30–2.65	27.5		114
33	*Bertholletia excelsis* (K)	0.917–0.918	0 to 3	1.4	193	90–106					28–30	31.1–32.2	56
34	*Camelina sativa* (*Myagrum sativa*) (S)	0.923–0.927	−18		188	132–152					13–14	17–18	107

Vegetable Semi-drying Oils.— (*Continued*)

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value *v.* p. viii	Saponification value *v.* p. viii	Iodine value *v.* p. viii	Acetyl value *v.* p. viii	Hehner value *v.* p. viii	Reichert-Meissl value *v.* p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C *v.* p. viii	*n* Finding No. *v.* p. 212
35	*Ceratotheca sesamoides* (S).........	0.916		0.63	190.2	110.6							83
35.5	*Citrus aurantium* (S).............	0.918–0.919			194–197	97–104		95–96	0.5–0.8				70.5
36	*Citrus limonum* (S)...............	0.916–0.918	−6		188.3	107.3	13.6	95.6	0.55			19.7–21.0	
37	*Croton tiglium* (S)...............	0.942–0.944	−8 to −18	27–30.9	193–215	108–109	19.8–38.6					17–19	115
37.5	*Cucumis melo* (S)................	0.921^{25}_{25}		0.43	192.3	125.9	15.8	95.1	0.33	1.1			
38	*Cucurbita pepo* (S)...............	0.923–0.925	−15		188–193	121–130		96	4.45			26–28	95
39	*Eriodendron anfractuosum* (S)......	0.923–0.933		3–15	189–194.5	78–93					38		64
40	*Fagus sylvatica F. Americana* (K)...	0.922	−17		191–196	97–111		95–96			23–24		73
41	*Gossypium* species (S)............	$0.917–0.918^{25}_{25}$	+12 to −13	0.6–0.9	194–196	103–111.3	21–25	95.7	0.95	1.1	34.5		
41.5	*Hydnocarpus alcalae*..............	0.948^{30}_{30}	24	6.7	202	94.0					55		143
42	*Hydnocarpus anthelmintica* (S).....	0.949^{30}_{30}		0.6	206–209.8	84.5–90.8	21.8	95.5	1.02		46		122
42.1	*Hydnocarpus Hutchinsonii* (S)......	0.943^{30}_{30}	23	5.3	199	83.5					43		
42.2	*Hydnocarpus subfalcata* (S)........	0.951^{30}_{30}	21	6.6	206	89.0					41		140, 142
42.3	*Hydnocarpus venenata* (S)..........	0.947^{30}_{30}	20	1.2	191	90.7					47		145
42.4	*Hydnocarpus Wightiana* (S)........	0.947^{30}_{30}	11	6.7	207	97.0					40		144
42.5	*Hydnocarpus Woodii* (S)...........		18	5.9	192	68.5					43		
43	*Lepidium sativum* (S).............	0.920–0.924	−15		180–183	102–118		95.5	0.2–0.4		16–18		
43.5	*Luffa Ægyptica* (S)...............	0.9254		28.8	188	108.5		95	1.4				86.5
44	*Lycopersicum esculentum* (S).......	0.922			187–192	107–125	11.4–20.5	95–96.6	0.1–0.3				97
45	*Madia sativa* (S).................	0.921–0.933	−10 to −12		193–194	121–129		95.5			21.7	22–26	
45.1	*Pangium edule* (S)................	0.925^{30}_{30}	7	6.9	200	78.5					18		137
46	*Quercus agrifolia* (S).............	0.916	−10		199.3	100.0					25		
47	*Sesamum indicum* (S)..............	0.919^{25}_{25}	−4 to −6	9.8	188–193	103–117		95	1.1–1.2		25–35	23–32	87
48	*Soja hispida* (*Dolichos hispida*) (S)	0.924–0.927	−10 to −16	0.3–1.8	189–193.5	122–134	4.9	93–94.5	0.5–2.8	1.27–1.54	26.2–27.5		96
49*	*Taraktogenos Kurzii* (S)...........	0.943–0.954	20–25	0.79–21.5	196–213	97.6–110.4							130
50	*Triticum sativum* (Gm)............	0.924–0.929	0 Viscous		183–190	115			2–3	2.4–2.6	39–40		100
51	*Zea mais* (S).....................	0.921–0.928	−10 to −20	1.37–2.02	187–193	111–128	7.5–11.5	93–95	4.3	1.5–2.8	17–20	14–16	86

Vegetable Drying Oils

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value *v.* p. viii	Saponification value *v.* p. viii	Iodine value *v.* p. viii	Acetyl value *v.* p. viii	Hehner value *v.* p. viii	Reichert-Meissl value *v.* p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C *v.* p. viii	*n* Finding No. *v.* p. 212
52	*Aleurites cordata* (S).............	0.934–0.940		3	194–197	150–158			0.39	0.4–0.8	30–49	36–39	149
53	*Aleurites Fordii* (S)..............	0.939–0.949		2	190–197	163–171			1.10	0.4–0.8			149
54	*Aleurites moluccana* (S)...........	0.925		2	189–195	163–164	9.8	95–96	1.2	0.5–0.9			111
55	*Aleurites montana* (S)............	0.939–0.949		2	190–197	163–171			0.35	0.4–0.8			149
56	*Aleurites triloba* (S).............	0.927			202–204	139–143.8						17.8	111
56.5	*Amoora rohituka* (S)	0.931–0.939		17.0	190–192	135		93.2	1.6		20–22	16–14	105.5
57	*Argemone Mexicana* (S)............	0.925		6.0	188–190	120–122.5		95.1	0.0	1.14	22.8		91
58	*Cannabis sativa* (S)..............	0.928–0.934	−15 to −28	0.45	190–195	145–161.7				1.08	17–21	15.6–16.6	126
59	*Carthamus tinctorius* (S)..........	0.925–0.928		0.6	188–203	122–141	16.1	95	0–0.2		11–17	7–12	102
60	*Conepia grandifolia* (S)...........	0.969		5.7	188.6	179.5					21.5 (begins) 65.0 (ends)		148
61	*Guizotia oleifera* (S).............	0.925–0.927	−8	0.95–2.94	189–192	126.4–133.8		95.4			25.4	22.6	
62	*Helianthus annuus* (S)............	0.924–0.926	−17		188–193	129–136			0.5	0.31	22–24	18–19.8	108
62.5	*Hesperis matronalis* (S)...........	0.931–0.934	−22		192	155							
63	*Hevea Braziliensis* (S)............	0.924–0.930			190–200	117–140	28	95.3	0.27–0.3			15–20	93
64	*Juglans nigra* (N)................	0.918–0.921	−12 turbid	8.6–9.0	190.1–191.5	141–142.7		95.8			0		
65	*Juglans regia* (N)................	0.925–0.927		2.5	190.1–197	139–150		93.4–95.4	0.92		15–20	14.3	113
66	*Lallemantia iberica* (S)...........	0.933^{20}	−25		185	162		93.3	1.55		22.2		
67	*Linum usitatissimum* (S)	0.930–0.938	−19 to −27	1–3.5	188–195	175–202		94.5–95.5	0.95	0.4–1.2	20–24	16–20.6	127, 128
68	*Manihot glaziovic* and *M. ceara* (S)..	0.924–0.932	−17		188–192	117–139	21	94–96	0.4–3.0		23–26	20–24	90
68.5	*Oncoba spinosa* (S)...............	0.930		12.1	192.2	177.0				1.3			125

* *Oleum Chaulmoograe* (U.S.P.X.): *d* 25, *ca.* 0.950; congeals below *ca.* 25°; sapon. value, 196–213; I value; 98–104; $[\alpha]^{25}_{D}$ 48–60°.

Vegetable Drying Oils.—(*Continued*)

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value *v.* p. viii	Saponification value *v.* p. viii	Iodine value *v.* p. viii	Acetyl value *v.* p. viii	Hehner value *v.* p. viii	Reichert-Meissl value *v.* p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C *v.* p. viii	*n* Finding No. *v.* p. 212
69	*Papaver somniferum* (S)...........	0.924–0.926	−16 to −18	2.5	193–195	128–141		95.4	0.6	0.43	20.5	17–19	106
70	*Paulownia imperialis* (S)..........	0.935–0.940	below −17		193.4–196.3	149–158							150
71	*Perilla ocimoides* (S)..............	0.930–0.937			188–194	185–206		95.8			−5		133
72	*Pimento officinialis* (S)............	0.923^{20}_{20}		0.03	171.4	134.4							
73	*Pinus abies* (S)....................	0.931	−26		192	120.5							101
74	*Pinus cembra* (S)..................	0.930–0.932	−20	1.5	191.8	150–159.2		93.27	2.0	1.3			116
75	*Pinus Gerardiana* (S)..............	0.931	−17		191–192	118–119					0		
76	*Pinus monophylla* (S)..............	0.933			189–192.8	101.3–108					19		72
77	*Pinus montana* (S).................	0.932	−25		180–190	145–146		92			0		
78	*Pinus picea* (S)....................	0.921	−18 to −20		191	119–120					16–19	10–16	146
79	*Pinus pinea* (S)....................	0.928–0.933	−27		191–193	120–121		91–92				10–15	98
80	*Pinus sylvestris* (S)...............	0.932	−28 to −29		189.8	147.1							105
81	*Ricinodendron Rautannenii* (S).....	0.928–0.930	−12 to −22		190–195	124–135		94–98	0.75		30–40		147
82	*Stillingia sebifera* (S).............	0.940–0.946		1.24	209–210.4	145–161	28.7	94.4–95.2	0.93–0.99	1.45	14.5		135

Fish and Marine Animal Oils

F = whole fish; B = blubber; L = liver

83	*Alosa menhaden* (*Brevortia tyrannus*) (F).......................	0.923–0.933	−5		189–192.9	148–185			1.2	0.6–1.43			123
84	*Balaena mysticetus* and other species (B)...........................	0.917–0.924	0 to −2	1.9	160–202	90–146	11–23	93–95	14	1–4	14–27	10–24	103
85	*Clupea harengus* (F)...............	0.920–0.939			170–194	102–149		95–96		1–2	30–32		112
86	*Clupea pilchardus, C. scombrinus* (F)...........................	0.920–0.934	20–22		187.7–196	150–193	21–22	93.3–96	0.5–1	0.98	30–34.8	28.2	134
87	*Clupanodon melanostica* (F)........	0.928–0.935		2.2	189–192.1	121.5–124.5		94.5–97		0.5–3	35–36	27.6–28.2	76
88	*Delphinus globiceps* (B)............	0.908–0.930	+5 to −3		187.3	99.5		93.1	5.6	2			26, 49
89	*Delphinus phocaena* (B)...........	0.926			290 (Jaw) 203.4 (Body) 253.7–272.3 (J)	32.8 (J) 126.9 (Bo) 30.9–49.6 (J)		65.9 (J) 68.4–72.0 (J)	65.9 (J) 46.9 (Bo) 132 (J)	16–17 (J)			32
90	*Gadus merlangus* (L)...............	0.925–0.930			177–189	123–181		95	0.4–0.7	0.7–7	31		
91	*Gadus morrhua* (L)................	0.922–0.931	−3	5.6	171–189	137–166	1.15	95.3	0.2	0.54–2.68	21.8–38	17.5–24.3	118
92	*Phoca species* (B)..................	0.915–0.926	3		187.5–196.2	130–152		93–96	0.2	0.3–1.0	22–23		109
93	*Selache* (*cetorhinus*) *maxima et al.* (L)	0.916–0.919			157–164	115–139	11.9	87–97		2.8–15.2	21–22		119, 121
94	*Squalus acanthias* (L).............	0.918			169.7	126.4				8.4			92
94.5	Various species Japanese sharks (L)*..........................	0.864–0.932		0.0–4.3	23–186	91–345				1–90	25–35		

*Extremes for 36 species (188).

Japanese salmon and trout oils: *see* Toyama, *142*, **26**: 273; 23. Liver oil of palm-crab, Kobayashi, *Ibid.*, 585.

Insect Oil

95	*Bombyx mori* (from pupae)........	0.928	0	18.6–27.5	190–194	116.3–131.9	19.7	94.5	3.4	2.61	36.5	27–28	99

Vegetable Fats

F = fruit pulp; G = whole grain; Gm = germ; K = kernel; N = nut; S = seed

96	*Acrocomia sclerocarpa* (F & K)......	0.866^{100} (K)		55.8 (F) 0.4–4.7 (K)	189 (F) 237–255 (K)	77.2(F) 16–30 (K)			5.7–7.2 (K)		20.5–21 (K)		10
97	*Akebia quinata* (S)................	0.934		25.4	246.4	78.38		85.8	39.76		31		22
98	*Allanblackia* (*Stearodendron*) *Stuhlmannii* (S).....................	$0.856–0.861^{100}$ 0.930	30.4–38	11.6–23	186.6–191.7	38.7–41.9					59	61.4–61.6	17
99	*Adansonia digitata* (S)............	0.915–0.920	+3 to −3		190–192	56–79					35–38		19, 39
100	*Astrocaryum vulgare* (S)...........	0.867^{100} (K)	28.6 (K)	43.8 (F) 0.54–1.69 (K)	220.2 (F) 240–250 (K)	46.4(F) 12.2–13.9 (K)			3. 8 (K)	0. 75 (F)	27 (K)		6
101	*Attalea cohune* (S)................	$0.868–0.871^{100}$			254	11–13.7			8		27–28		3
102	*Attalea funifera* (S)..............	0.868^{100}	22.7	2.8	246.9	15.6–16.3			5.8				
103	*Attalea spectabilis* (S)............	0.869^{100}	24.6	1.2	259.5	8.9			6.3	0.36	23.6		7

Vegetable Fats.—(*Continued*)

General Index No.	Scientific name and source	Density d^{15}_{15}	Congelation temperature °C	Acid value *v.* p. viii	Saponification value *v.* p. viii	Iodine value *v.* p. viii	Acetyl value *v.* p. viii	Hehner value *v.* p. viii	Reichert-Meissl value *v.* p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C *v.* p. viii	*n* Finding No. *v.* p. 212
104	*Bassia butyracea* (S)				188–190.8	42.1–42.6		94.8–95.6	0.4–1.31	1.36	58.4		20
105	*Bassia latifolia* (S)	0.862^{100}	19–22		192.2–199.9	53.4–67.8		94.7–94.9	0.44–0.88		39–45	38–40	41, 46
106	*Bassia longifolia* (S)	$0.858–0.862^{100}$	36		188.4–189.8	60.4–62.4		94–95	1–2			38–41	
107	*Bassia Mottleyana* (S)	0.864^{100} 0.917		11.3	189–192	31.5		95.7	0.6–0.8	0.5	56		50
108	*Bassia toxisperma* (S)	0.858^{100} 0.916	21	9.27	180–188.6	57–65		94.5–95	1.1–2.5	3.86	49–52.8	47	53
109	*Blighia sapida* (S)	0.858^{100}	20	20.1	194.6	49.1		93	0.9		42–46	38–49	
110	*Buchanania latifolia* (S)	0.858^{100}		15	191.8–195.4	54.7–59.9		94.8–95.8	0.33				
111	*Butyrospermum Parkii* (S)	0.859^{100} 0.917	25–30	2.8	178–190	54–63		93.8–95.8	1.25–1.4	5–9	52–53		81
112	*Calotropis gigantea* (S)				196–197	84–85		95–96	0.5		33–34		62
113	*Calophyllum inophyllum* (S)	0.915			194	95.5		93.6	0.38			28–29	132
114	*Canarium commune* (S)	0.905^{40}			193–200	59–66	15–16	95–96	0.1		40–42	37–40	
115	*Canarium ovatum* (S)	0.907^{30}_{4}		1.42	197.4	55.9				0.19			
116	*Caryocarpus tomentosum,* etc. (S)	0.898^{40}_{15}	23–29		199.5	49.5	6.6	96.6	0.65		48.3–50	46–47	31
117	*Cocos butyracea, C. nucifera* (K)	0.926 $0.864–0.868^{100}$	14–22	2.5–10.0	253.4–262	6.2–10	2.3–6.9	82.3–90.5	6.6–7.5		24–27	21.2–25.2	1
118	*Cocos syagras* (S)		26.8	2.9–3.2	252.5	12.5–13.4							5
119	*Elaeis guineensis* (W. Africa) (F)	0.924 0.858^{100}		10	200–205	49.2–58.9	15.7	94.5–97	0.9–1.9		50	42.5–45.5	59
120	*Elaeis guineensis* (W. Africa) (S)	$0.866–0.873^{100}$			243–255	10.5–17.5	7.6	91–91.5	5–6.8		25–28.5	20–25.5	12
121	*Elaeis guineensis* (S. America) (F)		21.9	29.8–20.5	197	78.1–88.3							
122	*Elaeis guineensis* (S. America) (S)		27.4	0.55–0.33	220.2–231.4	25.5–31.6							
123	*Garcinia indica* (S)	0.853^{100}		14.5–21.0	186.8–191.3	25–34.2		94.6–95.6	0.11–1.54		60–61		29
124	*Gossypium* species (S)	$0.867–0.868^{100}$		4–10		88.7–93.6		96.5	0.22		27–45	39.9–51	79
125	*Isoptera borneensis* (S)	0.856^{100}		11.3	192.1	31.5		95.7	1.1	0.5	56		23
126	*Laurus nobilis* (F)	0.880^{100}			198–199	68–80			1.6				124
127	*Lindera praecox* (S)	0.935			274	20.5		89.2	1.39			13	2
128	*Lindera serica* (S)	0.940			255	65.3		86.2	2.53			9–10	
129	*Lindera triloba* (S)	0.936			282	11.6		85.7	2.0			14	
130	*Lophira alata; L. procera* (S)	0.901^{40}_{40} 0.859^{100}			180–194.6	60–78			0.8–0.9		42–49		
131	*Mafureira oleifera* (S)	0.857^{100}	25–37		199–221	40–47		93	1–4		51–55	48–52	
132	*Mangifera Jabonensis* (*Irvingia Barteri*) (S)	0.860^{100}	27–35	4–10	241–245	29–31		94	0.2–0.4		35		4
133	*Maximiliana regia* (S)	0.867^{100}		0.33	240.9–253	13–16			3.0		24.2		9
134	*Melia azadirachta* (S)	0.925	35		185.6	72.9			8.27				51
135	*Myrica cerifera* (*M. Carolinensis*) (F)	0.995 0.875^{100}	39–43		205.5–211.7	3.9–9.5		92–94	0.5		47–48		8
136	*Myristica officinalis* (S)	0.945–0.996		17.2	154–178				1.1–4.2				
137	*Myristica otoba* (S)	0.892		16.8	185–199	20–54				20.4		37.2	117
138	*Myristica becuhyba* (S)	0.912	32–32.5		219–220	9–10		93–94			42.5–46		40
139	*Oenocarpus batava* (F)		7.0	0.48	191.8	78.2				1.1			48
139.5	*Oncoba echinata*	0.898^{100}		4.5	192.4	99.7				1.6			
140	*Palma Maripa* (K)	0.868^{100}	25.5–26		270.5	17.3		89	4–5		27–28		
141	*Pentaclethra macrophylla* (S)	0.912–0.921	14		182–186	87–101	21–37	94–96	0.6		50–57		74
142	*Pentadesma butyracea* (S)	0.869^{100}			186–197	45–49		95	0.3		57–60		25
143	*Pongamia glabra* (S)	$0.924–0.935^{40}$	8		178–185	78–94			1		44–45	36–42	131
144	*Rhus succedaneum* (F)	0.970–0.980 0.875^{100}	40.5–46	11–12	206.6–237.5	4.9–12.8	17.25–26.5	90–91		1.1–1.6	53–56.5		34
145	*Schleichera trijuga* (S)	0.924–0.942	10		215–230	48–55		91–91.5	9	3.1	52–55	49.7–50.7	42
146	*Stillingia sebifera* (S)	0.918–0.922	24–34	2.4	179–206	23–40.5		95.3	0.2–0.9		39–57	45.2–47.2 50.9–52.5	13
147	*Theobroma cacao* (S)	0.964–0.974 0.858^{100}		1.1–1.9	192.8–195	32.8–41.7	1.97	94–95	0.3–1		48–53	47.2–49.2	21
148	*Theobroma grandiflora* (S)	0.852^{100}		44.0	187.8	44.8			0.08	0.91		48.1	
149	*Vateria indica* (S)	0.915		5.8–15.3	188.7–192	37.8–39.1		95.1–95.2	0.2–0.4		56.6–57		35

Animal Fats

AT = Adipose tissue

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	*n* Finding No. v. p. 212
150	*Adeps* (AT)	0.934–0.938 $0.861^{100}_{15.5}$	27.1–29.9	0.5–0.8	195–203	47–66.5	2.6	93–95			37–46.6	36–42.4	24
151	*Adeps bovis*	0.895 0.862^{98}_{15}	31–38	0.25	196–200	35.4–42.3	2.7–8.6	96–96.5			42.5–44	37.9–46.2	
152	*Adeps ovis*	0.937–0.953 $0.858^{100}_{15.5}$			195–196	48–61					33.5–49	40–48.5	28
153	*Anser cinereus*	0.923–0.930	22–24		191–193	58–67		94.5–95.3	0.2–0.98		36.6–40	31–34	44
154	*Capellae lactis adeps*	$0.917–0.935^{37.7}_{37.7}$			233–236	25–37			20.8–27.7				14
155	*Cervus elephus,* etc	0.962–0.967		0.8–5.3	194.5–200	26–36		95.8	0.68	0.52	50–64	46–50	
156	*Equus caballus*	0.919–0.933			195–200	75–86		95–98			31.3–53.4		84
157	*Gallus domesticus* (AT)	0.924 $0.906^{33.7}_{33.7}$	21–27		193–204.6	66–71.5	45	94.6	1.8		38–40	32–34	36
158	*Lepus cuniculus*	0.934–0.936 0.861^{100}_{15}			199–203	70–99.8		99.5	0.7–2.8		39–50	35–41	
159	*Sevum*	0.925–0.950			193–198	35–45		95–96	0.5–1.0			40–50	
160	*Sevum ossis*				190–196	50–55	11.3	94–95	0.2–1.7		42.5–44		
161	*Vaccae lactis adeps*	$0.907–0.912^{40}_{15}$			210–230	26–28 (Extremes 19.5–49.5)	1.9–8.6	87.6–89.6	17.0–34.5		38–41	33–39	15, 27, 30

Sperm Oil

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	*n* Finding No. v. p. 212
162	*Hyperoodon rostratus*	0.880–0.881		0.4–0.5	123–134	80.4–82.0	4.1–6.4			36–41	10.3–10.8	8.3–8.6	11
163	*Physeter macrocephalus*	0.878–0.884			120–137	80–84	4.5–6.4				13.4		16

Vegetable Non-glyceridic Waxes

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	*n* Finding No. v. p. 212
164	*Corypha cerifera* (exudation from leaves)	0.995–0.999		4–8	79–84	13.5	55.2			54–55			104
165	*Euphorbia anti-syphilitica*			17.0	51								33
166	Montan wax (lignite tar, lignite peat)			73	74	16				47			

Animal Waxes

General Index No.	Scientific name and source	Density d_{15}^{15}	Congelation temperature °C	Acid value v. p. viii	Saponification value v. p. viii	Iodine value v. p. viii	Acetyl value v. p. viii	Hehner value v. p. viii	Reichert-Meissl value v. p. viii	Unsaponifiables %	Fatty acids M. P. °C	"Titer" test °C v. p. viii	*n* Finding No. v. p. 212
167	*Adeps lanae* (sheep's wool)	0.970–0.973		59.8	82–130	17–29	23			39–44	41.8		141
168	*Apis indica* (bees)			6–6.1	82–83	10							18
169	*Apis mellifera* (bees)	0.961–0.968 $0.822–0.827^{98}_{15.5}$	60.5–62	16.8–20.6	88–96	8.8–10.7	15.2						18
170	*Apis* (Chinese bees)			5.3–9.7	90.2–120.2								18
171	*Coccus cerifera* (insect on leaves of *Fraxinus chinensis*)	0.809–0.811	80–81	63									
172	Spermaceti (oils of *Cetacea*)	$0.905–0.945^{99}_{15.5}$ $0.806–0.812^{99}_{15.5}$		0.5–2.8	126–135		2.6			51.5			

3. COMPOSITION TABLE

(In weight %)

General Index Number

Class 1. Non-drying Oils of Almond and Olive Oil Type

Glycerides principally of oleic acid. Linolic acid present in small proportion

0.5. *v.* (98.5).

1. Similar to No. 13.

2. Oil from kernels is non-drying. Olein, 80.4; stearin, 17.3 (48). The oil from the pericarp is black and has high iodine value (294) (202).

3. Palmitin, stearin, arachidin, lignocerin, olein, linolin and possibly hypogaein. The mixed lignoceric and arachidic acids (Renard's "arachidic acid") vary from 4.3 to 5.4 (av. 4.8); stearic acid *ca.* 5. Unsaturated acids *ca.* 30, of which *ca.* 60% is linolic (63). Hypogaeic acid not found (164) but occurrence considered probable (78). For variations in constants *v.* (100). "Unsaturated" fatty acids 75–79.5, with iodine value, 109–126 (100).

3.5. Similar to No. 17 (185).

4. Non-drying glycerides.

5. Oleic acid, 85; palmitic, 9.4; stearic, 1; glycerol, 10.4; phytosterol, 0.5 (76).

5.5. *v.* (19, 28.5, 150).

7. Glycerides of oleic, stearic and palmitic acids, and, according to Völker, behenic acid.

8. *Ca.* 25 solid and 75 liquid glycerides, mainly olein. Linolic acid, 7; oleic, 93 (80). No stearic acid (83). A mixed glyceride (1–2%, M. P. 53–55°), probably stearic, palmitic and oleic, has been isolated (92). Ultimate composition: C, 77.2; H, 11.3; O, 11.5 (163). Highly unsaturated acids, 78–93.5, with iodine value, 89–98 (100).

9. Similar to No. 8. Solid acids, 9.7 (of which stearic, 40; palmitic, 60); liquid acids, oleic and linolic; no arachidic (110).

10. Oil from commercial rice meal contains free fatty acids, 43–77 (168). Impure fat from polishings *v.* (68).

11. The constants indicate presence of oleic and volatile insoluble fatty acids. On the border-line between oils and solid fats.

12. Largely oleic glycerides.

13. Fatty acids, mainly oleic, with *ca.* 6 linolic (63). No linolenic. Little, if any, stearic (84).

14. Similar to No. 13 *cf.* (160).

15. Resembles No. 13, but has higher iodine value (110–114), indicating larger amount linolic acid. HCN present (141).

16. Similar to No. 13, but contains more linolic acid.

16.5. *v.* (32, 200).

16.6. *v.* (21.1).

16.7. *v.* (72).

17. Very similar to No. 8. 88–93 liquid acids with iodine value 99.6–104.4 (118). This commercial oil is distinct from tea oil (*Thea sinensis*) *v.* (184).

Class 2. Non-drying Oils of Rape Oil Class

19. Greater proportion unsaturated fatty acids than No. 20.

20. Mainly glycerides of rapic and erucic acids (159.5); linolenic acid present (63); arachidic and lignoceric acids *ca.* 1.43 (11). Yields *ca.* 1% insoluble bromide of mixed glyceride (84). "Unsaturated" acids 94–95, with iodine value, 100.5–105 (100).

21. Larger amount less saturated glycerides than No. 20.

22. Similar to No. 24.

23. Resembles No. 20, but has less drying capacity.

24. Resembles No. 20. Contains *ca.* 1.3 arachidic and lignoceric acids (11). Yields *ca.* 1.5 insoluble bromide (84).

25. Similar to No. 24. "Unsaturated" acids, 91.5–94.5, with iodine value, 103–120 (100).

Class 3. Non-drying Oils: Castor Oil Type

26. Glycerides of hydroxylated fatty acid, not identical with ricinoleic. Liquid fatty acids, consist of equal proportions oleic and linolic (111). Solid fatty acids, *ca.* 10, of which palmitic, 80, and stearic, 20. No linolenic.

27. Largely glycerides of ricinoleic and isoricinoleic acids (79), with small amount saturated acids.

28. Palmitic, stearic, oleic and linolic acids, and hydroxy acids (*ca.* 25), not identical with ricinoleic (5).

Class 4. Animal Oils Largely Glycerides of Oleic Acid

29. Mainly olein, with small amount linolin, palmitin, and stearin. Practically free from volatile fatty acids.

30. Glycerides of oleic with very little solid acids.

31. Resembles No. 30, but contains more saturated glycerides. Stearic 2–3; palmitic, 17–18; oleic, 74.5–76.5; glycerol, 5–10; unsaponifiables, 0.1–0.5 (54).

Class 5. Semi-drying Oils

Glycerides of linolic acid are characteristic constituents

32. Resembles No. 51 (146).

33. Glycerides of oleic and linolic acids. Does not yield insoluble bromide.

34. Glycerides of oleic, linolic and palmitic acids, with small amount of erucic acid (141).

35. Similar to No. 47, but does not give Baudouin reaction (27).

35.5. *v.* (52, 91.5).

37. Glycerides of stearic, palmitic, myristic, lauric, caproic, butyric, and acetic acids; also tiglic and higher homologues of oleic acid, but no oleic (163).

38. Glycerides of oleic and linolic acids.

39. Glycerides of oleic and linolic acids. Slight reaction in Becchi's test and Halphen's test.

40. Olein, linolin, with small amount palmitin and stearin.

41. C, 76.4; H, 11.4; O, 12.2 (163). Glycerides of oleic and linolic acid in approx. proportion 3 to 4.5 (224). Linolic acid, 17–18 (63). Stearic acid present. Fatty acids liberated by hydrolysis in practically same proportion as in original oil (101). Unsaturated acids, 69.7–73.9, with iodine value, 144.2–148 (100).

42. Contains hydnocarpic acid, a cyclic fatty acid of general formula $C_nH_{2n-4}O_2$ (154); with neutralization value, 222.7; specific rotation +67.70°; iodine value, 100 (33). Method of separation from chaulmoogric acid, *v.* (51).

43.5. *v.* (48).

44. Glycerides of oleic, linolic, stearic and myristic acids, with 2.3 lecithin (16). Arachidic acid at least 0.4 (223).

45. Glycerides of oleic, linolic, stearic and palmitic acids.

45.2. *v.* (59.5).

47. C, 75.22; H, 11.13; O, 13.65 (163). Glycerides of oleic, and linolic acids, with small amount stearic, palmitic and myristic acids. Solid fatty acids, 12–14; linolic acid, *ca.* 16 (63). Glycerides of oleic, 48.1; linolic, 36.8; palmitic, 7.7; stearic, 4.6; arachidic, 0.4; unsaponifiables, 1.7. Unsaturated acids, 80.6%, with iodine value, 129.7 (104).

48. Saturated acids, *ca.* 12 (mainly stearic and palmitic); unsaturated, *ca.* 80 (linolic and oleic, with *ca.* 50 of isomer of linolic (109)). Insoluble fatty acids: palmitic, 10; stearic, 2; arachidic, 1; lignoceric, linolenic, linolic and oleic, 88 (199); *cf.* (18).

49. Glycerides of chaulmoogric, hydnocarpic, linolic and myristic acids (45). Chaulmoogric acid: neutralization value, 200–202; specific rotation, +58° to +59°; iodine value, 89.5–90.7 (33). For constants of oils from 8 authentic species of

seeds allied to chaulmoogra, *v.* (147). Also *v.* references for No. 42.

50. Contains glycerides of oleic and linolic acids.
51. Mainly glycerides of oleic and linolic acids, with small amounts palmitic, stearic, and arachidic acids (195). Saturated acids, 4.5; olein, 44.8; linolin, 48. 2 (95). Unsaturated acids, 84.6–86.4, with iodine value, 140.8–142.9 (102).

Class 6. Drying Oils

Usually characterized by linolenic and isolinolenic acids and linolic and isomeric acids

52. Glycerides of oleic (*ca.* 25) and elaeostearic acids (isomer of linolic acid). For constants of oils from different species *v.* (138).
53. Glycerides of α-elaeostearic and oleic acids [(1), p. 207].
54. Glycerides of oleic (56.9), linolic (33.4), stearic, palmitic, myristic and linolenic acids (6.5) (204). Yields *ca.* 8% insoluble bromide.
55. Glycerides of β-elaeostearic, oleic, and probably linolic acids (144).
56. Oleic, 57; linolic, 33.5; linolenic, 6.5; oxidised glycerides, 2.8 (203).
57. For general characteristics, *v.* (10).
58. Glycerides of linolic, 70; linolenic and isolinolenic, 15; oleic acid, 15 (224).
59. Glycerides of solid fatty acids (palmitic and stearic) *ca.* 10; liquid acids (oleic and linolic) *ca.* 90 (122).
60. For characteristics, *v.* (30).
61. Yields only small amount insoluble bromide (84).
62. Glycerides of oleic acid, 33.4; linolic, 57.5; palmitic, 3.5; stearic, 2.9; arachidic, 0.6; and lignoceric, 0.4 (99).
63. For characteristics, *v.* (29).
64. For characteristics, *v.* (108). Cross between *J. nigra* and *J. cinere* contains *ca.* 70 linolic acid glycerides, with those of stearic, oleic, and linolenic acids (65).
65. Glycerides of myristic, lauric, oleic, linolic, and linolenic acids. Liquid acids: linolic, 80; linolenic, and isolinolenic, 13; oleic, 7 (224).
66. Elaidin test indicates large proportion olein.
67. C, 78.11; H, 10.96; O, 10.93 (163). Glycerides of solid fatty acids, 10–15. Liquid acids: oleic, 15–20; linolic, 30; linolenic, 38 (62). Saturated acids: stearic, 64.4; palmitic, 20 (140). On bromination, liquid acids yield 20–25 linolenic hexabromide (84). Yields 2 insoluble mixed glycerides on bromination: (1) linolic-dilinolenic bromoglyceride, 22–25; (2) trilinolic bromoglyceride, or oleic-linolic-linolenic bromoglyceride (182). Oil contained: α-linolenic acid, 21.1; isomeric linolenic, 2.7; α-linolic, 17.0; hydoxy-acids, 0.5; saturated acids, 8.0; glyceryl radical, 4.1; phytosterol, 1.0; undetermined, 46.2 (55).
69. Glycerides of oleic (20); linolic (65); linolenic acids (5) (224).
70. *v.* Nos. 52, 53, 55.
71. Glycerides of oleic, linolic, linolenic, palmitic and stearic acids. Fatty acids yield 45–51 linolenic hexabromide (66). Linolenic acid yields hexabromide identical with that from No. 67 (17).
72. Unsaturated acids, 82.8, with iodine value, 157.9 (53).

73–80. For characteristics *v.* (73).

81. *v.* (74, 170).
82. For characteristics *v.* (52).

Class 7. Fish and Marine Animal Oils

Characterized by presence of highly unsaturated glycerides. These oils yield insoluble bromoglycerides, which blacken when heated

83. Glycerides of palmitic, 22.7; myristic, 9.2; stearic, 1.8; unsaturated acids with 18 carbon atoms, 24.9; 20 carbon atoms, 22.2; 22 carbon atoms, 20.2 (190).
84. Glycerides of fatty acids with: C_{14}, 4.5; C_{16} (palmitic), 11.5; palmitoleic, 17; C_{18} (stearic), 2.5; unsaturated (mainly oleic), 36.5; C_{20} (unsaturated), 16; C_{22} (unsaturated), 10; C_{24} (unsaturated), 1.5; unsaponifiables, 1.7 (136). Oil yields *ca.* 25% insoluble bromoglyceride (84). Clupanodonic octobromide (8.39%) from fatty acids.
85. Glycerides of highly unsaturated fatty acids (iodine value, 296–317) (40). Yields clupanodonic octobromide (3.8–6.5%) (183).
86. Glycerides of highly unsaturated acids. Jecoric acid, $C_{18}H_{30}O_2$ (isomeric with linolenic) and palmitic (13.6) (61). For characteristics of pilchard oil *v.* (119).
87. Glycerides of highly unsaturated acids 13% with iodine value 319.5 (40). From 13–14 of clupanodonic acid, $C_{18}H_{28}O_2$ (iodine value 344.4) in mixed fatty acids (183). Glycerides yielded 23.6 insoluble bromide (183).
88. High proportion glycerides of volatile fatty acids (139). Also esters of other alcohols. Deposits spermaceti. Isopropylacetic acid (Chevreul's "phocoenic" acid) in volatile acids (6).
89. Glycerides of highly unsaturated acids (14.3 with iodine value 285.4) (40). Valeric acid, 19.9–24 in jaw oil; 2.71 in body oil (139).
90. For characteristics *v.* (180, 181).
91. Glycerides of myristic, palmitic, stearic, oleic, erucic and unsaturated acids $C_{16}H_{30}O_2$ and $C_{20}H_{38}O_2$ (39, 40, 41). From 17–21 of highly unsaturated acids with iodine value, 324 (189). Clupanodonic acid present (189). Acid of general formula $C_nH_{2n-8}O_2$ (clupanodonic acid) isolated. Oil yields *ca.* 34–42 insoluble bromide (84).
92. Glycerides of saturated acids, 17; liquid acids (oleic and physetoleic) 83 (128); linolic (225); highly unsaturated acids (iodine value 330), 11.96 (40). Mixed fatty acids yield 13.9–14 insoluble bromides.
93. Glycerides of highly unsaturated acids (8.57 with iodine value 312.5) (40). Yields *ca.* 22 insoluble bromide (83). Oil from certain species contains large proportion of $C_{30}H_{50}$, spinacene (43) and squalene (186). For characteristics of liver oils (Jap. sharks) *v.* (187, 188). The liver of *Cetorhinus maximus*, 41.9–55.5 unsaponifiables, mainly squalene.
94. For characteristics *v.* (180). A shark oil.

Class 8. Insect Oil

95. Glycerides of oleic, linolic (4.38), solid fatty acids (mainly palmitic), phytosterol (not cholesterol); glycerol, 9.42 (185). Also *v.* (127).

Class 9. Vegetable Fats

96. *v.* (28).
97. *v.* (131).
98. Much stearic, little palmitic acid. Mixed glyceride, oleodistearin, isolated (86, 89).
99. *v.* (179).
100. *v.* (28).
101. *v.* (29).
102. *v.* (28).
103. *v.* (9).

104–106. *v.* (31).

107. *v.* (31, 34).
108. *v.* (31).
109. *v.* (94).
110. *v.* (48).
111. *v.* (31).
112. *v.* (52).
113. *v.* (64, 72). The crude oil contains *ca.* 3.5% resin, on removal of which a semi-drying oil containing a large amount of linolic acid is obtained. Cong. pt. *ca.* −2°, iodine value, 96.8 (169).

114. *v.* (145).

115. Glycerides of oleic acid, 59.6; palmitic, 38.2; and stearic, 1.8; unsaponifiables, 0.2 (201).

116. Solid fatty acids, mainly palmitic; liquid acids, oleic (124); *v.* (28).

117. Glycerides of fatty acids in approximately proportions given: caproic, 2; caprylic, 9; capric, 10; lauric, 45; myristic, 20; palmitic, 7; stearic, 5; oleic, 2 (57). For criticisms on method of alcoholysis, *v.* (59, 174). Glycerides of kernel oil: caprylic, 9.5; capric, 4.5; lauric, 51; myristic, 18.5; palmitic, 7.5; stearic, 3 (?); oleic, 5; linolic acid glycerides, 1.0 (13). Mixed glycerides isolated (24).

118. *v.* (28).

119. Palmitin, free palmitic acid, olein and small amount linolin (84).

120. Glycerides of caproic acid, 2; caprylic, 9; capric, 10; lauric, 45; myristic, 20; palmitic, 7; stearic, 5; oleic, 2 (58). *v.* No. 117. Mixed glycerides (5) isolated (26).

121–122. *v.* (28).

123. Mainly oleo-distearin (87); *v.* (48).

124. Mainly palmitin, with glycerides of oleic and linolic acids. Stearic acid, 3.3 (83).

125. Glycerides of stearic, palmitic and oleic acids. Oleo-distearin and oleo-dipalmitin isolated (115). For characteristics of fats from different varieties of pontianak nuts, *v.* (71). For relationship of constants, *v.* (178).

126. Largely laurin with glycerides of oleic and probably linolic acid; *v.* (60).

127–129. *v.* (192).

131. Solid acids, 71.4; liquid acid (oleic), 23 (141).

132. Glycerides of lauric, myristic and palmitic acids (121).

133. *v.* (28).

134. *v.* (126).

135. Glycerides of myristic, palmitic, stearic, and oleic acids. Glycerol, 13.4 (1).

136. Glycerides of myristic acid, 73–74; oleic, 20; butyric, 1; essential oil, 2–3 (1).

137. Glycerides of lauric acid, 15.1; myristic, 52.2; palmitic, 0.2; oleic, 3.9. Unsaponifiables, 20.4 (20).

138. Glycerides of myristic and oleic acids and an essential oil.

139. *v.* (28).

140. *v.* (72).

141. *v.* (196, 200).

142. *v.* (197).

143. *v.* (126).

144. Largely palmitic acid and its glycerides. Mixed glyceride isolated (69).

145. Insoluble fatty acids, including lauric and arachidic, 91 (163). Volatile acids contain butyric and acetic acids. Liquid acids, 55; unsaponifiables, 3.12 (207).

146. Glycerides of palmitic and oleic acids. No stearic acid (83). Oleo-dipalmitin isolated (114).

147. Glycerides of stearic, palmitic, oleic, and linolic acids. Stearic acid in fatty acids, 40 (83). Saturated acids, 59.7; oleic, 31.2; other acids, 6.3 (63). Mixed glycerides (113, 116). Oleic, 43–45; palmitic, 23–25; stearic, 31–33. Five mixed glycerides isolated (3).

149. *Ca.* 75 solid (palmitic) and 25 liquid acids (oleic) (121).

Class 10. Animal Fats

150. Mainly glycerides of palmitic, stearic and oleic acids, with small amounts linolic. Palmito-distearin and stearo-dipalmitin isolated (23). Stearic acid, 7–13 (83).

151. Mainly glycerides of palmitic, stearic, and oleic acids, with traces of linolic and linolenic acids (63). Mixed glycerides isolated include oleo-dipalmitin, stearo-dipalmitin, oleo-palmito-stearin and palmito-distearin (23). These crystallize in different form from lard glycerides.

152. Glycerides of palmitic, stearic and oleic acids. Stearic, 0–36 (83).

153. Mainly triolein, with small amounts stearo-dipalmitin, palmito-diolein, and oleo-dipalmitin (4). Fatty acids contain stearic, 3.8; palmitic, 21.2; and oleic, 72.3 (25.5).

154. For characteristics, *v.* (117).

155. Glycerides of palmitic, stearic and oleic acids.

156. Glycerides of oleic and linolic acids, 9.9 (63). Stearic acid sometimes present (1). No linolenic (63).

159. *v.* Nos. 151, 152.

160. Glycerides of stearic acid, 19–21; palmitic, 20–21; oleic, 53–59; glycerol, 5–10; unsaponifiables, *ca.* 0.5 (54).

161. Glycerides of butyric, caproic, caprylic, and capric acids, 8.35; oleic, 32.5; stearic, 1.83; palmitic, 38.61; myristic, 9.89; and lauric, 2.59, with 1.83 dihydroxystearic acid (35). Stearic acid, 0–22 (137). Mixed glycerides include butyro-diolein, butyro-palmito-olein and oleo-dipalmitin (2). For particulars of *ghee*, *v.* (29.1, 29.2, 109.5, 193.5).

Class 11. Liquid Animal Waxes

162. Mainly various alcohols (iodine value, 64.8–65.2) in combination with fatty acids of oleic series (1).

163. Mainly alcohols, chiefly of ethylene series, in combination with fatty acids of oleic series. Iodine value of alcohols, 63.9–74.1 (22).

Class 12. Vegetable Non-glyceridic Waxes

164. Contains a hydrocarbon (M. P. 59°), an alcohol, $C_{27}H_{56}O$; myricyl alcohol, carnaubic acid, cerotic acid, and a hydroxy acid (175).

165. From 50–52 hydrocarbons (37).

166. Esters of montanic acid and unsaponifiable matter (157, 162, 212).

Class 13. Animal Non-glyceridic Waxes

167. Complex mixture of esters of higher alcohols; also glycerides (50, 112, 165).

168. Free cerotic acid and esters of alcohols (36).

169. Free cerotic acid, myricin, with smaller amounts free melissic acid, unsaturated fatty acids, and ceryl and other alcohols (81, 96). Free hydrocarbons, 11.0–17.5 (38).

170. *v.* (36).

171. Chiefly ceryl cerotate with small amounts of other esters.

172. Mainly cetin or cetyl palmitate with very small amounts of similar esters or glycerides.

4. POLENSKE VALUES

General index No.	Polenske value	General index No.	Polenske value
148	0.12	133	7.0
134	0.25	120	9–10
36	0.3	116	9–12
81	0.4	102	10.2
104	0.5–0.65	96	10.2–12.6
161	1.5–3.0	103	15.6
154	4.9–8.7	117	16.8–17.8
100	5.9		

5. COMPRESSIBILITY

1 $\text{megabarye}^{-1} = 10^{-6}\ \text{cm}^2\ \text{dyne}^{-1} = 1.0133A_n^{-1} = 0.0690\ \text{in.}^2\ \text{lb.}^{-1} = 0.9807\ \text{cm}^2\ \text{kg}^{-1}$.

$t = 14.8°\text{C}$. $\Delta P = 1$ to 10 atm (134)

General index No.	27	67	13	91	8
$\frac{10^6}{V}\frac{\Delta V}{\Delta P}$ =	47	52	53	53	56

5. COMPRESSIBILITY.—(*Continued*)

$t = 40°$. d = density, g cm^{-3}. $C = \frac{10^6}{V}\frac{dV}{dP}$ per megabarye (96)

P kg cm^{-2}	General index No. 27		General index No. 20		General index No. 163	
	Castor oil		Rape oil		Sperm oil	
	d	C	d	C	d	C
0	0.9414		0.8980		0.8660	
157.5	0.9488	50.5	0.9058	55.7	0.8746	60.8
315.0	0.9558	48.6	0.9129	52.1	0.8820	58.2
472.5	0.9625	47.0	0.9199	51.1	0.8898	56.3
630.0	0.9686	45.3	0.9270	50.5	0.8958	53.4
787.5	0.9748	44.5	0.9330	48.2	0.9124	51.5
945.0	0.9808	43.2	0.9381	46.0	0.9088	50.5
1102.5	0.9858	41.5	0.9440	44.8	0.9136	48.1
1260.0	0.9906	40.1	0.9496	43.6	0.9196	46.9
1417.5	0.9958	39.4	0.9547	42.7	0.9249	45.7
1575.0	1.0010	38.3				

6. VISCOSITY

Conversion factors for different viscometer degrees, *v.* vol. I, p. 32.

Change of viscosity of oils with temperature (91).

Fish oils (205).

Solutions of camphor, of ethyl alcohol and of chloroform in olive oil (35.5).

Lubricating oils (12).

η in Poises

OILS (12, 171)
t = 60°F = 15.5°C

General index No.	$\eta_{15.5}$	General index No.	$\eta_{15.5}$
163	0.42–0.44	26	0.858–0.878
At 100°F	0.185	13	0.860
At 150°F	0.085	1	0.869
At 212°F	0.046	21	0.935
67	0.55	3	0.942–0.950
58	0.697	8	0.950–1.01
61	0.697	At 100°F	0.377
84	0.711	At 150°F	0.154
92	0.724	At 212°F	0.070
62	0.776	31	0.987–1.13
69	0.789	20	1.08–1.18
51	0.789	At 100°F	0.42–0.45
47	0.797	At 150°F	0.18–0.19
48	0.797	At 212°F	0.08–0.09
14	0.857	27	*v. infra*
41	0.82–0.994		

FATS (12, 171)
t = 50°C

General index No.	η_{50}	General index No.	η_{50}
117	0.154	150	0.258
120	0.171	159	0.274
147	0.171	167	
105	0.175	At 150°F	1.672
119	0.198	At 212°F	0.314
160	0.256		

Kinematic Viscosity

R = Redwood; degrees at 70°F = sec per 50 cc. η_{70} = (0.0026R − 1.715/R) × d (±5% approx.)

General index No.	R$_{70°F}$ *cf.* (48)	General index No.	R$_{70°F}$ *cf.* (48)
167	212	29	
84	188	At 60°F	356– 534
At 120°	71.3	52	853–1433
65	232	At 60°F	1230–2178
69	255–259	57	
59	249–294	At 100°F	1160–1190
61	263–292	117	
57	269–272	At 140°F	63.9
8	312	123	
3	350	At 140°F	101.1
22	371	106–104	
23	385	At 140°F	110.4
20	372–465	149	
24	402	At 140°F	104.0
25	425		

DENSITY AND VISCOSITY OF CASTOR OIL (No. 27) (12, 105)

t, °C	d, g cm^{-3}	η, poises	t, °C	d, g cm^{-3}	η, poises
5	0.9707	37.60	25	0.9569	6.51
6	.9700	34.475	26	.9562	6.04
7	.9693	31.56	27	.9555	5.61
8	.9686	28.90	28	.9548	5.21
9	.9679	26.45	29	.9541	4.85
10	.9672	24.18	30	.9534	4.51
11	.9665	22.075	31	.9527	4.21
12	.9659	20.075	32	.9520	3.94
13	.9652	18.25	33	.9513	3.65
14	.9645	16.61	34	.9506	3.40
15	.9638	15.14	35	.9499	3.16
16	.9631	13.805	36	.9492	2.94
17	.9624	12.65	37	.9485	2.74
18	.9617	11.625	38	.9478	2.58
19	.9610	10.71	39	.9471	2.44
20	.9603	9.86	40	.9464	2.31
21	.9596	9.06	37.8	.9473	2.729
22	.9589	8.34	65.6	.9284	0.605
23	.9583	7.67	100.0	.9050	0.169
24	.9576	7.06			

7. VISCOSITY UNDER PRESSURE

VALUES OF η_P/η_0 at 40°C (98)

P kg cm^{-2}	General index No. 20 Rape oil	General index No. 163 Sperm oil	P kg cm^{-2}	General index No. 27 Castor oil
0	1.00	1.00	0	1.00
157.5	1.125	1.23	23.94	1.03
315.0	1.44	1.535	227.6	1.365
472.5	1.875	1.94	550.5	2.295
630.0	2.345	2.39	864.6	3.625
787.5	3.905		1164.0	5.255
866.2		3.135		
945.0	3.495			
1102.5	4.21	4.02		
1260.0			(*v. also* Fig. 1.)	

Influence of Temperature on Viscosity under Pressure

400 kg cm^{-2} (6000 lb. in.$^{-2}$) produces approx. the following % increase in viscosity: Lard (No. 150) 75% at 25°, 34% at 100°; sperm (No. 163) 72% at 25°, 29% at 100°.

For lard oil (No. 150) the solidifying pressure at 21° is *ca.* 155 kg cm^{-2} (22 800 lb. in.$^{-2}$) and at 100° the viscosity is increased 240% by 1500 kg cm^{-2} and 600% by 3000 kg cm^{-2} (44 000 lb. in.$^{-2}$) [*Report of Research Sub-committee on Lubrication, Amer. Soc. Mechan. Engineers*, No. **1833** (Dec. 1921)].

8. MELTING POINT

General index No.	M. P., °C	General index No.	M. P., °C	General index No.	M. P., °C
4	16	117	20–28	148	32
11	22.4	118	29	149	37.5–42
20	−2 to −6	119	27–43	150	29.8–45.5
23	−4	120	23–30	151	42–50
32	*ca.* 8	121	30–30.5	152	47–49
52	Below −17	122	30.2–31	153	27.5–32.5
54	Below −18	123	41–42	155	48–54
65	−12 to −28	124	29–33	156	18–39
96	24.9 (pulp)	125	28–31	157	33–40
	19.4–24 (kernel)	126	32–36	158	35–46
97	38–39	130	10–24	159	41–51
98	40–41	131	35–40	160	44–45
100	35 (pulp)	132	38–42	161	28–36
	30.6–32.5 (kernel)	133	27–28.5	164	83–91
101	22–24	135	40–48	165	68–70
102	26.1	136	38–51	166	76
103	23.6	137	37.8		95–97*
105	23–29	138	39–43	167	39–42
106	42	140	26.5–27	168	65–66
107	28–31	141	4–18	169	62–66
109	25–35	142	32	170	62–66
110	32	144	53–56	171	81–83
111	37–42	145	22–28	172	42–49
113	37	146	36–46		
114	15–30	147	26.6–34.5		
116	29.5–35.5				

* Montan wax.

Under Pressure No. 172 (49)

P., atm.	M. P., °C	P., atm.	M. P., °C	P., atm.	M. P., °C
1	46.5	56	49.36	141	50.90
11	48.33	96	50.10	182	51.38
20	48.64				

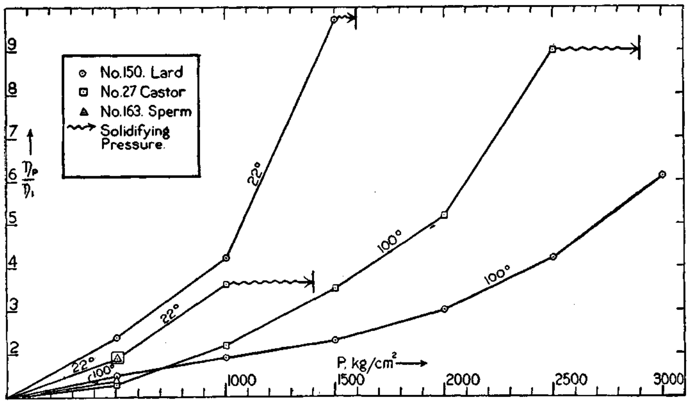

FIG. 1.—Effect of pressure on relative viscosity of oils.

9. BOILING POINT OF OILS

No. 27, castor, *ca.* 265°C. No. 67, linseed, *ca.* 287°C. B. P. varies with time owing to decomposition.

10. THERMAL EXPANSION

The value of $d^t_{15.5}$ for any oil for temperatures between 10° and 25° may be approximately calculated from the expression $d^t_{15.5} = d^0_{15.5}(1 - 0.0007\, t) = (\text{approx.})\, d^{15.5}_{15.5} - 0.0006_6(t - 15)$(210).

Values of $\frac{d^{t_1}_{15.5} - d^{t_2}_{15.5}}{t_2 - t_1} \times 1000$. $t_2 = 98°$ or $99°$ (1)

Values uncorrected for expansion of glass plummet of Westphal balance

General index No.	$t_1°$	Difference for 1°C	General index No.	$t_1°$	Difference for 1°C
117	40	642	159	50	673
119	50	717	161	40	617
120	40	657	164	90	97_5
144	60	692	169	80	75_0
147	50	717	172	60	716
150	40	650			

Correction in Density, $d^{15.5}_{15.5}$, for 1°C

$$A = -10^3 \frac{dd}{dt} \text{ at } 15°C$$

General index No.	A	General index No.	A	General index No.	A
3	0.655	41	0.629	84	0.722
8	.629	47	.624	89	.654
20	.620	61	.637	92	.615
27	.653	67	.648	93	.646
29	.658	83	.654	161	.643
31	.625	84	.697	162	.648

Empirical Equations

$$V_t = V_0(1 + a \times 10^{-6}t + b \times 10^{-6}t^2 + c \times 10^{-9}t^3)$$

General index No.	Name	*a*	*b*	*c*	Range	Lit.
169	Beeswax.....	738_6	1.75_2	−8.27	0–100	(132)
8	Olive oil......	798	-0.77_3	8.27	9–106	(214)
8	Olive oil......	682_{15}	1.140_{53}	5.39		(215)
8	Olive oil......	$d^{20}_4 = 0.91268$, $d^{30}_4 = 0.90590$				(216)

11. SPECIFIC HEAT

Mean c_p between 20° and 30°. 1 joule g^{-1}/°C = 0.2389 cal_{15} g^{-1}/°C or BTU_{60} $lb.^{-1}$/°F (130).

General index No.....	8	12	20	26	31
c_p, joules g^{-1}/°C......	1.98_8	2.05_1	1.96_3	2.08_4	1.91_3
General index No.............		40	47	52, 53	67
c_p, joules g^{-1}/°C..............		1.98_4	2.00_0	1.83_3	1.84_6
General index No..........	91	117	150	163	169 (221)
c_p, joules g^{-1}/°C...........	1.89_1	2.13_9	2.02_1	1.93_8	2.0

For thermal conductivity of beeswax *v.* p. 311.

12. HEAT OF COMBUSTION

H_v = heat of combustion, at constant volume, in kilojoules per gram. 1 kj g^{-1} = 238.9 cal_{15} g^{-1} = 430.1 BTU_{60} $lb.^{-1}$

General index No.	Oil	Iodine value	Free acids as oleic	H_v (166)
3	Arachis..................	105.9	0.16	39.39
8	Olive....................	85.1	2.51	39.58
13	Almond.................	98.1	5.13	39.56
20	Rape....................	107.4	0.82	39.71
27	Castor..................	84.1	0.26	37.09
47	Sesame.................	105.3	1.65	39.32
51	Maize...................	120.3	3.32	39.39
51	Maize (crude)...........	122.4	1.68	39.42
67	Linseed (fresh)..........	182.4	4.30	39.19

General index No.	Oil	Iodine value	Free acids as oleic	H_v (166)
69	Poppy	129.6	2.66	39.26
83	Menhaden		0.36	39.17
84	Whale			39.64
91	Cod liver	165.6	0.56	39.49
93	Shark			39.22
150	Lard	74.3	0.74	39.55
163	Sperm	78.7	0.78	41.62

General index No.	Fat	H_v	Lit.
150	Lard	39.77–40.40	
	Oleomargarine	40.18	
161	Butter fat	39.00–39.18 38.47–38.63	(173)
153	Goose fat	39.77	(173)
172	Spermaceti	41.62	(166)

$H_v \times d_{15}^{15} = 36\text{–}37$. For H_v of fatty acids *v.* (173).

13. FLASH POINTS OF OILS AND FATS

See also (12, 158)

1. Closed Test (42)

General index No.	Oil or fat	Average value °F	Average value °C	Extreme values, °F
8	Olive	437.5	225.2	410–465
162	Arctic sperm	446.2	230	390–485
163	Southern sperm	457.5	236.3	420–485
20	Rape, Black Sea refined	464.4	240.2	430–490
31	Neat's foot	470.3	243.5	410–540
84	White whale	476.0	246.4	430–530
20	Rape oil, E. Indian refined	478.6	248.1	410–510
41	Cottonseed	523.0	272.7	500–540

2. Methods Not Stated (8)

General index No.	Oil or fat	Flash point °F	Flash point °C	Fire point °F	Fire point °C
67	Linseed	378	192	572	300
67	Linseed, boiled	419	215	468	242
150	Lard, No. 2	419	215	468	242
163	Sperm, No. 1	428	220	518	270
31	Neat's foot	439	226	523	273
8	Olive	451	233	541	283
27	Castor	459	237		
51	Maize (corn)	480	249	635	237
163	Sperm, No. 2	486	252	574	302
150	Prime lard	530	277	644	340
41	Cottonseed	582	305.6	644	340

14. ELECTRICAL CONDUCTIVITY

$\kappa = A \times 10^{-5}$ mhos (*cf.* vol. 1, p. 35) (90)

General index No.		A (= $\kappa \times 10^5$) at 18°C
161	Butter	646–701
	Margarine	822–863
41	Cottonseed oil	863
3	Arachis oil	872
47	Sesame oil	878
8	Olive oil	993

Relative Values on an Arbitrary Scale (15)

Oils

General index No.	8	8	47	69	21	1
°C	Olive I	Olive II	Sesame	Poppy	Ravison rape	Peach kernel
0	0.00	0.00	0.2	0.48	7.9	42
20	0.00	0.00	0.9	3.2	19.4	132
40	0.00	0.06	1.7	7.0	45	252
60	0.00	0.14	2.3	17.0	108	501
80	0.00	0.70	8.6	34.9	168	1024
100	0.00		18.0	60.5	236	1748
120	0.01		28.8	115	340	2974
140	0.06		47.0	218	480	4400
160	0.51		107		670	6230
180	1.62	7.62	182.5		1000	8700
200	3.38	10.7	275		1450	11600
220	6.08	15.0	400		2030	14700
240	10.4	21.6	660		2840	18280
260	16.5	33.0	1200		4000	22250
280	23.7	52.5	2270		6000	27750
300	31.70	83.0				

Drying oils heated in contact with air acquire greater conductivity; also oils that have become rancid. If a definite temperature has not been reached (about 260°) the original conductivity is restored on cooling. Of the oils tested, linseed oil showed the greatest conductivity.

	Fats				Waxes			
General index No.	157	150	88	117	172	169	164	144
°C	Chicken fat	Lard	Dolphin oil	Coconut oil	Spermaceti	Beeswax (yellow)	Carnauba wax	Japan wax
0	1.7				0.0	0.0	14.5	0.0
20	2.2 (liquid)	6.6	5.8 (liquid)	0.48	0.02	0.10	28.0	0.0
40	3.3	8.8 (liquid)	9.4	1.25 (liquid)	1.3 (liquid)	1.0	55.6	0.0
60	5.3	18.5	14.8	5.02	2.9	7.1	85.5	0.0 (liquid)
80	7.8	24.0	30.9	7.80		29.0 (liquid)	100	19.0
100	11.0	28.5	58.0	14.0	4.5	36.0	175	27
120	14.1	38.0	87.5	22.4	8.6	64.0	316	50
140	17.6	61	157.4	33.7	13.6	121	520	90
160	21.5	101	280.0	48.0	19.0	260	1090	155
180	25.4	126	369	102	24.2	600		236
200	30.0	60	470		30.8			343
220	35.1	60.5	625					641
240	40.5	99	880					
260	46.8	158						
280	54.0	230						
300	63.5	339						

15. DIELECTRIC CONSTANTS

Mixtures of Castor Oil (No. 27) and Toluene (167, 107, 193); *cf.* (7)

Per cent castor oil	0	10	20	30	40
ϵ at 12.5°	2.655	2.820	3.102	3.264	3.452
ϵ at 20.0°	2.541	2.748	2.920	3.150	3.352
$-\frac{\Delta\epsilon}{\Delta t}$	0.0141	0.0158	0.0174	0.0190	0.0206

Per cent castor oil	50	60	70	80	90	100
ϵ at 12.5°	3.746	3.952	4.152	4.308	4.564	4.798
ϵ at 20.0°	3.536	3.684	3.950	4.182	4.334	4.578
$-\frac{\Delta\epsilon}{\Delta t}$	0.0223	0.0239	0.0255	0.0272	0.0288	0.0304

For castor, olive, and linseed oils *see* (222).

16. REFRACTIVE INDEX AND BUTYROREFRACTOMETER READING

In preparing Table 16*B* below, butyrorefractometer values have first been converted into values of n_D by means of the *conversion factors* given in Table 16*A*. Values of n_D below 25° and above 40°C have then been converted to 25° and 40°, respectively, by means of the convenient approximate relation,

$$\frac{\Delta n_D}{\Delta t} = -0.00037\ (106).$$

16*A*. Table for Converting Butyrorefractometer Readings into Refractive Indices

Scale divisions	n_D	Scale divisions	n_D	Scale divisions	n_D	Scale divisions	n_D
0.0	1.4220	19.5	1.4373	45.2	1.4560	72.7	1.4740
0.5	1.4224	20.0	1.4377	46.0	1.4566	73.5	1.4745
1.0	1.4228	20.4	1.4380	46.6	1.4570	74.3	1.4750
1.2	1.4230	21.1	1.4385	47.3	1.4575	75.1	1.4755
1.5	1.4232	21.7	1.4390	48.0	1.4580	76.0	1.4760
2.0	1.4236	22.5	1.4396	48.8	1.4585	76.8	1.4765
2.5	1.4240	23.0	1.4400	49.5	1.4590	77.7	1.4770
3.0	1.4244	23.5	1.4404	50.2	1.4595	78.6	1.4775
3.5	1.4248	24.3	1.4410	51.0	1.4600	79.4	1.4780
3.7	1.4250	25.0	1.4415	51.7	1.4607	80.3	1.4785
4.0	1.4254	25.6	1.4420	52.5	1.4610	81.2	1.4790
4.5	1.4256	26.3	1.4425	53.3	1.4615	82.0	1.4795
5.0	1.4260	27.0	1.4430	54.0	1.4620	82.9	1.4800
5.5	1.4264	28.3	1.4440	54.8	1.4625	83.8	1.4805
6.0	1.4268	29.0	1.4445	55.6	1.4630	84.6	1.4810
6.2	1.4270	29.7	1.4450	56.3	1.4635	85.5	1.4815
7.0	1.4276	30.0	1.4452	57.1	1.4640	86.4	1.4820
7.5	1.4280	31.0	1.4460	57.9	1.4645	87.3	1.4825
8.0	1.4284	31.8	1.4465	58.6	1.4650	88.2	1.4830
8.7	1.4290	32.5	1.4470	59.4	1.4655	89.1	1.4835
9.0	1.4292	33.0	1.4474	60.2	1.4660	90.0	1.4840
9.5	1.4296	33.9	1.4480	60.9	1.4665	90.9	1.4845
10.0	1.4300	34.6	1.4485	61.7	1.4670	91.8	1.4850
10.5	1.4304	35.3	1.4490	62.5	1.4675	92.7	1.4855
11.0	1.4308	36.0	1.4495	63.2	1.4680	93.6	1.4860
11.3	1.4310	36.7	1.4500	64.0	1.4685	94.0	1.4862
12.0	1.4316	38.1	1.4510	64.8	1.4690	94.5	1.4865
12.5	1.4320	38.7	1.4515	65.6	1.4695	95.4	1.4870
13.8	1.4330	39.5	1.4520	66.4	1.4700	96.0	1.4873
15.0	1.4340	40.0	1.4524	67.2	1.4705	96.3	1.4875
15.5	1.4343	40.9	1.4530	68.0	1.4710	97.2	1.4880
16.4	1.4350	41.5	1.4535	68.7	1.4715	98.1	1.4885
17.0	1.4354	42.3	1.4540	69.5	1.4720	99.1	1.4890
17.8	1.4360	43.0	1.4545	70.3	1.4725	100.0	1.4895
18.5	1.4366	43.7	1.4550	71.1	1.4730		
19.1	1.4370	44.4	1.4555	71.9	1.4735		

For more extensive data *v.* (106). For specific refraction (Lorenz) *v.* (156).

The following empirical relations have been proposed:

$$\frac{n^2-1}{n^2+2} \times \frac{100}{d_4^t} = 33.07 + 0.00075(I) - 0.01375\ (S) + 0.002(t - 15)$$

where d = density, S = saponification value, and I = iodine value, all at t°C. When hydroxy acids are present, the first constant of the equation is lower (14).

$$n_D^{40} = 1.4643 - 0.000046\ (S) - 0.0096\left(\frac{A}{S}\right) + 0.0001171\ (I),$$

where A = acid value.

An observed refractive index higher than that calculated from this formula indicates oxidation of the oil (149).

In the case of hydrogenated cottonseed, linseed, arachis, sesame and sardine oils, and bassia tallow,

$$n_D^{60} = [1.4468 + 1.03 \times 10^{-4}\ (I) + 7.3 \times 10^{-3}(I^2)] \pm 0.0005.$$

The refractive indices of hydrogenated castor oil are lower than those of other oils with similar iodine values, owing to reduction of the hydroxyl groups by the catalyst (178).

16*B*. Refractive Indices

Finding No.	General index No.	n_D^{25}	n_D^{40}
1	117	1.453	1.44*77–95*
2	127	1.4543	
3	101		1.449*0–6*
4	132		1.4499
5	118		1.4*496–505*
6	100		1.4*497–506*
7	103		1.4503
8	135		1.4511
9	133		1.4512
10	96		1.45*02–25*
11	162	1.45*67–71*	1.451*1–5*
12	120		1.4*492–543*
13	146		1.4*470–579*
14	154		1.4*499–551*
15	161*		1.4528
16	163	1.4573	1.4*488–581*
17	98		1.4540
18	168–170		1.45*38–66*
19	99		1.45*21–85*
20	104		1.4*552–656*
21	147		1.45*37–80*
22	97	1.4605	
23	125		1.45*59–66*
24	150	1.46*09–20*	1.45*42–81*
25	142	1.4617	1.45*59–66*
26	88†	1.4*517–717*	
27	161‡		1.45*34–89*
28	152		1.45*45–85*
29	123	1.4628	1.4566
30	161		1.45*55–78*
31	116		1.4567
32	89	1.462*2–5*	1.4568
33	165		1.4569
34	144		1.45*60–91*
35	149		1.4575
36	157		1.4580
37	11	1.4*535–633*	1.4581
38	15	1.4635	
39	99		1.45*21–85*
40	138		1.4*588–600*
41	105		1.4*578–614*
42	145		1.4597
43	4		1.4*593–613*
43.1	131		1.4*593–624*
44	153		1.4*583–626*
45	29		1.4607
46	105		1.46*05–13*
47	31	1.46*43–85*	
48	139		1.4610
48.5	16.7	1.4664	
49	88	1.4665	
50	107		1.46*09–16*
51	134		1.46*07–20*

* Indian cow.

† Japanese.

‡ Indian buffalo.

16*B*. REFRACTIVE INDICES.—(*Continued*)

Finding No.	General index No.	n_D^{25}	n_D^{40}
52	5	1.4667	
53	108		1.*4584–649*
54	17	1.*4662–89*	
55	17		1.4618
56	33	1.4671	
57	12	1.4672	
58	13		1.*4593–646*
59	119		1.*4603–39*
60	7		1.*4593–652*
61	2		1.4623
62	112	1.4678	1.4623
63	8	1.*4657–67*	1.*4603–56*
64	39		1.*4602–57*
65	9	1.*4682–8*	
66	3		1.*4620–53*
67	26	1.*4681–91*	1.4636
68	16	1.*4679–702*	
69	1	1.*4682–701*	1.*4630–49*
70	14	1.*4636–705*	1.*4635–49*
70.5	35.5		1.4641
71	23	1.*4640–6*	1.4642
72	76	1.4698	1.4643
73	40	1.4698	
74	141		1.*4637–54*
75	24		1.4649
76	87		1.*4633–66*
77	6	1.4705	
78	19	1.4710	1.4650
79	124	1.*4700–25**	1.*4646–54*
80	22		1.4653
81	111		1.*4642–64*
81.5	16.5		1.4654
82	20		1.*4649–59*
83	35		1.4656
84	156	1.*4658–702*	1.*4618–96*
85	10	1.4711	
86	51	1.4733	1.*4656–62*
86.5	43.5		1.4660
87	47	1.*4704–17*†	1.*4649–75*
88	25	1.4718	
89	28	1.*4713–25*	1.*4659–78*
90	68	1.4724	1.*4671–8*
91	57		1.4675
92	94	1.4730	1.4675
93	63		1.*4666–85*
94	21	1.*4710–74*	
95	38	1.*4724–39*	
96	48	1.*4723–56*	1.*4675–82*
97	44	1.*4715–36*	1.4679
98	79		1.*4678–85*
99	95	1.*4731–43*	
100	50	1.4751	
101	73	1.4756	
102	59	1.4769	1.*4679–91*
103	84	1.*4679–724*	1.*4659–713*
104	164		1.*4672–701*
105	80		1.4685
105.5	56.5		1.4688
106	69	1.*4739–42*	1.*4679–98*
107	34	1.4743	
108	62		1.*4659–721*

* U. S. A. Standard. † U. S. A. limits.

Finding No.	General index No.	n_D^{25}	n_D^{40}
109	92	1.*4742–62*	1.*4685–702*
110	27	1.4771	1.*4659–730*
111	54, 56	1.*4760–90*	1.4696
112	85		1.*4665–729*
113	65	1.4770	1.*4690–710*
114	32		1.4701
115	37		1.4710
116	74		1.4710
117	137		1.4710
118	91	1.*4758–83*	1.*4702–35*
119	94.5	1.*4701–852*	
121	93	1.4825	1.*4685–770*
122	42	1.*4775–91*	1.*4721–39*
123	83	1.4787	1.*4731–6*
124	126	1.4783	1.4735
125	68.5		1.474
126	58		1.*4740–5*
127	67	1.*4807–15**	1.*4739–48*
128	67	1.*4797–802*†	
130	49	1.*4777–9*	1.*4720–74*
131	143	1.4770	1.*4723–72*
132	113		1.*4737–60*
133	71		1.4753
134	86	1.*4763–852*	
135	82	1.4818	1.*4768–72*
137	45.3	1.474	
138	45.5	1.475	
140	42.2	1.4750	
141	167		1.*4784–822*
142	42.2	1.4778	
143	41.5	1.4780	
144	42.4	1.4780	
145	42.3	1.4786	
146	78		1.4861
147	81	1.4857	
148	60	1.4953	
149	52, 53, 55	1.*515–20*‡	1.*5080–128*
150	70	1.*5099–186*	

* Russian.
† American.
‡ Am. Soc. Testing Materials limits.

16*C*. OPTICAL DISPERSION

$$\omega = \frac{n_F - n_C}{n_D - 1}$$

Fryer and Weston ([67]) at 40°

General index No.	n_D	$n_F - n_C$	$1/\omega$
1	1.46439	0.00910	51.0
3	1.46431	0.00878	52.9
8	1.46184	0.00862	53.6
13	1.46403	0.00890	52.1
20	1.46770	0.00936	50.0
27	1.47194	0.00897	52.7
41	1.46535	0.00910	51.1
47	1.46650	0.00908	51.3
51	1.46711	0.00938	49.8
52	1.51256	0.01904	26.9
58	1.47404	0.00980	48.4
61	1.46968	0.00935	50.2
62	1.47211	0.00973	48.5
65	1.47054	0.00985	47.8
67	1.47379	0.01032	45.8

16*C*. Optical Dispersion.—(*Continued*)

General index No.	n_D	$n_F - n_C$	$1/\omega$
69	1.46984	0.00978	48.0
71	1.47527	0.00984	48.3
83	1.47361	0.00979	48.4
84	1.46630	0.00918	50.8
92	1.47018	0.00918	50.8
93	1.46849	0.00955	49.0
117	1.44924	0.00751	59.8
120	1.45034	0.00812	55.4
147	1.45724	0.00853	53.6
150	1.45928	0.00851	53.8
161	1.45427	0.00830	54.7
163	1.45814	0.00864	53.0
172	1.44066*	0.00740	59.5
	Szalagyi (177) at 45°		
3	1.46444	0.00949	48.9
8	1.46040	0.00877	52.5
20	1.46553	0.00933	49.9
27	1.47027	0.00904	52.0
41	1.46394	0.00917	48.7
47	1.46398	0.00917	50.6
58	1.46889	0.00962	48.7
67	1.47224	0.01018	45.1
91	1.46984	0.00988	47.5
117	1.44746	0.00739	60.5
150	1.45716	0.00818	55.9
150	1.45753	0.00882	51.9
161	1.45213	0.00830	54.4
161	1.45296	0.00784	57.6

* At 56°.

(93) describes a method based on the inversion of the spectrum colors shown by tung oil.

17. OPTICAL ROTATION OF OILS

Values expressed in reading on Laurent's saccharimeter (200 mm at 20°) unless otherwise stated (148)

General index No.	Oil or fat	Optical rotation
69	Poppy oil	0.0
3	Arachis oil	−0.1 to −0.4
14	Apricot kernel oil	−0.2
65	Walnut oil	−0.3
13	Almond oil	−0.7
20	Rape oil	−1.6 to −2.1
82	Stillingia oil	−18.6
8	Olive oil	+0.2 to +0.6
47	Sesame oil	+0.8 to +2.4
27	Castor oil	+7.6 to +9
37	Croton oil	+14.5 to +16.4
42	Hydnocarpus oil α_D^{20}	+49.50 to +51.5
49	Chaulmoogra oil α_D^{20}	+50.8 to +58.2

PROPERTY-SUBSTANCE TABLES

The bold-faced numbers are intervals on the scale of property values. The other numbers are General Index Numbers in the order of the value of the property.

18. DENSITY

Oils.—15/15: **0.861**: 163, 162, 6, 88, 94.5. **0.91**: 88, and all others except 60. **0.95**: 49, 27, 60, 42.2. **0.97.**

Fats.—100/15.5: **0.852**: 148, 138, 141, 149, 125, 116, 119, 147, 131, 108, 115, 109, 111, 99, 130, 146, 117. **0.86**: 141, 146, 117, and all others except 155. **0.90**: 155. **0.91.**

Waxes.—100/15.5: **0.805**: 172, 171, 169, 167, 164. **0.85.**

19. MELTING POINT

Fats.—**4°**: 141. **10°**: 141, 130, 114, 156, 96. **20°**: 130, 114, 156, 117, 145, 101, 103, 105, 120, 96. **25°**: 114, 156, 117, 145, 105, 120, 109, 102, 140, 147, 119, 133, 153, 125, 107, 161, 100, 118, 116, 124, 150. **30°**: 156, 109, 147, 119, 153, 125, 107, 161, 116, 124, 150, 121, 148, 142, 126, 110, 157. **35°**: 156, 119, 161, 116, 150, 126, 157, 158, 131, 146, 113, 111, 149, 137, 97, 132, 136, 167, 138. **40°**: 119, 150, 158, 146, 111, 149, 132, 136, 167, 138, 98, 135, 123, 159, 106, 172, 151, 160. **45°**: 150, 158, 146, 136, 135, 159, 172, 151, 152, 155, 144. **50°**: 136, 159, 155, 144. **60°**: 169, 170, 168, 165. **70°**: 166. **80°**: 171, 164. **90°**: 166, 164.

20. CONGELATION TEMPERATURE

Oils.—**−30°**: 66, 59, 51, 80, 65, 79, 58, 73, 67, 77, 13. **−20°**: 51, 65, 58, 77, 13, 81, 54, 66, 59, 51, 80, 65, 79, 58, 73, 67, 77, 13, 81, 54, 52, 53, 15, 74, 14, 1, 45, 34, 69, 5, 27, 37, 28, 75, 40, 25, 68, 62, 24, 88, 38. **−15°**: 51, 65, 77, 13, 14, 45, 27, 37, 28, 48, 23, 43, 41, 61, 64, 17. **−10°**: 37, 39, 12, 16, 10, 46, 20, 21, 3, 36, 8. **−5°**: 20, 3, 8, 47, 83, 99, 91, 84, 29, 31, 30, 92, 82. **0°**: 41, 99, 29, 31, 53, 30, 7, 95, 33, 26, 6. **5°**: 41, 31, 30, 4, 45.3. **10°**: 41, 30, 4, 11, 42.4, 42.5. **20°**: 30, 42.3, 42.2, 42.1, 41.5. **75°.**

21. ACETYL VALUE

0: 91, 161, 117, 172, 150, 147, 3. **3**: 3, 5, 163, 13. **5**: 163, 13, 51, 116, 26, 120, 58, 31, 159, 54. **10**: 51, 26, 54, 8, 65, 125, 84, 44, 69, 160, 36, 20, 41, 28. **15**: 26, 84, 37.5, 44, 41, 169, 92, 119, 59, 153, 28, 144, 37. **20**: 26, 84, 44, 41, 144, 68, 141, 63, 82, 28. **30**: 141, 37, 28, 113. **40**: 28, 2. **50**: 164. **55. 149**: 27. **150.**

22. IODINE VALUE

Oils.—**50**: 11, 30, 31, 4. **60**: 30, 31, 4, 29, 42.5. **70**: 31, 29, 16.5, 6, 5.5, 39, 2, 8, 45.3. **80**: 16.5, 39, 8, 42.1, 18, 12, 27, 42, 5, 9, 3, 42.2. **90**: 42.3, 39, 42, 3, 33, 17, 1, 13, 24, 20, 41.5, 28, 10, 22, 49, 113,[1] 40, 42.4, 26, 88, 25. **100**: 33, 13, 20, 28, 22, 49, 40, 26, 25, 16, 46, 14, 73–80, 19, 35.5, 41, 47, 36, 44, 37, 7, 21. **110**: 28, 49, 40, 73–80, 41, 47, 44, 7, 21, 35, 15, 51, 93, 84. **120**: 44, 21, 51, 93, 84, 57, 87, 45, 38, 48, 59, 61, 37.5, 89, 62, 81. **130**: 93, 48, 59, 61, 56.5, 62, 63, 34, 72, 68, 91, 56, 65. **140**: 59, 34, 72, 68, 82, 91, 56, 65, 58, 83, 82, 55, 70. **150**: 34, 52, 91, 58, 83, 52, 53, 55, 70, 74, 82. **160**: 53, 55, 91, 58, 83, 54. **170**: 83, 86, 67, 60, 68.5. **180**: 83, 86, 67, 71. **190**: 86, 67, 71. **200**: 67, 71. **205**: 71. **260**: 92. **344.**

Fats and Waxes.—**4**: 135, 167, 144, 172, 103, 168–170, 117, 138. **10**: 167, 144, 168–170, 120, 101, 129, 100, 118, 133, 164, 102, 166, 96, 167, 140, 161. **20**: 96, 167, 137, 127, 146, 155, 161, 122, 132. **30**: 167, 137, 146, 155, 161, 122, 132, 125, 147, 123, 159, 151, 148, 98. **40**: 167, 137, 146, 161, 147, 159, 151, 98, 104, 131, 142, 100, 150, 152, 145, 109, 116. **50**: 167, 137, 150, 152, 145, 160, 105, 111, 110, 115, 99, 108, 153. **60**: 150, 152, 105, 111, 99, 108, 153, 106, 107, 128, 157, 126, 158, 130. **70**: 99, 157, 126, 158, 130, 134, 156, 96, 139, 121, 97. **80**: 158, 156, 121, 124. **90**: 158, 124, 113, 139.5. **100.**

23. SAPONIFICATION VALUE

50: 165, 166, 164, 167, 168, 169, 170. **100**: 167, 168, 170, 163, 162, 172. **150**: 136, 93, 84, 20, 94, 85, 72, 91, 24, 28, 19, 25, 6, 23, 27, 21, 90, 146, 143, 111. **180**: 84, 85, 91, 28, 19, 27, 21, 90, 143, 111, 146, 43, 108, 76, 16.7, 130, 9, 141, 50, 13, 66, 134, 7, 8, 137, 142, 51, 3, 88, 60, 123, 98, 44, 92, 34, 36, 148, 68, 106, 104, 38, 47, 62, 71, 4, 67, 86, 59, 96, 61, 87, 107, 149, 48, 83, 39, 54, 49. **190**: 84, 85, 28, 146, 130, 13, 8, 42.3, 68.5, 137, 142, 51, 139.5, 3, 123, 98, 44, 42.5, 92, 68, 104, 38, 47, 62, 71, 4, 67, 86, 59, 61, 87, 107, 149, 37.5, 48, 83, 39, 54, 49, 35, 80, 32, 99, 64, 17, 95, 81, 58, 160, 65, 63, 12, 78, 75, 18, 1, 16, 79, 153, 40, 5, 14, 73, 74, 125, 139, 110, 10, 26, 33, 57, 45, 69, 147, 15, 70, 29, 159, 30, 31, 105, 114, 157, 37, 113, 41, 52, 53, 55, 2. **195**: 84, 13, 8, 137, 142, 92, 86, 59, 49, 160, 65, 63, 40, 5, 14, 10, 26, 70, 29, 159, 30, 31, 105, 114, 157, 37, 41, 52, 53, 55, 2, 109, 152, 155, 156, 150, 112, 151, 115, 121, 126, 46, 116, 158, 131, 119, 56, 89, 135, 42, 144, 82, 42, 45.3, 41.5, 42.2,

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[1] *v.* Table 3.

42.4. **210:** 37, 131, 135, 144, 161, 11, 145, 138, 100, 122, 154, 96, 100. **240:** 96, 100, 132, 133, 190, 97, 102. **250:** 89, 96, 133, 190, 118, 117, 101, 128, 103. **260:** 117, 140, 127, 89. **280:** 129, 85 **290.**

24. HEHNER VALUE

65: 88, 89. **82:** 97, 117, 127, 128, 129, 140, 161, 93, 17. **90:** 117, 93, 17, 120, 16.7, 144, 145. **92:** 3.5, 4, 16.6, 18, 28, 48, 51, 65, 66, 74, 77, 79, 84, 88, 95, 106, 108, 109, 111, 113, 119, 131, 132, 135, 138, 141, 142, 147, 149, 150, 153, 157, 160, 81, 87. **95:** 93, 119, 141, and all others for which data are available. **96:** 0.5, 12, 93, 119, 141, 86, 151. **97:** 29, 81, 87, 156, 158.

25. REICHERT-MEISSL VALUES

General index No.	Reichert-Meissl value	General index No.	Reichert-Meissl value
57	0.0	65	0.92
59	0 –1.2	31	0.9 –1.2
20	0 –0.79	119	0.9 –1.9
17	0.1	41	0.95
114	0.1	82	0.93–0.99
44	0.1 –1.3	67	0.95
123	0.11–1.54	5	0.99
91, 92	0.2	143	1
14	0.2	106	1 –2
124	0.22	131	1 –4
132	0.2 –0.4	42	1.02
43	0.2 –0.4	53	1.1
149	0.2 –0.4	125	1.1
153	0.2 –0.8	47	1.1 –1.2
146	0.2 –0.9	108	1.1 –2.5
160	0.2 –1.7	136	1.1 –4.2
26	0.28–0.48	54	1.2
142	0.3	83	1.2
147	0.3 –1.0	111	1.25–1.4
110	0.33	127	1.39
37.5	0.33	27	1.4
19	0.33–0.89	66	1.5
55	0.35	126	1.6
113	0.38	157	1.8
52	0.39	74	2.0
3	0.4	129	2.0
90	0.4 –0.7	50	2 –3
104	0.4 –1.31	4	2.5 –3.3
69	0.4 –3.0	128	2.53
105	0.44–0.88	133	3.0
28	0.46	95	3.4
7, 13	0.5	100	3.8
62, 138	0.5	51	4.2 –9.9
112	0.5	140	4.5
48	0.5 –2.8	38	4.45
86	0.5 –1	120	5 –6.8
159	0.5 –1	88	5.6
36	0.55	96	5.7 –7.2
2, 69	0.6	102	5.8
141	0.6	103	6.3
107	0.6 –0.5	117	6.6 –7.5
8	0.6 –1.8	101	8
116	0.65	134	8.27
155	0.68	145	9
158	0.7 –2.8	84	14
23	0.75	161	17.0–34.5
22	0.75	154	20.8–27.7
81	0.75	89 (Body)	64.9
130	0.8 –0.9	88 (Jaw)	65.9
11	0.88	89 (Jaw)	132

26. UNSAPONIFIABLE MATTER

General index No.	%	General index No.	%
31	0.12–0.65	84	1 –4
115	0.19	139	1.1
134	0.25	144	1.1 –1.6
92	0.3 –1.0	57	1.14
103	0.36	51	1.25–1.60
52	0.41	48	1.27–1.54
8	0.4 –1.0	74	1.3
67	0.4 –1.2	68.5	1.3
69	0.43	32	1.30–2.65
5	0.5	104	1.36
54	0.5 –0.9	82	1.45
107	0.5	139.5	1.6
3	0.5 –0.9	88	2
87	0.5 –3.0	50	2.4 –2.6
125	0.5	95	2.61
62	0.51	10	3
155	0.52	25	3.3
91	0.54–2.68	108	3.86
53	0.59	93	2.8 –15.2
29	0.6	111	5 –9
83	0.6 –1.45	133	7.0
90	0.7 –7.0	94	8.4
13	0.75	89	16 –17
100	0.75	137	20.4
86	0.98	162	36 –41
55	0.99	167	39 –44
85	1 –2	166	47
58	1.08	172	51.5
37.5	1.1	164	54 –55
41	1.1	94.5	1 –90

27. MELTING AND SOLIDIFICATION POINTS OF FATTY ACIDS

General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C	General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C
71	–5		51	17 –22	19
64	0		45.3	18	
75	0		20	18.5–20	11.7–13.6
77	0		18	19	10
14	2.3– 4.5		76	19	
162	10.3–10.8	8.3– 8.6	15	19 –21	13 –15
128		9 –10	23	20	13 –15
59	11 –17	7 –12	21		13.5–16.5
163	13.4		63		15 –20
13	13 –14	9.5–11.8	69	20.5	17 –19
34	13 –14		56		17.6
16	13.4–18		67	20 –24	16 –21
84	14 –27	10 –24	96	20.5–21	
82	14.5		60	21.5 (begins) 65.0 (complete)	
127		13			
65	15 –20	14.3			
25	16 –17	13.4–13.7			
43	16 –18		37		17 –19
78	16 –19	10 –16	45	21.7	22 –26
79		10 –15	93	21 –22	
58	17 –21	15.6–16.6	91	21.8–38	17.5–24.3
12	17 –20		5	22 –25	19 –20

27. MELTING AND SOLIDIFICATION POINTS OF FATTY ACIDS.—(*Continued*)

General index No.	Melting point, fatty acids, °C	Solidification point, fatty acids, "titer" test, °C
92	22–23	
62	22–24	18–19.8
66	22.2	
57	22.8	
46	23	
28	23–25	
40	23–24	
36		19.7–21.0
68	23–26	20–24
103	23.6	
26	24–30	
133	24.2	
117	24–27	21.2–25.2
120	25–28.5	20–25.5
61	25.4	22.6
94.5	25–35	
47	25–35	23–32
8	26–30	16.9–26.4
48	26.2–27.5	
100	27	
140	27–28	
101	27–28	
124	27–45	39.9–51
32	27.5	
33	28–30	31.1–32.2
31	29–41	16–26.5
81	30–40	
27	30	
85	30–32	
38		26–28
113		28–29
86	30–34.8	28.2
3		30.5–39
52	30–49.4	36–39
90	31	
97	31	
156	31.3–53.4	
112	33–34	
29	33–38.4	
152	33.5–49	40–48.5
41	34.5	
132	35	
87	35–36	27.5–28.2
99	35–38	
153	36.6–40	31–34
95	36.5	27–28
150	37–46.6	36–42.4
6	37.6	
39	38	
4	38.8	
157	38–40	32–34
161	38–41	33–39
50	39–40	
30		35–37
158	39–50	35–41
146	39–57	45.2–47.2 50.9–52.5
105	39–45	38–40
42.4	40	
106		38–41
114	40–42	37–40
42.2	41	
167	41.8	
109	42–46	38–40
130	42–49	
151	42.5–44	37.9–46.2
138	42.5–46	
42.1	43	
42.5	43	
143	44–45	36–42
42	46	
137		37.2
160		42.5–44
159		40–50
42.3	47	
135	47–48	
116	48.3–50	46–47
147	48–53	47.2–49.2
108	49–52.8	47
119	50	42.5–45.5
141	50–57	
155	50–64	46–50
131	51–55	48–52
148		48.1
111	52–53	
145	52–55	49.7–50.7
144	53–56.5	
41.5	55	
125	56	
107	56	
149	56–57	
142	57–60	
104	58.4	
98	59	61.4–61.5
123	60–61	

HYDROGENATED OILS

Hydrogenation reduces the iodine value, and refractive index, (56) but has little influence upon the acid value, saponification value and unsaponifiable matter.

In oils, such as castor oil, containing hydroxyl groups, the hydroxyl value is lowered (143). The amount of insoluble bromides is reduced. The stearic acid formed on hydrogenation is identical with normal stearic acid (120).

A method of differentiating hydrogenated and natural oils has been based on the ratio between the amounts of stearic acid and palmitic acid (135). Hydrogenated oil may be recognized by a determination of the iso-oleic acid formed in the process (208).

PARTLY HYDROGENATED OILS (218)

General index No.	Oil	M. P., °C	Congelation point, °C	Butyrorefractometer reading (40°)	Acid value	Saponification value	Iodine value
117	Coconut	44.5	27.7	35.9	0.4	254.1	1.0
47	Sesame (techn.)	62.1	45.3	38.4	4.7	188.9	25.4
84	Whale	45.1	33.9	49.1	1.2	192.3	45.2
3	Arachis	51.2	36.5	50.1	1.0	188.7	47.4
47	Sesame	47.8	33.4	51.5	0.5	190.6	54.8
41	Cottonseed	38.5	25.4	53.8	0.6	195.7	69.7

WHALE OIL (GEN. IND. NO. 84) AT DIFFERENT STAGES OF HYDROGENATION (219)

	M. P., °C	Congelation point, °C	Acid value	Saponification value	Iodine value	Molecular equivalence of fatty acids
Original oil	Fluid	Fluid	9.50	192.2	144.8	287.7
Artificial tallow	47.5	38.1	9.88	183.7	56.9	296.4
Artificial stearine	54.3	47.3	7.80	187.7	11.7	297.0
Hydrogenated whale oil	41.9	31.9	5.30	190.9	57.8	282.9

COMPLETELY HYDROGENATED OILS (220)

General index No.	Hydrogenated oil or fat	M. P., °C	Iodine value	Saponification value	Fatty acid, M. P., °C
159	Tallow	62	0.1	197.7	64
150	Lard	64	1.0	196.8	62
147	Cacao butter	63.5–64	0.0	193.9	65.5
3	Arachis	64–64.5	0.0	191.6	67
91	Cod liver	65	1.2	186.2	59
67	Linseed	68	0.2	189.6	70.5
47	Sesame	68.5	0.7	190.6	69.5
8	Olive	70	0.2	190.9	71
69	Poppy	70.5	0.3	191.3	71
13	Almond	72	0.0	191.8	71

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ADHESIVES AND GELATINS

JEROME ALEXANDER

INTRODUCTION

Most practical adhesives are mixtures of several ingredients, with or without some kind of salt, and may be classified as:

(*A*) Animal adhesives: *e.g.*, glues, gelatins, casein, albumin;

(*B*) Vegetable adhesives: *e.g.*, flours, starches, dextrins, gums, gum resins, oils, and proteins;

(*C*) Mineral adhesives: *e.g.*, silicate of soda, cements, limes, plasters, clays, pitches, tars, artificial resins, solders, and such mixtures as iron + sulfur and litharge + glycerin.

In using an adhesive to join two surfaces, the surfaces concerned are the ultimate exterior ones and the adhesive must either take hold of these exterior surfaces or must remove them and take hold on the surface below. Thus, if the articles to be joined are not cleaned, the exterior surface is frequently a layer of grease. Setting and drying are promoted by any agency which increases the concentration of the adhesive; for example, by removing the solvent. Joint strength is influenced by quantity of adhesive used, by speed of set and drying, and by the application of pressure.

Animal Glues

Use.—(1) Keep dry and from excessive heat; (2) use definite weights of glue and water; (3) soak glue in cold water until softened; (4) melt on water bath and keep temperature as low as work permits (usually below 65°C); melt small batches successively to avoid prolonged heating which injures strength; (5) supply evaporation losses; (6) use clean vessels, and, if necessary, a preservative.

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(180) Thomson and Dunlop, *54*, **25**: 272; 06. (181) Tolman, *45*, **1**: 340; 09- (182) Toms, *173*, **49**: 71; 24. (183) Tsujimoto, *43*, **4**: 11; 06. (184) Tsuji, moto, *252*, **15**: 224; 08. (185) Tsujimoto, *43*, **4**: 63; 06. (186) Tsujimoto. *45*, **8**: 889; 16. (187) Tsujimoto, *142*, **21**: 1015; 19. (188) Tsujimoto, *45*, **12**: 63; 20. (189) Tsujimoto and Kimura, *142*, **26**: 1162; 23.

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(220) Mannich and Thiele, *273*, **26**: 36; 16. (221) Person, *34*, **29**: 300; 49. (222) Bell and Poynton, *3*, **49**: 1065; 25. (223) Jamieson and Bailey, *54*, **38**: 781A; 19. *45*, **11**: 850; 19. (224) Hazura, *57*, **9**: 180; 88. **10**: 190; 89. (225) Kurbatoff, *in* (211), p. 596.

ADHESIVES AND GELATINS

JEROME ALEXANDER

INTRODUCTION

Most practical adhesives are mixtures of several ingredients, with or without some kind of salt, and may be classified as:

(*A*) Animal adhesives: *e.g.*, glues, gelatins, casein, albumin;

(*B*) Vegetable adhesives: *e.g.*, flours, starches, dextrins, gums, gum resins, oils, and proteins;

(*C*) Mineral adhesives: *e.g.*, silicate of soda, cements, limes, plasters, clays, pitches, tars, artificial resins, solders, and such mixtures as iron + sulfur and litharge + glycerin.

In using an adhesive to join two surfaces, the surfaces concerned are the ultimate exterior ones and the adhesive must either take hold of these exterior surfaces or must remove them and take hold on the surface below. Thus, if the articles to be joined are not cleaned, the exterior surface is frequently a layer of grease.

Setting and drying are promoted by any agency which increases the concentration of the adhesive; for example, by removing the solvent. Joint strength is influenced by quantity of adhesive used, by speed of set and drying, and by the application of pressure.

Animal Glues

Use.—(1) Keep dry and from excessive heat; (2) use definite weights of glue and water; (3) soak glue in cold water until softened; (4) melt on water bath and keep temperature as low as work permits (usually below 65°C); melt small batches successively to avoid prolonged heating which injures strength; (5) supply evaporation losses; (6) use clean vessels, and, if necessary, a preservative.

SELECTION

Wood Joints.—Hide-stock glues, grades 70–130.[1] Joining pressure before setting increases joint strength rapidly up to 200, and then more slowly up to 1000 lb./in.^{2}. Surfaces must be well joined, dry, and preferably warm. Good joints are stronger than the wood, and may show shearing strength of 2000 to 3000 lb./in.^{2}

Veneers.—Bone and hide stock mixtures between 50 and 70. Avoid foam.

Paper Boxes.—For hand setting-up, 70 to 90 test; for machine, 100 to 160 test. For covering or stripping, 30 to 60 test.

Book Binding.—For rounding and backing, grades above 90 are best (usually mixed with some glycerin). For hand pasting, grades about 50. For case-making machines, grades 60 to 100.

Leather Belting, Printer's Rollers, Plaster Molds.—Hide glues above 120; usually with addition of glycerin, etc.

Gelatins

Photographic Gelatin (1).—Jelly strength, 130 or above. pH, 5–6 (limit 4–7). Ash <3%. Fe and Cu <50–60, Pb <50, parts per million. Al_2O_3 <0.2%, SO_2 <0.1%, of dry gelatin. Mucin, grease, and ammonia$\ngtr$traces. Traces of thiocarbimides are essential(55).

Food Gelatin.—U. S. Dept. of Agriculture, Bureau of Chemistry, tolerance limits (parts per million): As_2O_3, 1.4; Zn, 100; Cu, 30; Pb, 20; SO_2 must be declared on label.

1. ADHESIVES

COMPARISON OF AMERICAN GRADES OF GLUE AND GELATIN (1, 5, 22)

Cooper	Alexander			Bogue	National Assn. Glue Mfrs. (U. S. A.)		
Grade	Grade	S*	η†	Grade	Grade	S‡	η§
	10		15.5 ± 0.25		1	10	20
	20		16 ± 0.25	1	2	27	24
2	30		16.5 ± 0.25	2	3	47	28
1⅞	40	1701	17 ± 0.25	3	4	70	32
1¾	50	2324	18 ± 0.5	4	5	95	37
1⅝	60	2948	19 ± 0.5	5	6	122	42
1½	70	3572	20 ± 0.5	6	7	150	47
1⅜	80	4196	21 ± 0.5	7	8	178	53
1¼	90	4820	22 ± 0.75	8	9	207	60
1 X	100	5443	23 ± 0.75	9	10	237	67
1	110	6067	24 ± 0.75	10	11	267	75
1 Extra	120	6691	25 ± 1	11	12	299	83
A Extra	130	7314	26 ± 3	12	13	331	92
	140		28 ± 5		14	363	102
	150		34 ± 8		15	395	113
	160		40 ± 12		16	428	125
					17	461	138
					18	495	152
					19	530	167
					20	565	183
					21	600	200

* Jelly "strength" in grams, Alexander tester.

† Viscosity in seconds (water = 15).

‡ Lower limit of jelly "strength" in grams, Bloom gelometer.

§ Viscosity in millipoises, lower limit.

SPECIFIC GRAVITY OF GLUE SOLUTIONS (40)

Wt. % glue	d_{75}^{75}	°Bé, 54.4°C	°Bé, 32°C	°Bé, 15.6°C
7	1.001			
8	1.003			
9	1.006			
10	1.009	2.2	3.1	4.0
15	1.023	4.2	5.1	6.0
20	1.037	6.1	7.0	7.9
25	1.051	8.0	9.0	9.8
30	1.065	9.8	10.7	11.6
35	1.079	11.5	12.4	13.3
40	1.093	13.2	14.1	15.0
45	1.107	14.9	15.7	16.5
50	1.121	16.5	17.4	18.3

NITROGEN CONTENT OF GLUES, WT. % (10)

H = hide glue; B = bone glue; F = fish glue; P = protein; I = isinglass

Form	H*	B*	F	P	I
Ammonia	2.9	4.6	5.2	1.3–3.6	4.0
Melanin	0.6	0.9	1.1	0.7	0.7
Cystine	0	0	tr	tr	0
Arginine	13.9	13.2	13.8	11–12.6	14.2
Histidine	2.2	1.8	2.0	0.8–2.2	2.3
Lysine	8.0	8.3	8.6	8.3–8.6	6.1
Amino†	56.8	56.3	60.2	58–60	58.7
Non-amino†	15.6	15.3	9.7	15.5	13.6

* Av. of 6 samples.

† Soluble.

Joint Strength

The strength of joints made with an adhesive depends upon the kind of material joined and the condition of its surface, upon the thickness of the adhesive film, and upon such conditions as temperature, humidity, time of drying, and pressure used in forming the joint.

TENSILE STRENGTH (DEF. 4): OAK TO OAK (32)

Unit: kg/cm^2

Effect of air humidity and temperature

At t°C		15°	20°	25°	25°
Air humidity		50%	75%	90%	95%
Liquid glues	A*	49.6	45.8	35.4	26.4
	B*	45.7	44.1	39.1	29.0
	C†	31.7	31.3	31.1	30.3
	D†	42.7	41.2	39.4	37.7

* Very hygroscopic.

† Slightly hygroscopic.

TENSILE (TS) AND SHEARING (SS) STRENGTH OF METAL TO METAL JOINTS (21)

A = High grade commercial gelatin. B = Silicate of soda. C = Commercial nitrocellulose cement "A." D = Molten shellac (pure). E = American commercial cement (hard). F = American commercial cement (medium). G = A wax. H = Fish glue. I = Liquid commercial glue "C." J = Rubber solution. K = Marine glue. L = Commercial glue "B." M = Gum arabic. T = Drying or setting time in days. Stl. = Mild steel. Fe = cast iron. Bra. = Brass. Unit: kg/cm^2.

Adhesive	Days	Metal	Ni	Stl.	Fe	Cu	Bra.	Al	Sn	Pb
A	17	TS	63	70	77	84	49	(21)	56	56
	20	SS		70	49	56	77		35	
B	20	TS	35	49†	49	56‡	70	49	35	21
C*	14–21	TS	112	112	98	140	105	119	70	35
	21	SS		49	56	35	35	56	42	28

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[1] The "grades" here referred to are the Alexander grades listed in Table 1.

TENSILE (TS) AND SHEARING (SS) STRENGTH OF METAL TO METAL JOINTS (21).—(*Continued*)

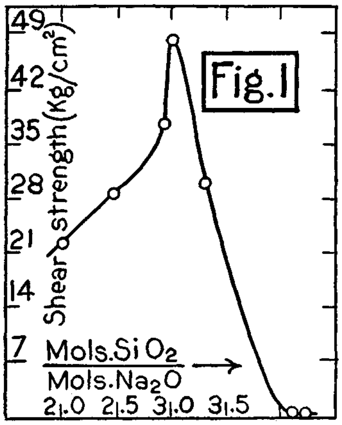
Adhesive	Days	Metal	Ni	Stl.	Fe	Cu	Bra.	Al	Sn	Pb
D	1–5	TS	246	225	211	232	176	197	77	42
	1–3	SS		239	211	232	232	155		
E	1–2	TS	295	337	309	281	204	162	105	35
	1–3	SS		295	288	288	267	218	77	42
F	1	TS				309		169		
	1	SS		260	225	239	246	147		
G	1–2	TS	84	70	98	70	77	70	56	35
	1	SS	35			35	42	42	42	35
H	16	TS	84	56	84	98	49	70		
	16	SS	35	98	84	77	98	(14)		
I§	18	TS				21		28	28	
	18	SS		35	28	35	21	21		
J	16	TS			21					
K	4–5	TS	77	120	63		105	98	56	
	4–5	SS	42	84	56	42		63	63	
L	77	TS	88	133	112	112	140	70	77	
	77	SS	88	112	106	105	84	91		
M	77	TS	84	63	77	112	112	49	56	
	77	SS	(98)	88	70	(112)	56	105	56	

* TS = 28 with amalgamated Cu and 77 with platinized Cu.

† When rough = 21, oxidized = 35.

‡ Amalgamated Cu.

§ TS = 28 with platinized Cu.



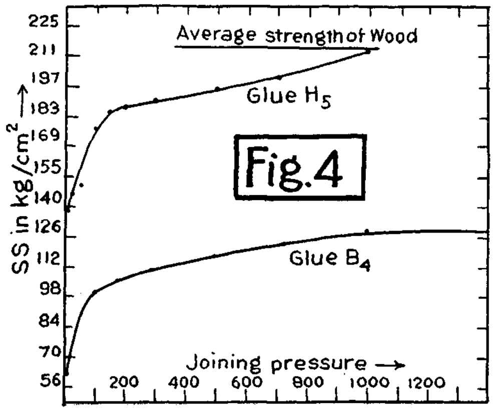


FIG. 1.—Shearing strength of water-glass joints between walnut surfaces (21).

FIG. 4.—Effect of joining pressure (11). Shearing strength of wood to wood joints with a hide glue H_5 and a bone glue B_4.

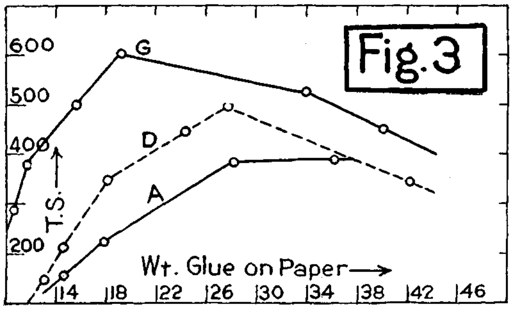


FIG. 3.—Effect of film thickness (2). TS = tearing strength, in kg/cm², of glue.

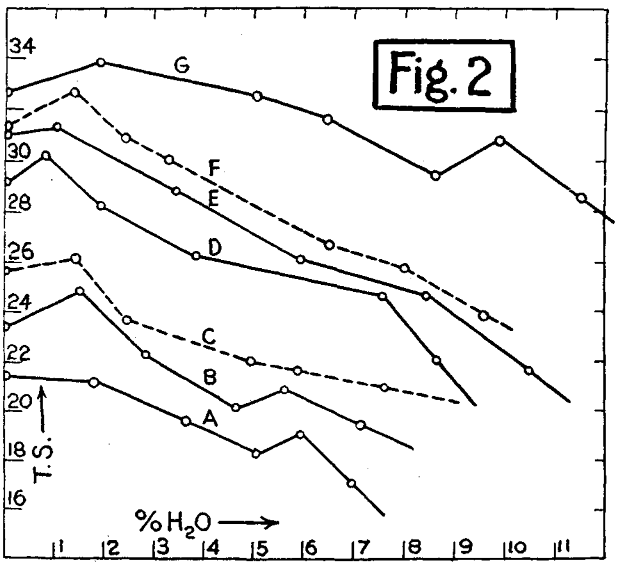


FIG. 2.—Effect of moisture content on joint strength (2). A, B = bone glues. C, D, E, F = hide glues. G = gelatin.

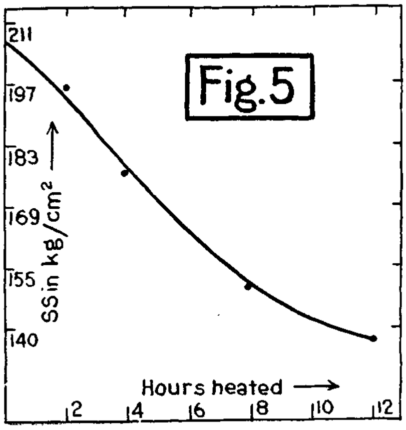


FIG. 5.—Effect of heat (11). Shearing strength of wood-to-wood joints made under constant joining pressure of 14 kg/cm² using a glue heated to 80°C.

SHEARING STRENGTH, WALNUT TO WALNUT (21)
Unit: kg/cm²

Adhesive	Days dried	kg/cm²
Fish glue	7	98
Liquid commercial glue "C"	7	84
High grade gelatin	6	84*
Fish glue + bone gelatin	7	49
Casein + borax cement	6	42
Gum arabic	6	28
Commercial glue "B"	12	28
Casein and silicate cement	8	21
Commercial nitrocellulose cement "A"	30	21
Starch	9	21†

* Reduced to about 30 if the joint be heated to 100° for 4 days while clamped.

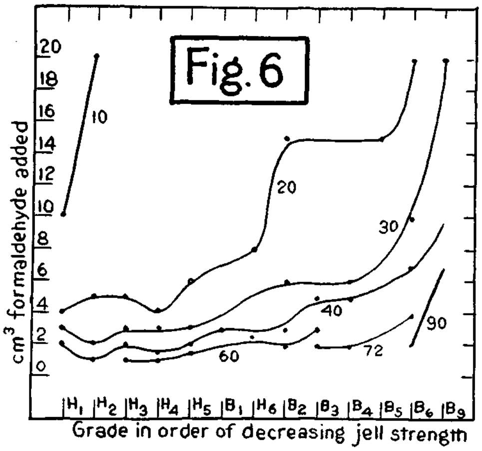
† Film not complete. Three coatings raise value to 112; values have been measured as high as 600. Additional data are given in Figs. 1–5.

TENSILE STRENGTH OF SOME COMMON ADHESIVES
Unit: kg/cm²

Glue (calculated)	700–2000
Collagen	1300
Gelatin	960
Viscose	2100

Jelly Strength

The jelly strength of a glue is usually measured by the force required to cause a definite compression of the jelly. The addition of formaldehyde to glues decreases the jelly strength in direct proportion to the amount of HCHO added, until the glue becomes insoluble. Figure 6 shows the number of cm³ of 10% HCHO required to produce insolubility in various glues, the numbers on the curve giving the grams of glue to 180 g total weight of solution (⁷).



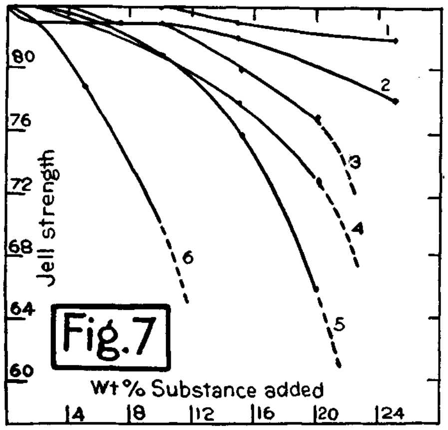


Figure 7 shows the effect of added substances upon the jelly strength. 1 H_2SO_4; 2 NaOH; 3 $MgCl_2$; 4 Acetic acid; 5 Chloral hydrate; 6 KI. 1 and 2 in cm³ of 0.5*N* soln. added instead of wt. % (⁷).

The relation between the nitrogenous constituents and the jelly strengths of hide (H) and bone (B) glues is shown in Figs. 8 and 9 (⁹).

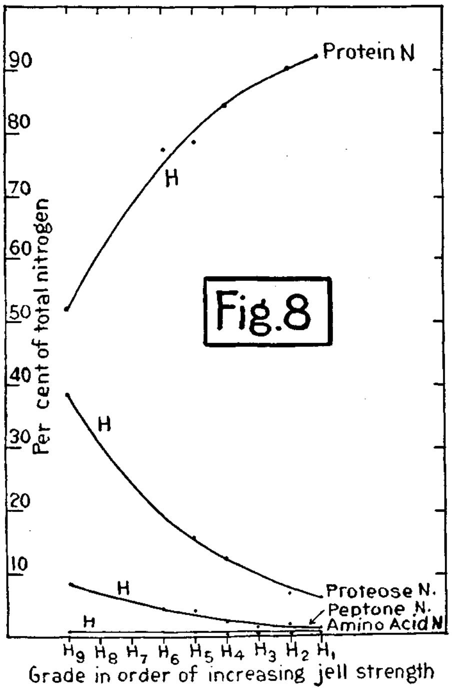
Viscosity; η

The viscosity of 20% solutions of hide and bone glues at 15.5°C (60°F) is constant for at least 90 minutes after preparation. Vigorous agitation lowers η slightly (2% after 2 minutes beating) (⁷).

The increase in η produced in dilute solutions of glues by formaldehyde is slight, but rises rapidly with increasing glue content. Agitation increases η of HCHO treated glues slightly and after drying such glues exhibit increased η on re-solution or become insoluble with increasing HCHO content (⁷).

The amount of protein precipitated by 24–30% $MgSO_4$ solution from liquid glue varies directly as η for glue solutions having the same jelly strength (⁹).

The amount of material absorbable from glue solutions decreases as η decreases (³⁴).



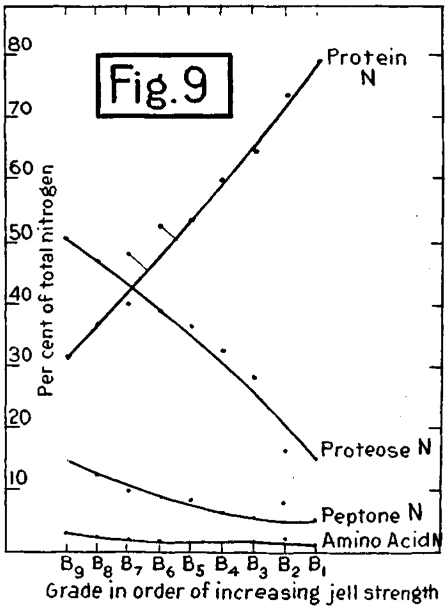


Figure 10 shows the effect of time on η (in seconds, H_2O = 42) of HCHO treated glues and Fig. 11 the effect of temperature. (Numbers on curve = cm³; 10% HCHO added.) (⁷).

Figure 12 shows the effect of alums on η of glue solutions; Fig. 13 the effect of time, and Fig. 14 the effect of temperature on the η of alum-treated glues (⁷).

Figure 15 shows the variation of η (in seconds, H_2O = 42) of glue solutions with temperature, the melting point of the glue solution being taken as temperature at which the slope of the curve approaches infinity (⁸).

Figure 16 shows the effect of temperature on the η of hide glues, and Fig. 17 on the η of bone glues (η in MacMichael degrees) (8).

Figure 18 shows the relation of η to jelly strength of hide glues (11).

The flow of starch pastes, under pressure, through a capillary tube is shown in Fig. 19 and of dextrin pastes in Fig. 20. The numbers on the curves give the wt. % of dry solids in the pastes (16).

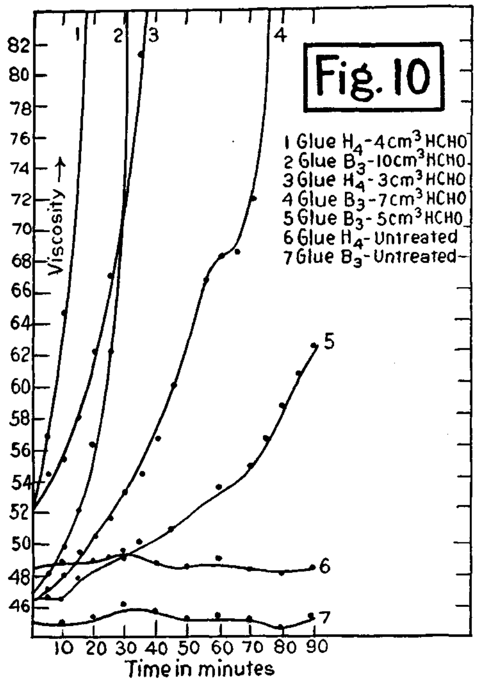


Fig. 10

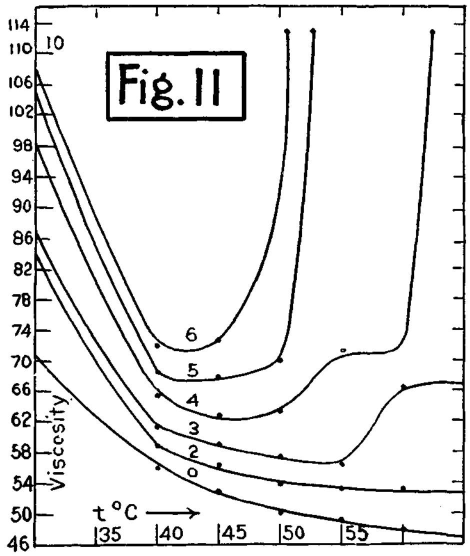


Fig. 11

The η of 10% hide and glue solutions, measured at 35°C, is decreased considerably by heating under pressure up to 5 atm. for 1 to 5 hr. (23).

Addition of anhydrous chrome alum in small percentages has little or no effect on the η of glue solutions (33).

Gelling point

The gelling point of a glue is the temperature at which appreciable flow under the action of gravity ceases.

Chrome alum (anhydrous salt = 0.8% wt. of dry glue) raises the setting or gelling point *ca.* 2°C with 20% glue solutions and *ca.* 10° with 50% glue solutions. The gelling points (in °F on curves) of glue solutions as affected by addition of chrome alum are shown in Fig. 21 (33).

Drying Behavior

High grade liquid glues lose water much more slowly than low grade glues when dried at room temperatures (2).

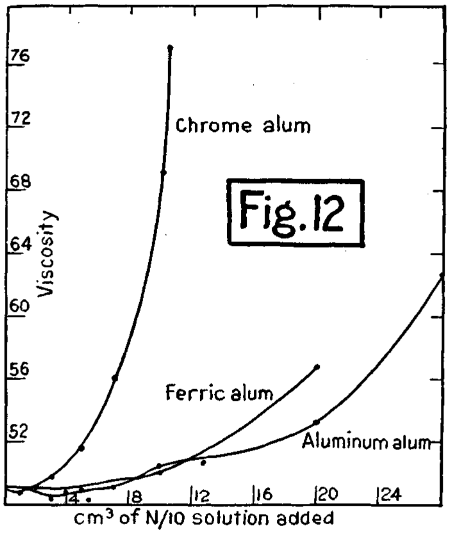


Fig. 12

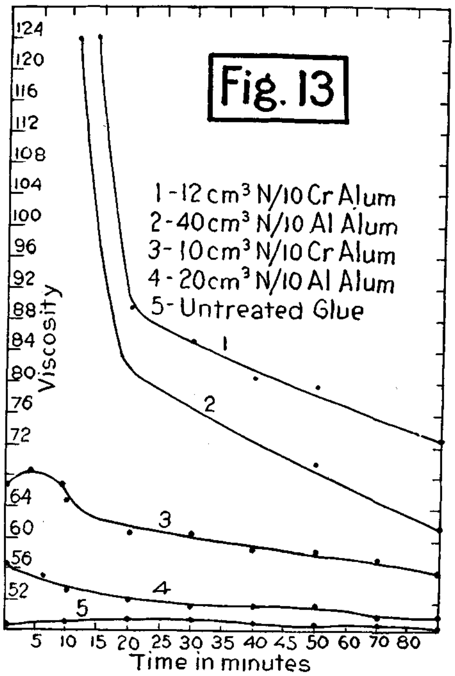


Fig. 13

2. GELATINS

Jelly Strength

Alcohol up to *ca.* 25 vol. % tends to increase the rigidity of 10% gelatin gels; larger amounts cause a decrease. Acetone acts similarly (20).

According to Bogue (15) the maximum jelly strength occurs at pH = *ca.* 4, and minimum at pH = *ca.* 5, near the isoelectric point. Sheppard and Sweet (27) find the maximum at the isoelectric point, pH = 4.7, with a minimum at pH = *ca.* 5.5 and a second maximum at pH = 7.8.

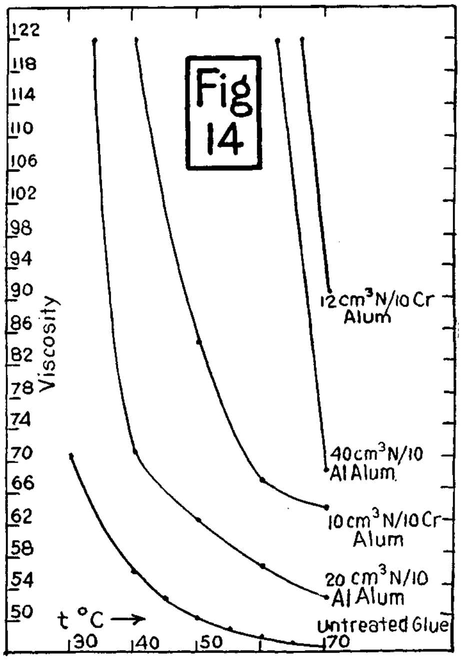


Fig 14

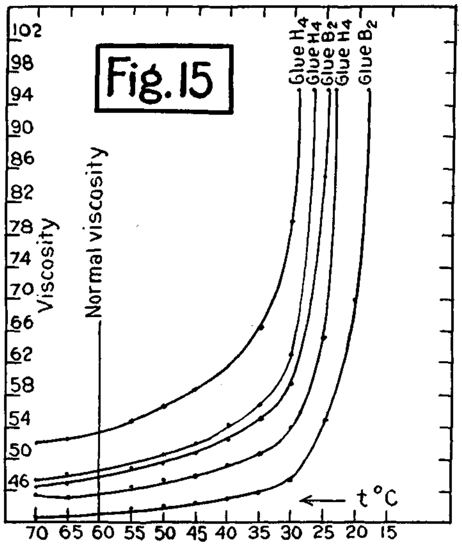


Fig. 15

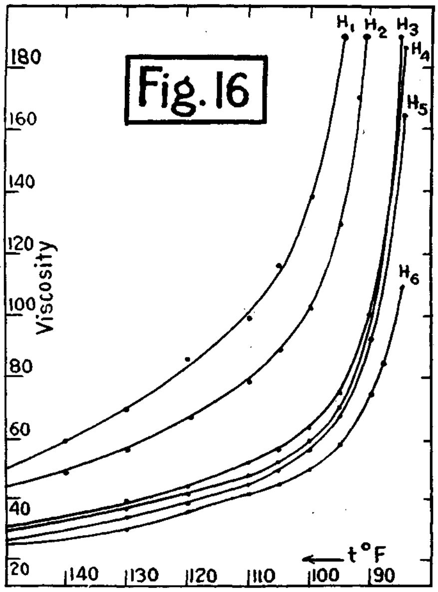


Fig. 16

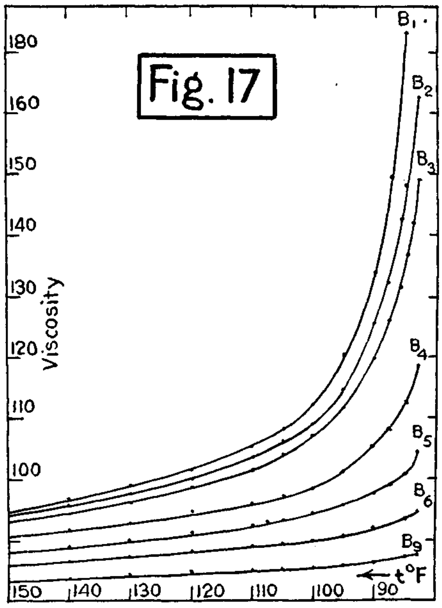


Fig. 17

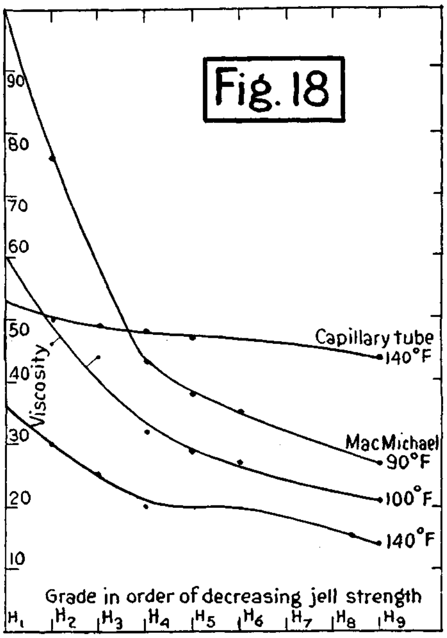


Fig. 18

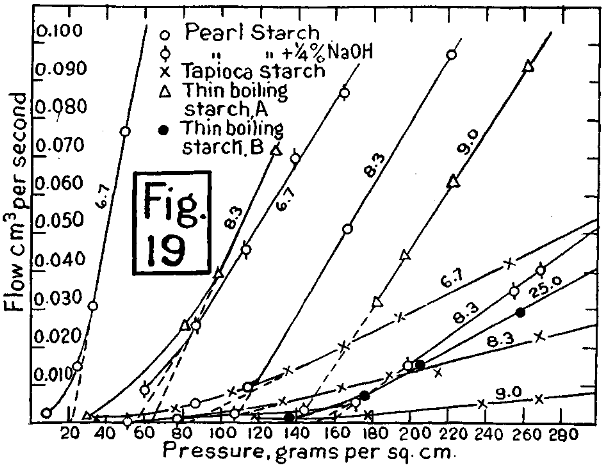


Fig. 19

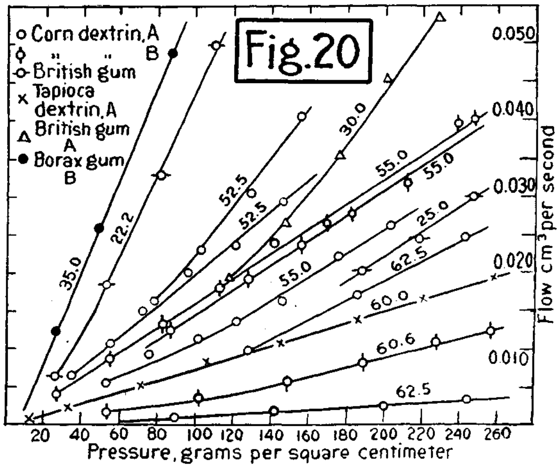


Fig. 20

Figure 22 shows the influence of traces of Al salts on the rigidity of a 7% gelatin jelly (28).

For the effect of sulfuric, phosphoric and lactic acids on jelly strength, *see* (4).

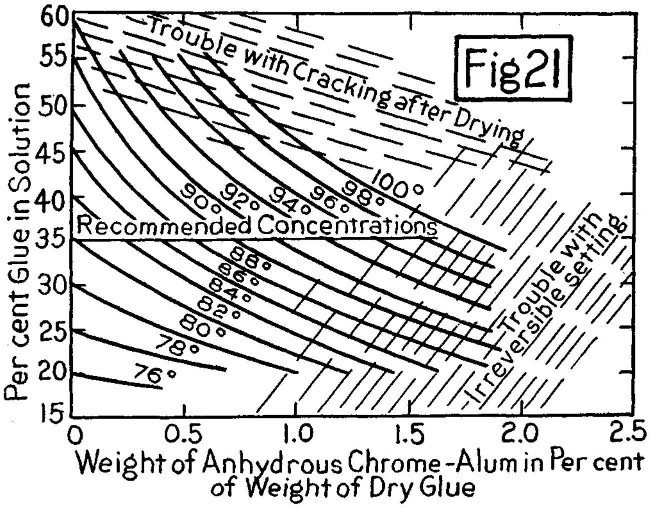


Fig 21

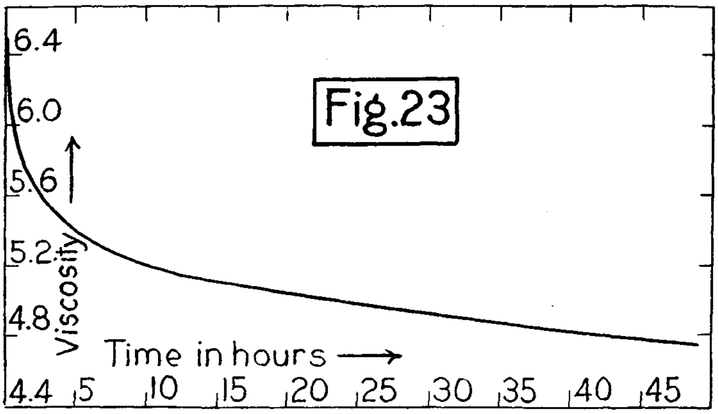


Fig.23

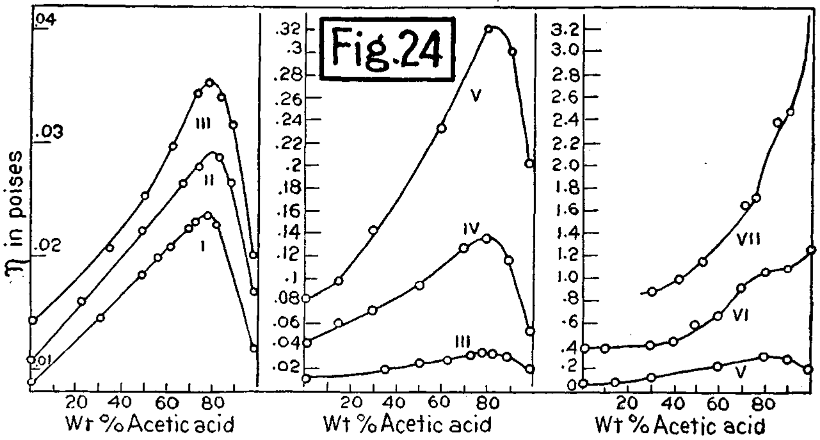


Fig.24

Adhesive Strength

Slight hydrolysis increases the adhesive strength of high-grade gelatin, while continued hydrolysis decreases it (13).

Viscosity

Gelatin in aqueous solution, as measured by the MacMichael viscometer, follows the laws of viscous flow at temperatures above *ca.* 40°C, but exhibits the properties of plastic flow below the solidification point. The sol-gel transformation occurs over a range rather than at a point. At 35°C, time rate of change of η varies with the pH of the solution, the concentration and nature of inorganic ions, and the amount of hydrolyzed protein present (3).

Figure 23 shows the variation of η at 35°C (in arbitrary units) with time for a 5% purified photographic gelatin, pH = 4.9 (18).

The η at 25°C of solutions of gelatin in aqueous acetic acid is given in Fig. 24. Curve (1) is for the two liquids alone, (2) for 0.2 g gelatin per 100 cm^3 of solution, (3) for 0.6 g, (4) for 5 g, (5) for 10 g, (6) for 15 g, (7) for 20 g per 100 cm^3 (20).

The η at 25°C of solutions of gelatin (10 g per 100 cm^3) in formamide + water and formamide + acetic acid is given in Fig. 25. The dotted curves are the η of the mixtures without the gelatin (20).

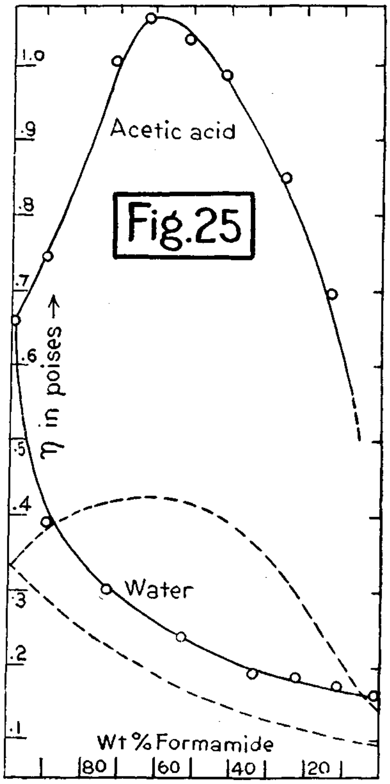


Fig.25

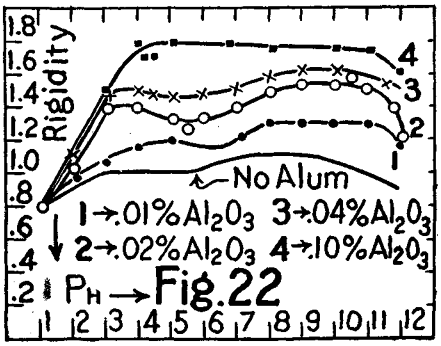
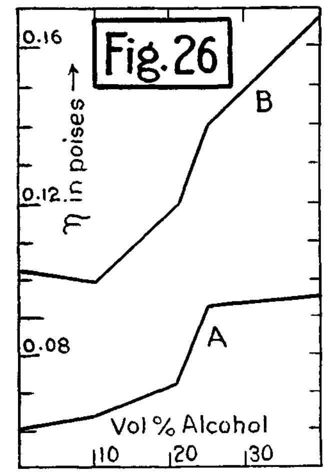


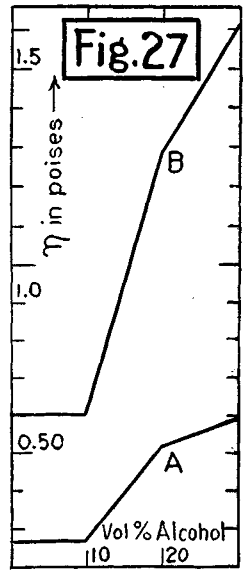
Fig.22

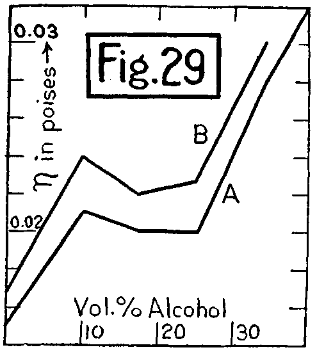
Figure 26 shows the η at 28°C of solutions of gelatin (5 g per 100 cm^3) in methyl alcohol-water mixtures. A = η of fresh solution; B = η after 30 min (20).

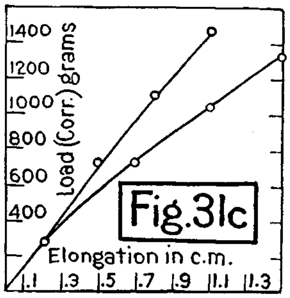
Figure 27 shows η at 30°C of solutions of gelatin (15 g per 100 cm^3) in methyl alcohol-water mixtures. A = freshly prepared; B = after 15 min (20).

Figure 28 gives η at 25°C of solutions of gelatin (2 g per 100 cm^3) in ethyl alcohol-water mixtures. A = freshly prepared; B = after 30 min (20).









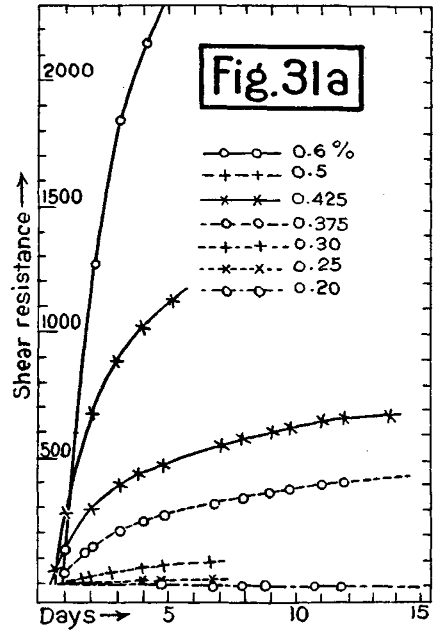
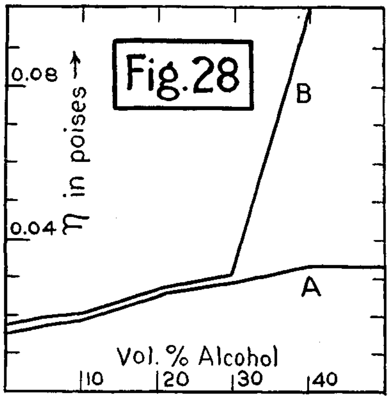
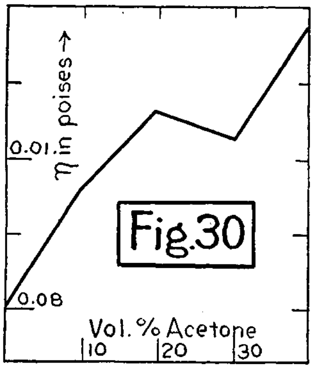
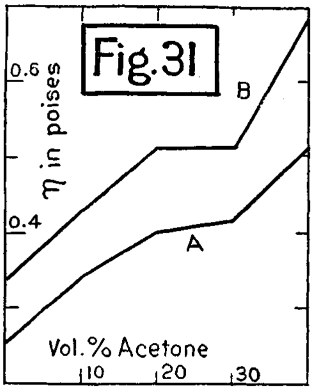


Figure 29 gives η at 30°C of solutions of gelatin (10 g per 100 cm³) in ethyl alcohol-water mixtures. A = freshly prepared; B = after 30 min (20).

Figure 30 gives η at 35°C of solutions of gelatin (10 g per 100 cm³) in acetone-water mixtures (20).







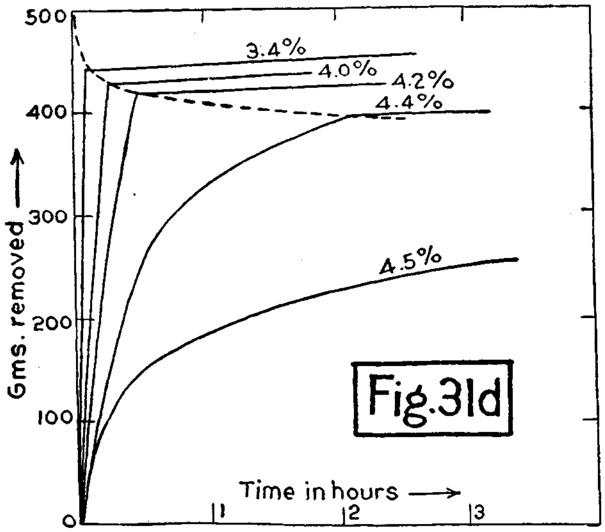


Figure 31 gives η at 30° of solutions of gelatin (15 g per 100 cm³) in acetone-water mixtures. A = freshly prepared; B = after 15 min (20).

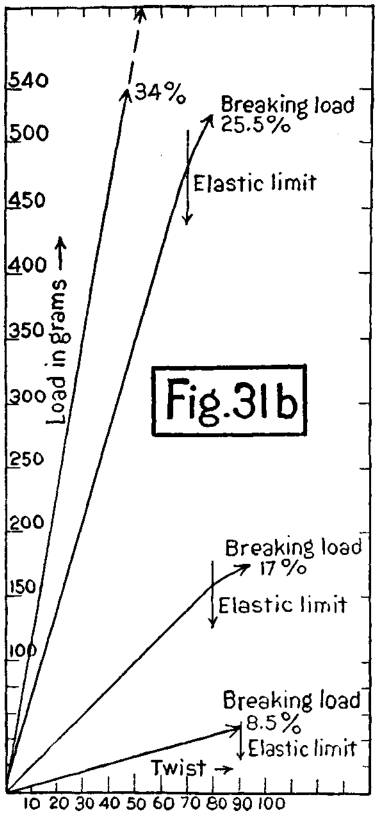
The addition of pyridine to solutions of gelatin in water increases η, while addition of dimethylamine and diethylamine up to *ca.* 25 wt. % of solution decreases, and over 30% again increases η (20) *cf.* (45, 46, 47).

Plasticity and Elasticity

The temperature at which plasticity appears in gelatin solutions depends both on the concentration and on the way in which the solution is prepared (49).

Figure 31*a* gives the change with time of the elastic resistance to shear of dilute gelatin solutions (0.2–0.6%) at 8°C (50).

Figures 31*b* and 31*c* show the behavior of gelatin jellies under torsion and stretch, respectively. The gelatin content of the jellies is given in wt. % (51).



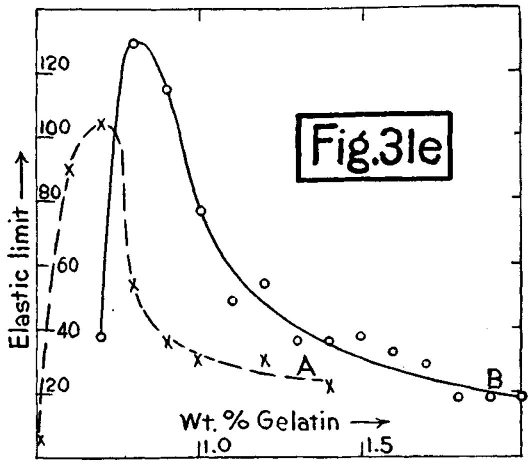


Figure 31*d* shows the behavior of gelatin jellies (3.4–4.5 wt. % gelatin) which have been under a load of 500 g at 16.5°F. The portion of the load removed in order to keep the deformation constant is given as a function of time (52).

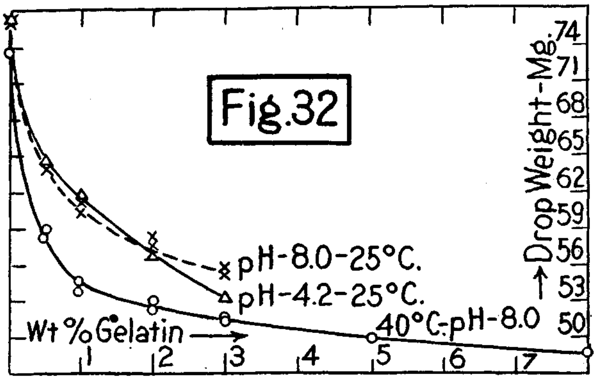
Figure 31*e* shows the relation between the elastic limit of gelatin solutions and the concentration of the gelatin in the solution. A = purified gelatin; B = a commercial gelatin.

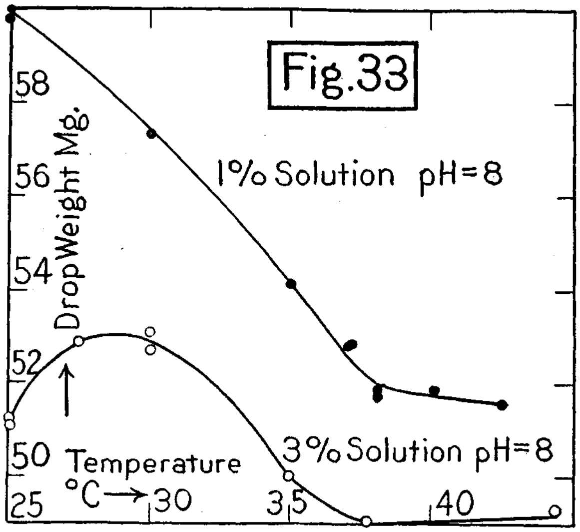
Surface Tension; γ

Figure 32 shows the variation in the drop-weight of water solutions of ossein gelatin with varying concentrations of gelatin (13).

Figure 33 shows the variation of drop weight of gelatin-water solutions with temperature, and Fig. 34 with pH (13).

Figure 35 shows the effect of pH on the drop weight of various gelatin-water solutions containing 0.5% gelatin (13).





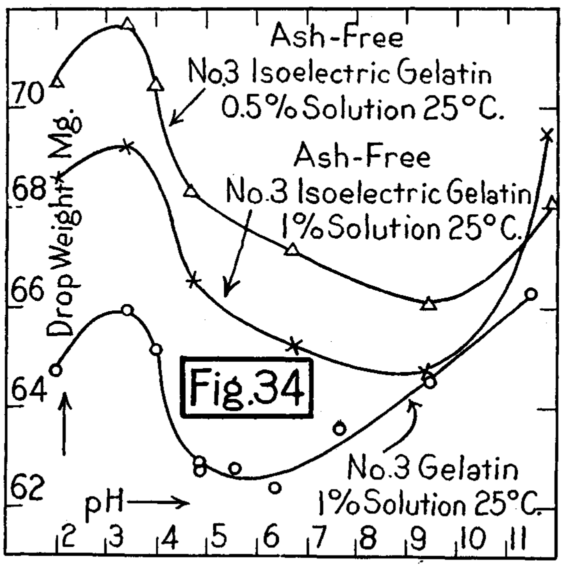


Figure 36 shows the effect of pH on a hide gelatin (0.5 and 1 wt. % of gelatin) solution in water at 25° and 40°C (13).

Figure 37 gives the variation in drop weight of 1 and 2% gelatin in water solutions with time (13).

Figure 38 (20) shows the variation of γ with temperature for various gelatin solutions. A_1 = pure H_2O. A_2 = 5 g gelatin per 100 cc water solution. B = pure formamide (same for 5 g gelatin per 100 cc formamide solution). C = phenol-acetic acid mixture (dotted line gives values of γ after addition of gelatin, 5 g per 100 cm³ of mixture). D = *o*-cresol-acetic acid mixture (dotted line after addition of 5 g gelatin per 100 cm³ of mixture). E_1 = pure acetic acid. E_2 = pure acetic acid + 5 g gelatin per 100 cm³. The inset gives γ for water-alcohol solutions of gelatin against temperature. Solid curve for mixtures of alcohol-water. Dotted curve for mixtures with 10 g gelatin per 100 cm³ solution.

Two per cent gelatin solutions at 30°C by stalagmometer show a rise in γ to a maximum at pH = 8–9, falling to a minimum at pH = 4.5 and rising to a lower maximum at pH = 3 (12).

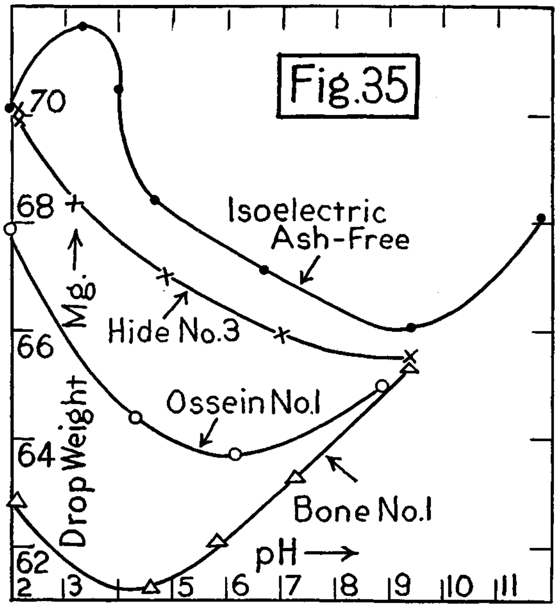


Fig.35

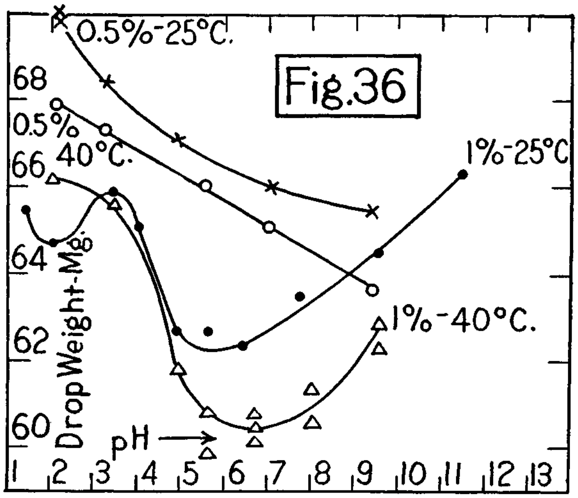


Fig.36

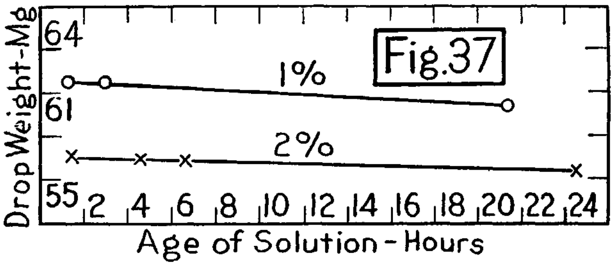


Fig.37

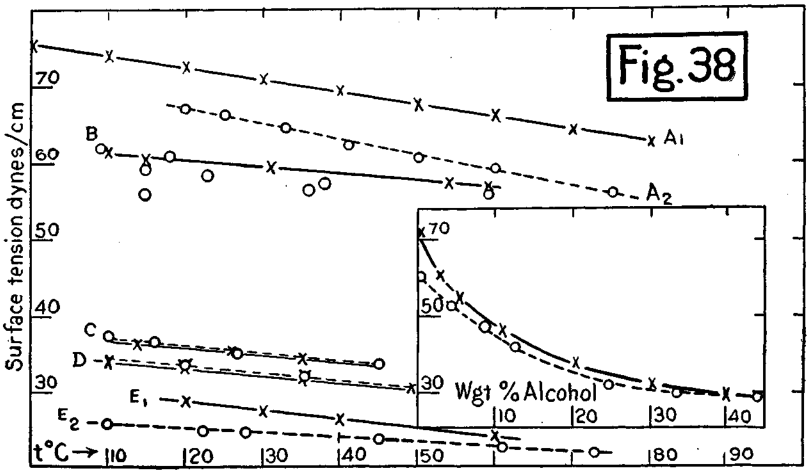


Fig.38

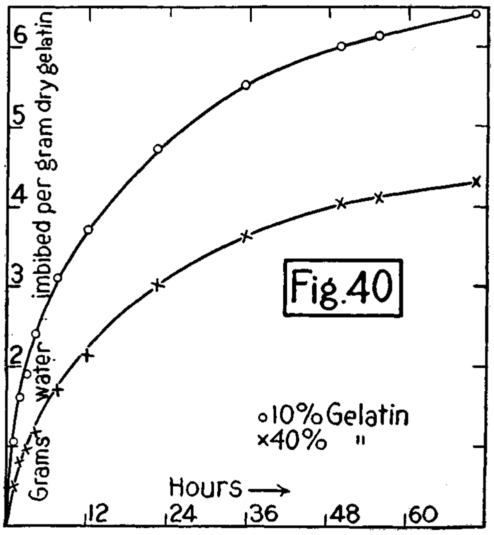


Fig.40

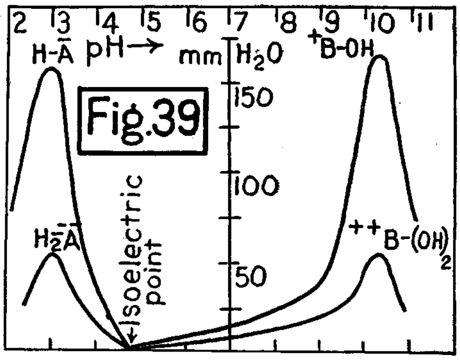


Fig.39

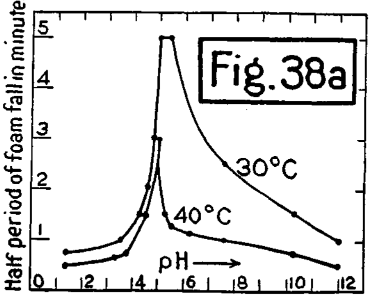
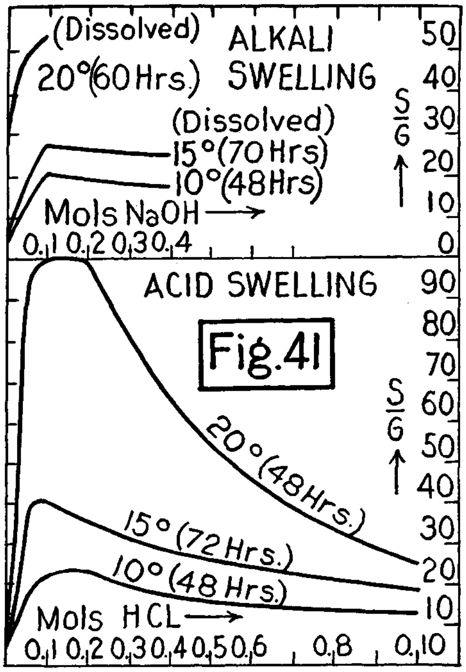
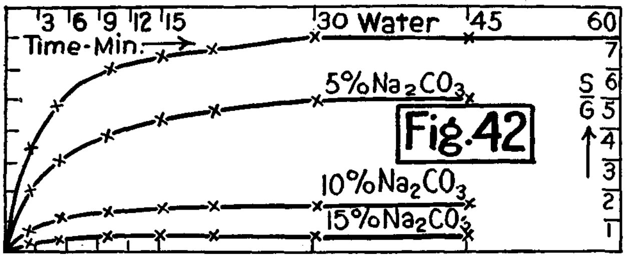
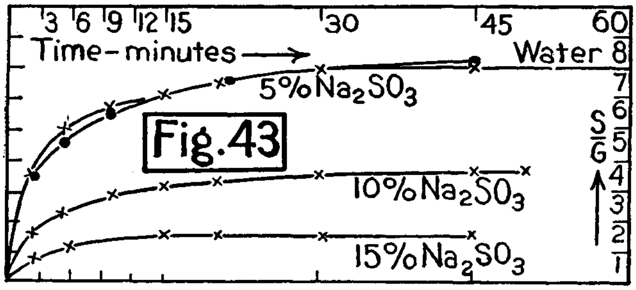
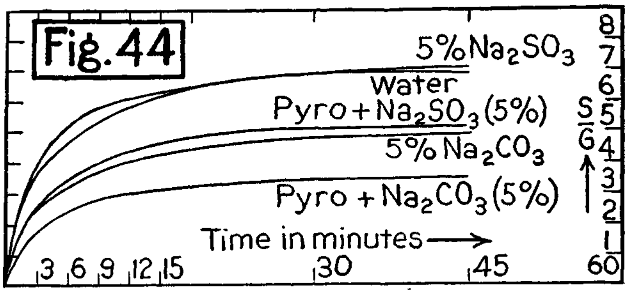


Fig.38a









See (54) for γ between toluene and gelatin solutions.

Figure 38*a* shows the relation between pH and foam on aqueous gelatin solutions, γ for the solution being smallest at the isoelectric point where the foam is most stable.

THERMAL EXPANSION

Aqueous solutions of gelatin (37)

Wt. % gelatin	0.0	2.02	5.04	8.9	10.4	16.5	24.8
$\frac{10^6}{V}\frac{\Delta V}{\Delta t}$ (15°–32°C)	241	249	267	289	300	341	386

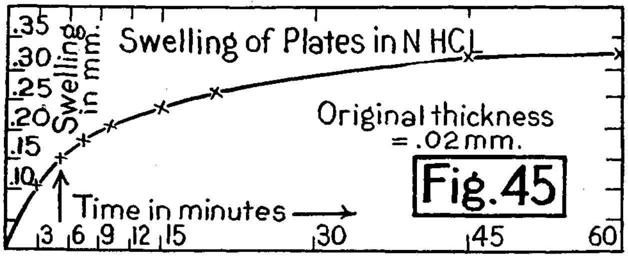
Wt. % gelatin	0.0	3.60	7.05	13.00
Temp. of max. density	+4.0°	+2.5°	+1.3°	−1.2°

Osmotic Pressure

Figure 39 gives the osmotic pressure at 10°C of 0.5 g gelatin per 100 cm³ water solution against solutions of acids and bases of pH value indicated (29).

Swelling and Contractility

Figure 40 shows the swelling behavior of dry gelatins when immersed in pure H_2O for the times indicated. The 10% gel was prepared by drying a solution made from 90 g H_2O + 10 g gelatin and the 40% gel from a solution of 60 g H_2O + 40 g gelatin, the dried pieces being of the same area and thickness (15).



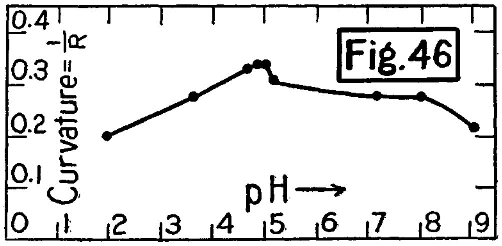


Figure 41 shows the influence of temperature, S/G = grams H_2O imbibed per gram gelatin (25).

Figures 42, 43, 44, and 45. Silver bromide emulsion gelatin on plates when immersed in the solutions indicated for varying times (25).

The following table and Fig. 46 show the contractility of gelatin films as measured by the curvature produced in thin Al discs coated on one side with 10% gelatin solution and dried under uniform conditions. In Fig. 46, the gelatin films were prepared from de-ashed material, in solutions of the pH indicated (26).

CONTRACTILITY

Gelatin	Radius in cm	Curvature 1/R	Remarks
Commercial hard A	24	0.041	Good grade
Commercial hard B	24.5	0.0405	photographic gelatins
Ossein gelatin	26	0.038	Photographic quality
Hide gelatin No. 6902	31	0.032	Good grade hide gelatin
Same, de-ashed	31	0.032	Ash less than 0.01%
Sizing gelatin	34	0.029	Poor grade

There is no definite relation between the contractility of gelatins and their swelling on immersion in H_2O, indicating that there are individual structural differences in gelatins, depending not simply on physico-chemical conditions but on origin and previous history (26).

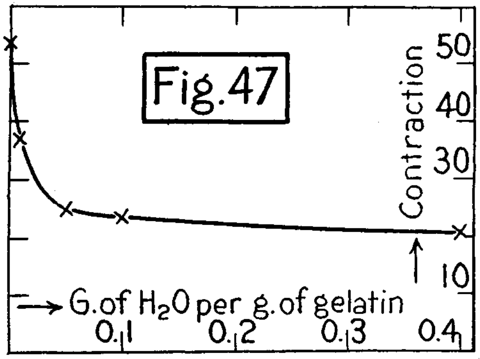


Fig. 47

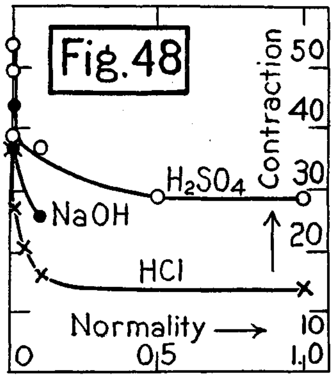


Fig. 48

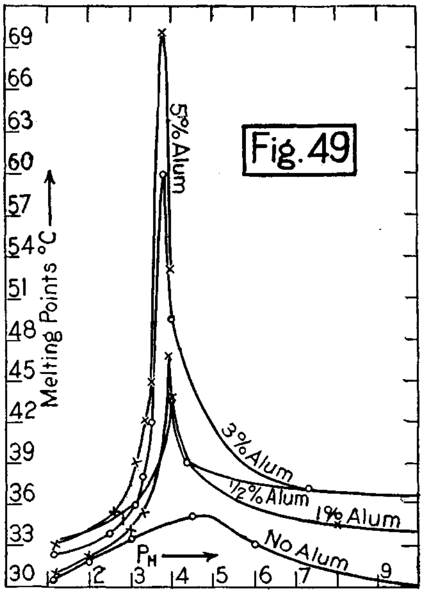


Fig. 49

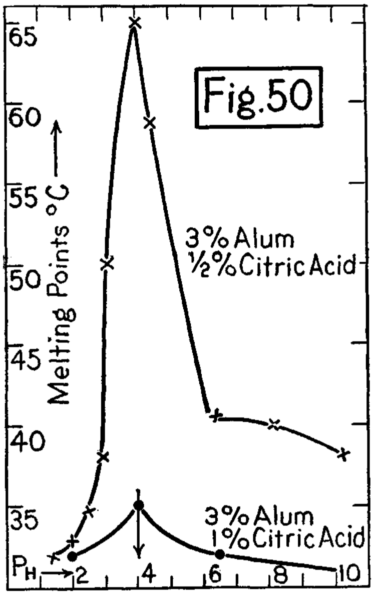


Fig. 50

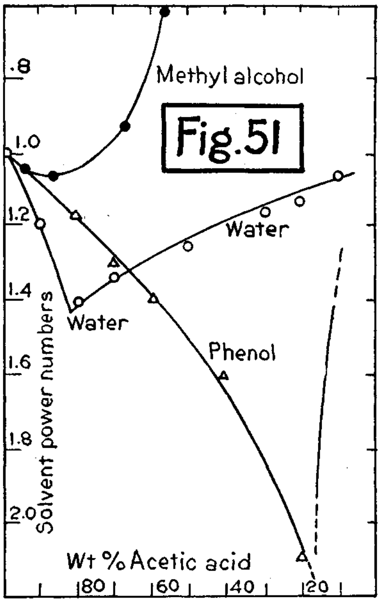


Fig. 51

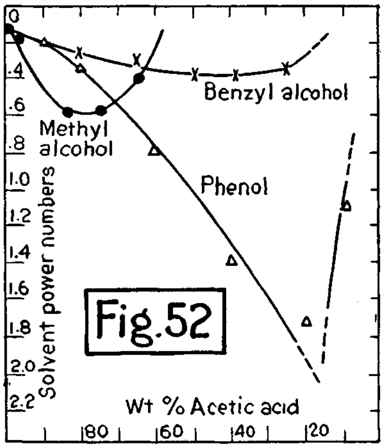


Fig. 52

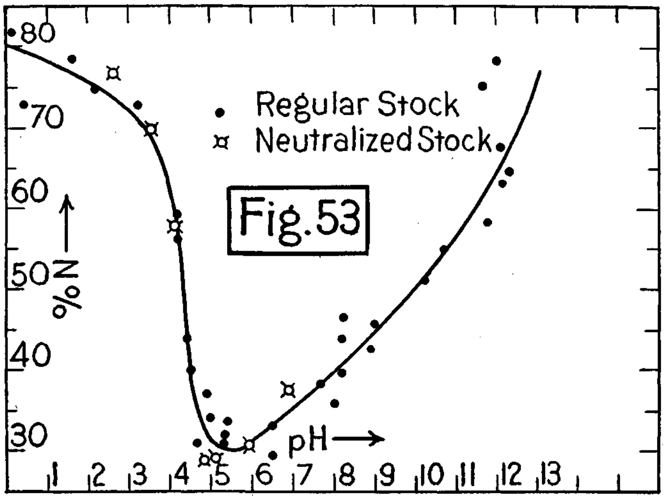


Fig. 53

Gelatin shows two points of minimum swelling with change in pH, one at pH = 4.7 and the other at pH = 7.7 (41).

For the swelling of gelatin in solutions of polybasic acids and their salts, *see* (42).

Figure 47 shows the contraction in mm³ per g of gelatin on dissolving in 100 cm³ of H_2O as a function of the H_2O content of the gelatin before dissolving, and Fig. 48 shows the contraction on dissolving a gelatin of constant H_2O content in 100 cm³ of acid or alkali of varying normality (31).

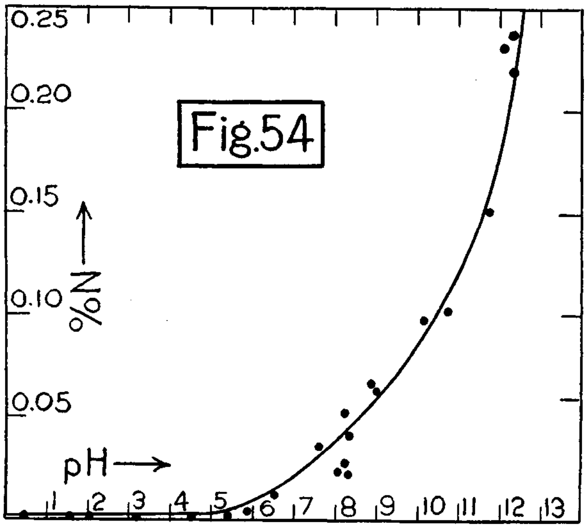


Fig. 54

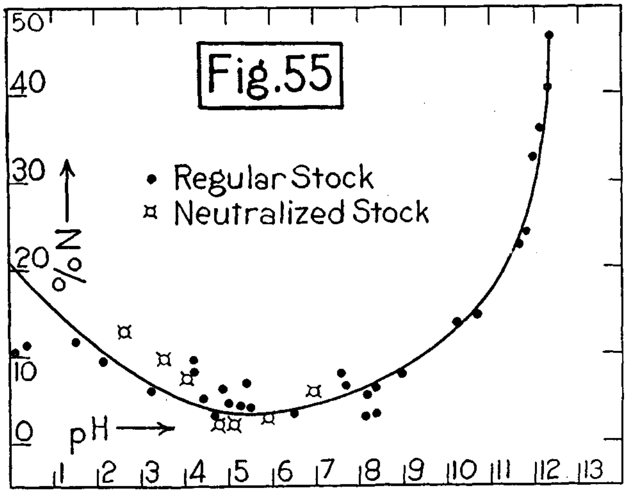
The swelling of gelatin gels shows a maximum at pH = 3–3.5 and a minimum at pH = 5 (4). For effects of certain solutes in increasing swelling *v.* (36).

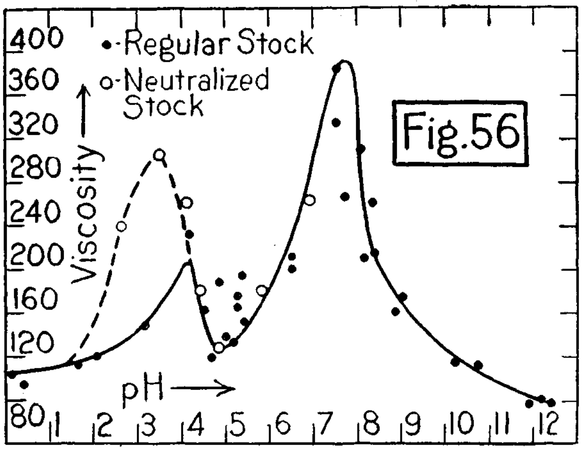
Gelatin gels show a minimum resistance to stretch at pH = 4.7 and a maximum at pH = 3 and 11 (24).

Melting Point

Figure 49 shows the "M. P." of gelatins, prepared with different pH values, as determined after immersion for a constant time in alum solutions of the concentrations indicated (25).

Figure 50 shows the "M. P." of gelatins, prepared with different pH values, as determined after immersion for a constant time in alum solutions with 0.5 and 1.0% of citric acid (25).





Solubility in H_2O

<0.01 wt. % at room temp. (17, 18).

Parts ‰. 22°C, 1; 18.3°, 0.7; 15–17°, 0.5; 0°, 0.2 (35).

Solvent Power Numbers

The solvent power number is the relative volume of a liquid required to start the precipitation of gelatin from a solution containing 15 g gelatin per 100 cm³, upon mixing at 25°C.

Figure 51 shows the solvent power numbers for acetone on solutions of gelatin in acetic acid mixtures and Fig. 52 the same values for xylene (20).

Hydrolysis of Collagen to Gelatin (6)

The experiments covered by the following figs. were carried out on well limed hide pieces for periods of 8 hr unless otherwise indicated and exhibit the effect of the pH during hydrolyzing on the factors named:

Fig. 53. On the % of total N recovered in the solution.

Fig. 54. On the % of N evolved as NH_3.

Fig. 55. On the % of amino acid N recovered in the solution.

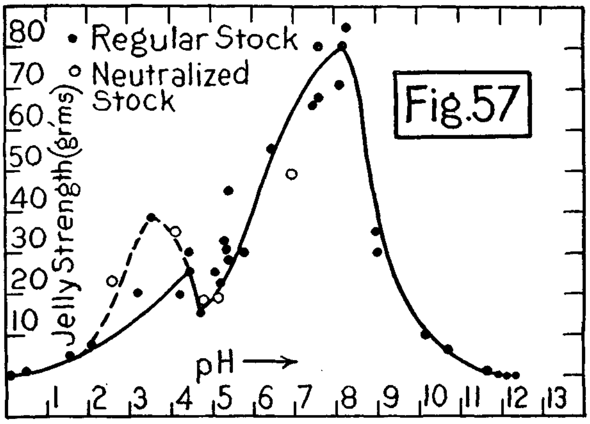
Fig. 56. On the viscosity (in arbitrary units) of the product at 35°C.

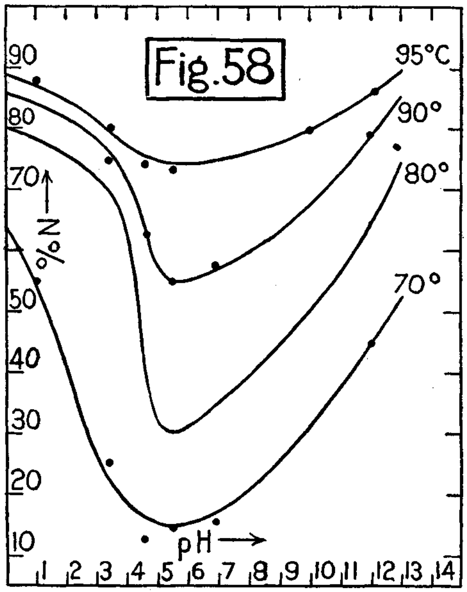
Fig. 57. On the jelly strength of the product at 10°C.

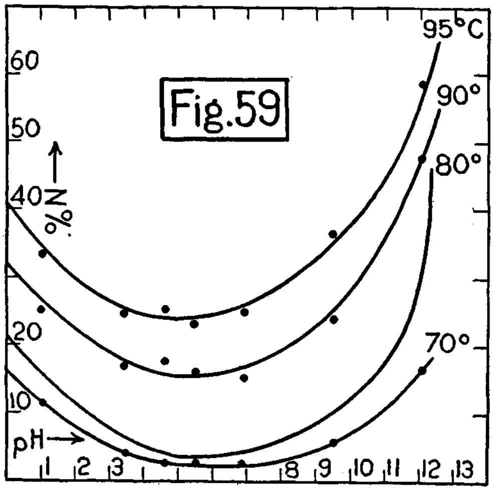
Fig. 58. On total N recovered in the solution after hydrolyzing at temperatures indicated.

Fig. 59. On amino acid N in the solution after hydrolyzing at temperatures indicated.

Fig. 60. On the total N recovered and Fig. 61 on the amino acid N, in the solution after hydrolyzing at 80°C for times indicated.







Mutarotation

The change in specific rotation (mutarotation) of gelatin solutions of constant concentration, upon reducing the temperature from 35° to 15°C, decreases very rapidly with decreasing jelly consistency of the gelatin or glue (4). *See also* (17, 35, 48).

Electrical Conductivity

The conductivity of gelatin solutions in water is a useful criterion of the purity of the gelatin. The purest solutions which have been prepared have the same conductivity as pure water (38). *See* (39) for the conductivity of some gelatin and glutin solutions.

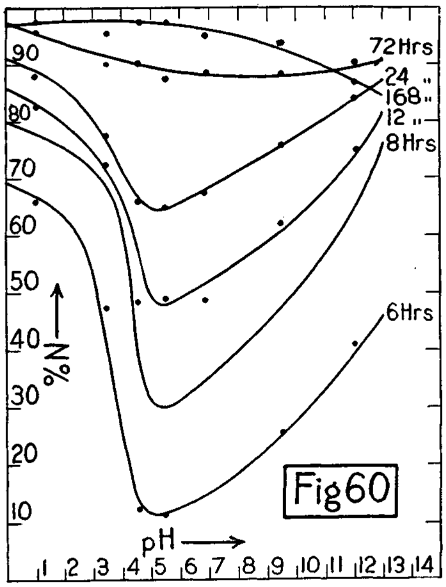


Fig60

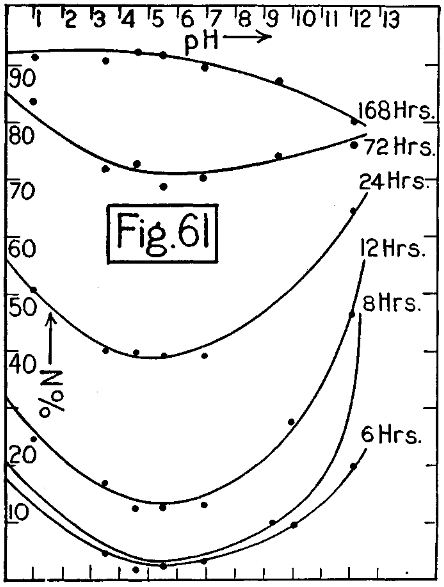


Fig.61

Miscellaneous

For the extraction of gelatin from bones as a function of temperature and time, *see* (19).

Figure 62 shows the influence of pH on the alcohol number, turbidity, and foam of gelatin solutions (4).

A method of determining the gelling power of gelatins is given in (43).

For the liquefaction of gelatins by salt solutions, *see* (44).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Alexander, *Glue and Gelatin,* New York, Chem. Cat. Co., 1923. (2) Bechhold and Neumann, *92,* **37**: 534; 24. (3) Bogue, *1,* **44**: 1313; 22. (4) Bogue, *1,* **44**: 1343; 22. (5) Bogue, *Chemistry and Technology of Gelatine and Glue.* New York and London, McGraw-Hill Book Company, Inc., 1923. (6) Bogue, *First Colloid Symposium Monograph.* New York, Chem. Cat. Co., 1923. (7) Bogue, *33,* **23**: 5; 20. (8) Bogue, *33,* **23**: 61; 20. (9) Bogue, *33,* **23**: 105; 20.

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(20) Mardles, *230,* **18**: 215; 24. (21) McBain and Hopkins, *50,* **29**: 188; 25. (22) National Assoc. of Glue Mfrs., *45,* **16**: 310; 24. (23) Sauer, *136;* **83**: 473; 24. (24) Scarth, *50,* **29**: 1009; 25. (25) Sheppard, *45,* **14**: 1025. 22. (26) Sheppard, Elliott and Sweet, *83,* **19 II**: 1; 23. (27) Sheppard and Sweet, *45,* **16**: 593; 24. (28) Sheppard, Sweet and Benedict, *1,* **44**: 1857; 22. (29) Smith, *1,* **43**: 1350; 21.

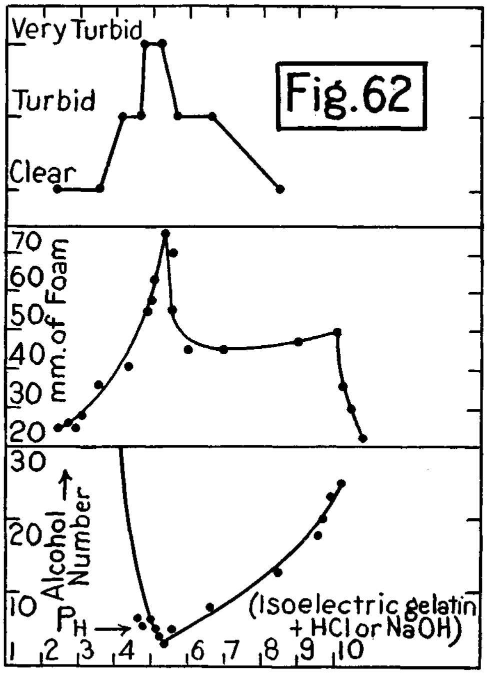

Fig.62

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(50) Rohloff and Shinjo, *63,* **8**: 442; 07. (51) Sheppard and Sweet, *1,* **43**: 540; 21. (52) Rankine, *3,* **11**: 447; 06. (53) Freundlich and Seifriz, *7,* **104**: 233; 23. (54) Sheppard and Sweet, *1,* **44**: 2797; 22. (55) Sheppard, *Third Colloid Symposium Monograph.* New York, Chem. Cat. Co., 1925. (56) *Second Report of the Adhesives Research Committee* (Dept. of Sci. Ind. Research, London, 1926) contains valuable information on adhesive action, glue, gelatin, etc.

TEXTILE FIBERS

J. MERRITT MATTHEWS

BOTANICAL CLASSIFICATION OF IMPORTANT VEGETABLE FIBERS

(*A*) Vegetable hairs.
  1. Cotton (seed-hairs of *Gossypium* sp.).
  2. Bombax cotton (fruit-hairs of *Bombaceæ*).
  3. Vegetable silks (seed-hairs of various *Asclepiadaceæ* and *Apocynaceæ*).

(*B*) Bast fibers from the stalks and stems of dicotyledonous plants.
  (*a*) Flax-like fibers.
    4. Flax (*Linum usitatissimum*).
    5. Hemp (*Cannabis sativa*).
    6. Gambo hemp (*Hibiscus cannabinus*).
    7. Sunn hemp (*Crotalaria juncea*).
    8. Queensland hemp (*Sida retusa*).
    9. Yercum fiber (*Calotropis gigantea*).
  (*b*) Bœhmeria fibers.
    10. Ramie or China grass (*Bœhmeria nivea*).
  (*c*) Jute-like fibers.
    11. Jute (*Corchorus capsularis* and *C. olitorius*).
    12. Raibhenda (*Abelmoschus tetraphyllos*).
    13. Pseudo-jute (*Urena sinuata*).
  (*d*) Coarse bast fibers.
    14. Bast fibers from *Bauhinia racemosa*.
    15. Bast fibers from *Thespesia lampas*.
    16. Bast fibers from *Cordia latifolia*.
  (*e*) Basts.
    17. Linden bast (*Tilia* sp.).
    18. Bast from *Sterculia villosa*.
    19. Bast from *Holoptelea integrifolia*.
    20. Bast from *Kydia calycina*.
    21. Bast from *Lasiosyphon speciosus*.
    22. Bast from *Sponia Wightii*.

(*C*) Vascular bundles from monocotyledonous plants.
  (*a*) Leaf fibers.
    23. Manila hemp or abaca (*Musa textilis* and others of this kind).
    24. Pita (*Agave americana* and *A. mexicana*).
    25. Sisal (*Agave rigida*).
    26. Mauritius hemp (*Agave fœtida*).
    27. New Zealand flax (*Phormium tenax*).
    28. Aloe fibers (*Aloë* sp.).
    29. Bromelia fibers (*Bromelia* sp.).
    30. Pandanus fibers (*Pandanus* sp.).
    31. Sansevieria fibers (*Sansevieria* sp.).
    32. Esparto fibers (*Stipa tenacissima*).
    33. Piassave (*Attalea funifera*, *Raphia vinifera*, etc.).
  (*b*) Stem fibers.
    34. Tillandsia fibers, southern moss (*Tillandsia usneoides*).
  (*c*) Fruit fibers.
    35. Coir or coconut fiber (*Cocos nucifera*).
    36. Peat fibers.
  (*d*) Paper fibers.
    37. Straw fibers (rye, wheat, oat, rice).
    38. Esparto fibers (leaf fibers of *Stipa tenacissima*).
    39. Bamboo fibers (*Bambusa* sp.).
    40. Wood fiber (pine, fir, aspen, etc.).
    41. Bast fiber from paper mulberry (*Broussonetia papyrifera*).
    42. Bast fiber from *Edgeworthia papyrifera*.
    43. Peat fibers.

(Wiesner, *Die Rohstoffe des Pflanzenreiches*)

MICROSCOPICAL CHARACTERISTICS OF IMPORTANT VEGETABLE FIBERS

Fiber	Microscopical appearance
Cotton	Appears as a flat, ribbon-like band, more or less twisted on its longitudinal axis. Twist of fiber not continuous in one direction; cell-walls thick; lumen breadth much thicker than cell-wall; between thickened edges fiber shows finely granulated surface. Diameter uniform for ¾ length, then tapers to a point where it is cylindrical and solid
Flax	Cylindrical tapering to sharp point; cell-wall so thick that lumen appears as thread; fine cross-lines at intervals give appearance of joints or nodes, sometimes intersecting like letter X
Hemp	Lumen is broad, equaling or exceeding the thickness of the walls. Pronounced longitudinal striations. Ends of fibers blunt and thick-walled, often with lateral branches. Dislocations or folds; also swellings and cross-fissures. Fibers less transparent than flax and canal more difficult to distinguish
Jute	Lumen irregular, at times as wide as or wider than cell-wall; at ends of fiber lumen broadens out; end round. Longitudinal striations, no transverse markings, no jointed ridges
Manila hemp (abaca)	Lumen broad, distinct and uniform; cell-wall thin; ends narrow and sharp; no markings; diameter uniform
Manila hemp, sisal or Domingo hemp.	Fibers usually very stiff, and become very broad toward middle; have broad lumen, broad, blunt, thick ends, which are seldom forked. Short thick-walled cells are abundant, and show a narrow lumen and distinct surface pores. Peculiar spiral and parenchyma cells are often present
Straw	Bast cells are long thin fibers of regular structure with small canal; very slender and taper to fine point. Epidermal cells are thick-walled, short, broad, serrated. Parenchyma cells thin-walled and shaped like coffee bean
Esparto	Cells smaller than, but very similar to, straw cellulose. Esparto does not have the thin-walled bean-shaped cells, but has very small characteristic pear-shaped cells. Bast cells have numerous cross-markings
Ramie	Bast cells very long and broad, diameter very irregular; base very irregular; lumen, sometimes quite distinct, and sometimes disappearing entirely; fibers show numerous joints and transverse fissures; ends of fibers form a thick-walled, rounded point, and the lumen is reduced to a line
New Zealand flax.	Fiber elements, or cells, are usually very regular and uniform, surface is smooth in general. Lumen is usually narrower than cell-wall and very uniform in width. Ends are sharply pointed, and not divided. Fragments of parenchyma and epidermis can often be seen on the fibers
Pita fiber	Fiber is stiff and short, has a rather thin wall. Fiber has a distinctive wavy appearance and is very elastic. Very similar to sisal hemp in microscopical appearance
Pineapple leaf fiber.	Fiber very fine and has great durability. Lumen narrow and appears like a line. This fiber is distinguished from all other leaf fibers by its extreme fineness
Coniferous wood fibers.	Fibers from coniferous trees have a characteristic flat ribbon-like appearance, and numerous circular spots or pores are to be seen on many of them. The circular markings are more prominent in hard, strong sulfites or sulfates, but are often less distinct in well-boiled pulps. Occasionally the cells are twisted something like cotton fibers. The shape and distribution of the pores in the fibers give some indication of the tree used
Broad-leaf hardwood fibers.	The fibers from broad-leaf trees are shorter and more cylindrical in shape, and are always pointed at each end, and occasionally exhibit cross-markings. In addition to the true fibers, there are always a number of vessels, tubular in shape, short and of very large diameter, which show numerous pits; these establish the presence of fibers from broad-leaf trees

DIMENSIONS OF FIBER ELEMENTS

Name	Length, mm			Breadth, microns			Source
	Min.	Max.	Mean	Min.	Max.	Mean	
Abelmoschus tetraphyllos	0.1	1.6		8	29	13	W
Agave americana (pita)	1.0	2.2		16	21	17	W
	1.5	4	2.5	20	32	24	V
Aloë perfoliata	1.3	3.7		15	24		W
Asclepias (vegetable silk)	10	30		20	44		W
Bauhinia racemosa	1.5	4.0		8	20		W
Beaumontia (vegetable silk)	30	45		33	50		W
Boehmeria nivea (China grass)			22.0	40	80	50	W
Boehmeria tenacissima (ramie)			8.0	16	12.6		W
Bombax heptaphyllum (cotton wool)	20	30		19	29		W
Bromelia karatas (silk grass)	1.4	6.7		27	42		W
	2.5	10	5	20	32	24	V
Bromelia pinguin (wild pineapple)	0.8	2.5	2	8	16	13	V
Calotropis gigantea (bast)	0.7	3.0		18	25		W
Calotropis gigantea (vegetable silk)	20	30		12	42	38	W
Cannabis sativa (hemp)	0.8	4.1		16	32	20	W
	5	55	20	16	50	22	V
Cocos nucifera (coir fiber)	0.4	0.9		12	20	16	W
	0.4	1	0.7	12	24	20	V
Corchorus capsularis (jute)	0.8	4.1		10	21	16	W
	1.5	5	2	20	25	22.5	V
Corchorus olitorius (jute)	0.8	4.1		16	32	20	W
Cordia latifolia	0.1	1.6		14.7	16.8	15	W
Corypha umbraculifera (talipot palm)	1.5	5	3	16	28	24	V
Crotalaria juncea (sunn hemp)	0.5	6.9		20	42		W
	4	12	8	25	50	30	V
Elaeis guineensis	1.5	3.5	2.5	10	13	11	V
Esparto grass	1.5	1.9		9	15		W
	0.5	3.5	1.5	7	18	12	V
Gossypium acuminatum (cotton)			28.4	20.1	29.9	29.4	W
Gossypium arboreum (cotton)			25.0	20	37.8	29.9	W
Gossypium barbadense (cotton)			40.5	19.2	27.9	25.2	W
Gossypium conglomeratum (cotton)			35.1	17	27.1	25.9	W
Gossypium herbaceum (cotton). *See also* following table			18.2	11.9	22	18.5	W
Hibiscus cannabinus (gambo hemp)	2	6	5	14	33	21	V
	4.0	12.0		20	41		W
Holoptelea integrifolia	0.9	2.1		9	14	12	W
Humulus lupulus (hop)	4	19	10	12	26	16	V
Kydia calycina	1	2		17	24		W
Lagetta lintearia (lace bark)	3	6	5	10	20		V
Lasiosyphon speciosus	0.4	5.1		8	29		W
Linen	4	66	25	15	37	20	V
Linum usitatissimum (flax)	2.0	4.0		12	25	16	W
Lygaeum spartum	1.3	4.5	2.5	12	20	15	V

Dimensions of Fiber Elements.—(*Continued*)

Name	Length, mm			Breadth, microns			Source
	Min.	Max.	Mean	Min.	Max.	Mean	
Marsdenia (vegetable silk)	10	25		19	33		W
Mauritia flexuosa (ita palm)	1	3	1.5	10	16	12	V
Melilotus alba (sweet clover)	5	18	10	20	36	30	V
Musa paradisaica (banana)			5	20	40	28	V
Musa textilis (Manila)	3	12	6	16	32	24	V
Pandanus odoratissimus	1.0	4.2				20	W
Paper mulberry		25	10			30	V
Phoenix dactylifera (date palm)	2	6	3	16	24	20	V
Phormium tenax (New Zealand flax)	2.5	5.6		8	29	13	W
	5	15	9	10	20	16	V
Pineapple	3	9	5	4	8	6	V
Raphia toedigera	1.5	3	2.5	12	20	16	V
Salix alba (willow)		3	2	17	30	22	V
Sansevieria	1.5	6	3	15	26	20	V
Sarothamnus vulgaris (broom-grass)	2	9	5	10	25	15	V
Sida retusa	0.8	2.3		15	25		W
Spartium junceum (feather-grass)	5	16	10			20	V
Sponia Wightii			4			21	W
Sterculia villosa	1.5	3.5		17	25	20	W
Strophanthus (vegetable silk)	10	56		49	92		W
Thespesia lampas	0.9	4.7		12	21	16	W
Tilia europaea (linden-bast)	1.2	5	2	14	20	16	V
	1.1	2.6				15	W
Tillandsia	0.2	0.5		6	15		W
Urena sinuata	1.1	3.2		9	24	15	W
Urtica dioica (nettle)	4	57	27	20	70	50	V
Urtica nivea (ramie) *See also Boehmeria*	60	250	120		80	50	V
Yucca	0.5	6	4	10	20	15	V

V = Vétillard, *Études sur les fibres végétales textiles.* W = Wiesner, *Die Rohstoffe des Pflanzenreiches.*

COTTON

Dimensions of Cotton Fibers

	Length, mm			Diameter, microns
	Max.	Min.	Av.	
African	30.2	22.1	26.2	20.8
Algerian			37.5	
Brazilian				
Ceara	30.2	22.1	26.2	20.1
Maceo			29.3	
Maranham	30.2	23.9	26.9	20.1
Paraiba			29.7	
Pernambuco	34.8	28.4	31.8	20.1
Surinam			30.2	
American				
Georgia			25.4	10.3
Louisiana			25.0	
Mississippi			24.2	13.4
Mobile	25.4	19.1	22.1	19.4
Orleans	28.4	23.9	26.2	19.2
Tennessee			25.1	15.0
Texas	28.4	22.1	25.4	19.4
Upland	26.9	20.6	23.9	19.4
Chinese			21.4	24.1
Egyptian				
Brown	38.1	28.4	33.3	18.7
Gallini	42.4	31.7	36.3	17.1
Smyrna	28.4	22.1	25.4	22.8
White	34.8	28.4	31.7	19.5
Indian				
Bengal	25.4	19.1	22.1	22.1
Broach	25.4	17.5	21.3	21.1
Comptah	25.4	19.1	22.1	21.5
Dharwar	22.6	17.5	22.1	21.1
Dhollerah	26.9	21.3	22.6	21.5
Hingunghat	30.2	22.1	26.2	21.1
Madras	25.4	19.1	22.1	21.1
Oomrawutte	26.9	19.1	21.9	21.5
Scinde	22.1	12.7	16.5	21.3
Tinnevelly	26.9	17.5	22.1	21.1
Peruvian				
Rough	36.6	23.5	32.5	19.8
Smooth	36.6	23.5	32.5	19.5
Sea Island				
Edisto			41.9	9.65
Fiji	53.8	42.4	46.6	16.2
Fitschi			48.7	16.7
Florida	45.9	38.1	41.9	16.2
John Isle			39.3	
Peruvian	44.5	34.8	39.6	17.1
Tahiti	44.5	31.7	38.1	16.3
Wodomalam			39.0	
West Indian	34.8	26.9	31.0	22.8

Physical Properties of Individual Cotton Fibers

Variety	Length, cm	Rigidity, dynes cm^2	Weight, 10^{-6} g
Sea-island	4.2–5	0.010–0.021	5.9–6.7
Egyptian nubarri	3.6	0.024	6.3
Egyptian affifi	3.1	0.032	5.6
Peruvian hybrid	2.9	0.063	7.7
Trinidad native	2.6	0.045	4.9
Upland Memphis	2.6	0.039	5.3
American FGM	2.4	0.061	5.6
Upland cross	2.3	0.045	5.0
Pernams	2.2	0.071	6.7
Indian Bharat	1.7	0.111	5.8

The rigidity of the fiber is the torque, or twisting force, in the fiber when 1 cm is given one complete twist.

Pierce[1] furnishes the following physical factors for the cotton fiber, that may be calculated approximately from the staple length:

Staple length	L (in cm)
Fiber mass	5.8×10^{-6} g
Mass per centimeter	$(5.8/L) \times 10^{-6}$ g
Wall cross section	$(3.9/L) \times 10^{-6}$ cm^2
Rigidity	$0.3/L^2$ dynes cm^2
Breaking load	$20/L$ g
Fibers in yarn section	$1000L/N$ or $(L''/4N) \times 10^4$
Initial couple in yarn	$300t/LN = 300p/L\sqrt{N}$

The density of the cotton fiber is assumed as 1.51; N is the count of the yarn, L'' is the staple length in inches, t is the twist, and p the spinning factor $t/\sqrt{N}$.

Breaking Strengths of Different Varieties of Cotton

Cotton	Mean breaking strain	
	Grains	Grams
Sea-island (Edisto)	83.9	5.45
Queensland	147.6	9.59
Egyptian	127.2	7.26
Maranham	107.1	6.96
Bengal	100.6	6.53
Pernambuco	140.2	9.11
New Orleans	147.7	9.61
Upland	104.5	6.79
Surat (Dhollerah)	141.9	9.22
Surat (Comptah)	163.7	10.64

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[1] *415*, **14**: 7; 23.

ABSORPTION OF SODIUM HYDROXIDE BY COTTON[1]

Concn. NaOH, g per 100 cc H_2O..	0.4	2.0	6.0	8.0	12	16	20	24	28	33	35	40
g NaOH fixed per 100 g cotton....	0.4	0.9	2.7	4.4	8.4	12.6	13	13	15.4	20.4	22.5	22.5

[1] Vieweg, *25*, **40**: 3876; 07.

Effect of Mercerizing on the Physical Properties of Cotton Yarns

Thoms[1] obtained the following results on the effect of mercerizing and bleaching on cotton yarns:

	Gray	Boiled	Mercerized	Mercerized and bleached, chloride of lime
Loss in weight, %..........	0	5.53	4.61	3.02
Loss in length, %..........	0	1.95	1.00	0.37
Mean count.................	16.46	17.66	17.42	17.35
Lea break, in lb...........	97.0	72.41	82.19	86.41
Double thread break, in oz...	27.68	23.26	26.12	27.55
Double thread stretch, in $\frac{1}{16}$ in......................	20.57	14.22	11.08	10.25
Mean turns per in..........	20.18	19.88	19.57	19.99
Moisture, % as regain.......	5.86	5.07	7.18	7.34

	Mercerized and bleached, sodium hypochlorite	Mercerized and bleached, electrolytic bleach	Bleached, chloride of lime	Bleached, sodium hypochlorite
Loss in weight, %...	3.03	3.06	5.00	4.91
Loss in length, %...	1.11	1.14	2.04	1.73
Mean count........	17.02	17.02	17.35	17.45
Lea break, in lb....	87.12	85.94	17.66	79.97
Double thread break, in oz......	28.08	27.58	24.14	23.93
Double thread stretch, in $\frac{1}{16}$ in...	11.09	10.78	13.76	13.97
Mean turns per in..	20.20	20.25	20.07	20.11
Moisture, % as regain............	7.55	7.59	5.28	5.46

	Bleached, electrolytic bleach	Bleached, chloride of lime and mercerized	Bleached, sodium hypochlorite and mercerized	Bleached, electrolytic bleach and mercerized
Loss in weight, %	4.88	3.40	3.37	3.37
Loss in length, %.	1.97	0.17	0.63	0.10 gain
Mean count......	17.40	17.58	17.24	17.40
Lea break, in lb..	79.78	80.28	80.47	78.28
Double thread break, in oz....	23.65	26.52	26.14	25.85
Double thread stretch, in $\frac{1}{16}$ in.	13.78	9.08	9.23	8.90
Mean turns per in.	19.89	19.91	19.32	19.59
Moisture, % as regain........	5.42	7.63	7.69	8.19

[1] *290*, **27**: 178; 11.

SILK

SIZES OF COCOON THREADS FROM DIFFERENT SOURCES[1]

Source	Size in deniers
Yellow Piedmont........................	3.06
Yellow Cevennes........................	3.03
White Persians.........................	2.87
Yellow Adrianople......................	2.84
Yellow Tuscan..........................	2.81
Yellow Salonika........................	2.73
Yellow Greece..........................	2.61
Yellow Hungarian.......................	2.64
White Turkestan........................	2.68
White Japanese.........................	2.12
White Chinese..........................	1.96

[1] Report Lyon's Conditioning House.

The single silk filament in the double cocoon thread, therefore, is about 1¼ to 1½ deniers in size.

COMPARISON OF DIFFERENT VARIETIES OF SILK FIBERS[1]

Name of silk	Country	Diameter, in.		Elasticity, in. in 1 ft.		Tensile strength, dr		Size of cocoon, in.
		Outer fibers	Inner fibers	Outer fibers	Inner fibers	Outer fibers	Inner fibers	
Bombyx mori.....	China	0.00052	0.00071	1.3	1.9	1.6	2.6	1.1×0.5
Bombyx mori.....	Italy	0.00053	0.00068	1.2	1.9	1.9	2.6	1.2×0.6
Bombyx mori.....	Japan	0.00057	0.00069	1.2	1.4	2.0	3.1	1.1×0.6
Bombyx fortunatus..........	Bengal	0.00045	0.00051	1.8	2.3	1.6	2.8	1.2×0.5
Bombyx textor....	India	0.00042	0.00047	1.5	1.9	1.4	2.6	1.2×1.5
Antheræa mylitta	India	0.00161	0.00172	1.9	2.7	6.6	7.8	1.5×0.8
Attacus ricini....	India	0.00085	0.00093	1.7	2.0	1.5	3.0	1.5×0.8
Attacus cynthia..	India	0.00083	0.00097	2.6	2.9	2.4	3.5	1.8×0.8
Antheræa assama.	India	0.00128	0.00125	2.4	2.9	2.8	4.8	1.8×1.0
Attacus selene....	India	0.00100	0.00109	2.0	2.8	2.4	4.0	3.0×1.2
Attacus atlas.....	India	0.00102	0.00111	1.9	2.8	2.1	4.1	3.5×0.8
Antheræa yamamai..........	Japan	0.00088	0.00096	2.0	4.0	6.8	7.5	1.5×0.8
Cricula trifenestrata........	India		0.00120					2.0×0.8
Antheræa pernyi..	China	0.00118	0.00138	2.0	2.7	3.2	5.8	1.6×0.8

[1] Murphy, *Textile Industries*, p. 6.

TENSILE STRENGTH

	kg/mm²	
	Dry	Wet
Chinese silk..................................	53.2	46.7
French raw silk...............................	50.4	40.9
French silk, boiled off.......................	25.5	13.6
French silk, dyed red and weighted..........	20.0	15.6
French silk, blue-black, weighted 110 %......	12.1	8.0
French silk, black, weighted 140 %..........	7.9	6.3
French silk, black, weighted 500 %..........	2.2	

RAYONS OR ARTIFICIAL SILKS

PHYSICAL PROPERTIES

Type	Breaking strain per denier in g	Elasticity, %
Natural silk..................	2.50	21.6
Chardonnet....................	0.93	8.0
Lehner........................	1.43	7.5
Cuprammonium..................	1.64	12.5
Gelatin.......................	0.63	3.8
Viscose.......................	1.40	9.5

Breaking Strength

Type	kg/mm²	
	Dry	Wet
Chardonnet's collodion, undyed	14.7	1.7
Lenher's collodion, undyed	17.1	4.3
Strehlenert's collodion, undyed	15.9	3.6
Cuprammonium, undyed	19.1	3.2
Viscose early samples	11.4	3.5
Viscose latest samples	21.5	
Cotton yarn (for comparison)	11.5	18.6

Type	Tensile strength per denier in g		Elasticity, %
	Dry	Wet	
Viscose	1.3–1.8	0.4–0.8	15
Acetate	1.3–1.4	1.5	20
Cuprammonium	1.4	0.55	16

WOOL

Effect of Moisture Content on Strength[1]

Treatment	Average strength of warp strips, lb.	Average elongation before rupture, in.	Moisture content, %
Before treatment	160.0	2.26	10.04
After wetting	130.7	4.53	53.0
Damp	123.6	4.46	33.0
Air-dry	156.3	2.67	10.54

[1] Woodmansey, *290*, **1918**, 227.

Breaking Strength[1]

Kind of wool	Strength in g		
	High	Low	Average
Cotswold	44.54	16.10	30.44
Leicester	30.00	15.50	23.70
Lincoln	36.72	15.79	25.66
Southdown	21.29	6.48	12.78
Oxford	45.15	19.15	30.43
Merino	11.92	3.86	7.35

[1] McMurtie, *Reports on the examination of wool fibers.*

Action of Caustic Soda on Breaking Strength

NaOH solution, °Bé	Breaking strength, g	NaOH solution, °Bé	Breaking strength, g
Untreated wool	610	32	420
4	510	36	580
8	475	40	770
12	250	42	815
16	180	44	740
20	95	48	720
24	200	50	620
28	240		

Absorption of Various Acids[1]

% acid used	Hydrochloric acid		Sulfuric acid		Oxalic acid		Acetic acid		Formic acid	
	Absorbed, %	Permanently retained, %	Absorbed, %	Permanently retained, %	Absorbed, %	Permanently retained, %	Absorbed, %	Permanently retained, %	Absorbed, %	Permanently retained, %
1	0.97	0.63	0.97	0.78	0.94	0.72	0.73	0.63	0.33	0.15
2	1.51	0.58	1.90	1.48	1.72	0.95	0.94	0.73	0.71	0.34
3	1.97	0.71	2.67	1.76	2.46	0.94	0.97	0.72	0.95	0.54
4	2.32	0.78	3.58	2.12	3.16	1.33	0.35	1.06	1.35	0.83
5	2.25	0.61	3.48	1.97	3.62	1.51	1.27	0.91	1.51	0.86
6	2.40	0.72	3.86	1.90	4.06	1.31	1.19	0.83	1.78	1.16
7	2.47	0.63	3.72	2.09	4.67	1.53	1.09	0.68	1.58	0.64
8	2.71	0.76	3.80	2.04	5.16	1.78	1.25	0.70	1.55	0.65
9	2.40	0.51	3.62	1.92	5.03	1.53	1.30	0.68	1.71	0.71
10	2.58	0.61	3.79	2.00	5.16	1.39	1.39	0.73	1.48	0.55
11	2.81	0.74	4.17	2.23	5.61	1.71	1.41	0.78	1.81	0.65
12	2.69	0.61	4.06	2.03	5.77	1.47	1.40	0.64	1.54	0.56

[1] Fort and Lloyd, *290*, **1914**, 5.

CORDAGE FIBERS

Relative Strengths

Fiber	Breaking strain of thread in g	Calculated cross section in mm²	Breaking strain, g per mm²	Breaking strain, tons per in.²	Breaking length, km
Sisal	1375	0.0240	57 300	36.2	38.2
Sansevieria	1289	0.0224	57 540	36.6	38.4
Manila (abaca)	1655	0.0181	91 430	58.0	60.9
Hedychium	828	0.0093	89 300	56.7	59.1
Cotton fiber	8.2	0.00026	31 458	20.0	22.8
Cellulose monofil	294	0.0140	21 000	13.3	14.0
Strong paper					10.0

MINOR HAIR FIBERS[1]

	Mohair	Alpaca	Camel-hair	Cashmere
Length, in	9	12	5	3
Strength	Very strong	Fairly strong	Fairly strong	Fairly strong
Luster	Very high	High	Good	Good
Color	White	Vari-colored	Brownish	Brown and white
Fineness, in	1/700	1/800	1/800	1/12 000
Handle	Fairly soft	Soft	Soft	Very soft
Form of staple	Straight	Straight	Fairly curly	Fairly curly
Uniformity	Uniform	Uniform	Fair	Fair
Uses	Dress fabrics, linings, upholsteries	Dress fabrics, linings	Dress fabrics	Shawls and hosiery

[1] Barker, *Textile Mfr.*

The "breaking length" refers to a length of fiber or thread that will break of its own weight.

PHYSICAL PROPERTIES[1]

Fiber	Weight per yd., gr	Breaking strain per strand, g	Breaking length in yd.
Abaca (Manila hemp), *Musa textilis:*			
Highest	0.567	46.6	82.2
Lowest	0.962	31.0	32.2
Average	0.772	34.8	45.0
Henequen (Yucatan sisal), *Agave fourcroya*	0.765	16.7	21.8
Sisal (Hawaii and East Africa), *Agave sisalana*	0.616	22.7	38.4
Cantala (Manila maguey), *Agave cantala*	0.429	9.6	22.3
Phormium (New Zealand hemp), *Phormium tenax*	0.659	18.8	28.5
Zapupe Vincent (*Agave lespinassei*)	0.722	21.5	29.7
Cabuya (from Costa Rica), *Furcraea cabuya*	0.574	20.0	32.2

[1] Bureau of Plant Industry, Washington, D. C.

Comparative Strengths

The following results were from tests made on ropes of the same size and 1.2 m in length[1]:

COMPARATIVE STRENGTHS, DRY AND WET

Fiber	Dry, kg	Wet, kg
Hemp from Calcutta	72	86
Sunn hemp (fresh retted)	51	72
Sunn hemp (retted after drying)	27	35
Jute (*Corchorus capsularis*)	65	66
Jute (*Corchorus olitorius*)	51	56
Jute (*Corchorus strictus*)	47	52
Gambo hemp (*Hibiscus cannabinus*)	52	60
Roselle hemp (*Hibiscus sabdariffa*)	41	53
Hibiscus abelmoschus	49	49
Ramie (*Bœhmeria tenacissima*)	110	126

[1] Royle, *Fibrous Plants of India.*

COMPARATIVE STRENGTHS OF PREPARED ROPES, AND OF ROPES AFTER STEEPING IN WATER 116 DAYS

Fiber	Prepared ropes			Water-soaked, natural
	Natural	Tanned	Tarred	
Hemp, English	47			Rotted
Hemp, Calcutta	34	63	20	Rotted
Coir	39			24
Sunn hemp	31	31	27	Rotted
Jute	31	31	28	18
Linen, Calcutta	17			Rotted
Agave americana	50	36	35	Rotted
Sansevieria zeylanica	54	33	22	13

OKRA, JUTE AND OTHER CORDAGE FIBERS

	Breaking strain, lb.	
	Dry	Wet
Indian okra	79	95
Jute	113	125
Hemp (Bengal)	158	190
Hibiscus cannabinus	115	133
Hibiscus sabdariffa	95	117
Hibiscus strictus	104	115
Hibiscus furcatus	89	92

FUR FIBERS[1]

RELATIVE DURABILITY

Species	Durability (otter = 100)
Beaver	90
Bear, black or brown	94
Chinchilla	15
Ermine	25
Fox, natural	40
Fox, dyed	20–25
Goat	15
Hare	5
Kolinsky	25
Leopard	75
Lynx	25
Marten (skunk)	70
Mink, natural	70
Mink, dyed	35
Mole	7
Muskrat	45
Nutria (Coypu rat), plucked	25
Otter, sea	100
Otter, inland	100
Opossum	37
Rabbit	5
Raccoon, natural	65
Racoon, dyed	50
Sable	60
Seal, hair	80
Seal, fur	80
Squirrel, gray	20–25
Wolf	50
Wolverene	100

[1] Peterson, *The Fur Trade and Fur Bearing Animals.*

COMPARATIVE BREAKING STRENGTHS

Fiber	Breaking length in km	Breaking strength, kg per mm²
Cotton	25.0	37.6
Wool	8.3	10.9
Raw silk	33.0	44.8
Flax fibers	24.0	35.2
Jute	20.0	28.7
Ramie	20.0	28.7
Hemp	30.0	45.0
Manila hemp	31.8	47.7
Coconut fiber	17.8	29.2
Vegetable silk	24.5	35.9

	Ramie	Hemp	Flax	Silk	Cotton
Tensile strength	100	36	25	13	12
Elasticity	100	75	66	400	100
Torsion	100	95	80	600	400

TENSILE STRENGTHS OF FIBERS FOR EQUAL CROSS SECTIONS

Kind of fiber	Relative strength
Human hair	100
Lincoln wool	96.4
Leicester	119.9
Northumberland	130.9
Southdown	62.3
Australian merino	122.8

Tensile Strengths of Fibers for Equal Cross Sections.—(*Continued*)

Kind of fiber	Relative strength
Saxony merino	224.6
Mohair	136.2
Alpaca	358.5
Cotton, Egyptian	201.8

Comparative Strengths of Equivalent Yarns

Kind of yarn	Breaking strain, in oz.	
	1-in. test	27-in. test
Tram silk	45.0	40.0
Ramie	34.5	24.5
Linen	29.5	18.0
American cotton	17.0	13.5
Viscose rayon	11.0	11.0
Luster worsted	9.0	5.0
Botany worsted	7.5	3.5

SPECIFIC GRAVITIES

Determined in benzene (Vignon)

Silk, raw	1.30 to 1.37
Silk, boiled-off	1.25
Wool	1.28 to 1.33
Cotton	1.50 to 1.55
Mohair	1.30
Hemp	1.48
Ramie	1.51 to 1.52
Linen	1.50
Jute	1.48

SPECIFIC HEAT

The specific heat of all vegetable textile fibers thus far tested is practically that of cellulose, 0.32;[1] wool, 0.325; silk, 0.33; asbestos, 0.25; glass wool, 0.157.

[1] Limits observed by Dietz, *Leipzig Monatsch. Textilind.*, **1912**: 85, 0.319–0.327.

HYGROSCOPIC MOISTURE

Vegetable Fibers[1]

Fiber	Air-dry condition, %	Maximum amount hygroscopic water, %
Cotton	6.66	20.99
Flax (Belgian)	5.70	13.90
Jute	6.00	23.30
China-grass	6.52	18.15
Manila hemp (abaca)	12.50	50.00
Sunn hemp	5.31	10.87
Hibiscus cannabinus	7.38	14.61
Abelmoschus tetraphyllos	6.80	13.00
Esparto	6.95	13.32
Urena sinuata	7.02	15.20
Piassave	9.26	16.98
Sida retusa	7.49	17.11
Aloë perfoliata	6.95	18.03
Bromelia karatas	6.82	18.19
Thespesia lampas	10.83	18.19
Cordia latifolia	8.93	18.22
Bauhinia racemosa	7.84	19.12
Tillandsia fiber	9.00	20.50
Pita	12.30	30.00
Calotropis gigantea (bast)	5.67	13.13

[1] Wiesner, *Die Rohstoffe des Pflanzenreiches.*

Cotton and Mercerized Cotton[1]

	%
Ordinary cotton, unbleached	6.52
Ordinary cotton, bleached	6.25
Mercerized without tension, unbleached	9.33
Mercerized without tension, bleached	9.12
Mercerized with tension, unbleached	8.28
Mercerized with tension, bleached	8.05

[1] Higgins, *54*, **28**: 188; 09.

Moisture Fixed by Various Fibers at 100°C in an Atmosphere Saturated with Steam

Fiber, previously dried at 100°C	Water fixed, %
Bleached white cotton	23.0
Unbleached linen	27.7
Unbleached jute	28.4
Bleached silk	36.5
Bleached and mordanted wool	50.0

(Scheurer, *Bull. Soc. Ind. Mulh.*, **1900**: 89.)

Moisture Absorbed by Various Fibers at 75°F under Different Conditions of Humidity

Relative humidity, %	Moisture, %			Relative humidity, %	Moisture, %		
	Cotton	Silk	Wool		Cotton	Silk	Wool
5	1.4	1.8	2.2	55	6.3	9.4	13.4
10	2.4	3.2	4.0	60	6.7	9.9	14.2
15	3.0	4.4	5.7	65	7.3	10.5	15.0
20	3.6	5.4	7.1	70	7.9	11.4	16.0
25	3.9	6.1	8.3	75	8.8	12.5	17.1
30	4.3	6.7	9.4	80	9.9	14.0	18.6
35	4.6	7.3	10.4	85	11.4	15.9	20.5
40	5.0	7.8	11.0	90	13.6	18.4	23.2
45	5.3	8.4	11.8	95	17.5	22.7	27.0
50	5.7	8.8	12.6				

See also pp. 316, 323.

EFFECT OF HUMIDITY

Effect of Humidity on the Tensile Strength of Fabrics of Cotton, Linen and Wool

Humidity, %	Tensile strength in kg		
	Cotton	Linen	Wool
44	236	272	84.5
44	237	278	82.7
47	244	284	82.2
56	240	296	81.8
56	246	297	79.5
57	248	295	78.6
59	245.5	295	79.0
60	241	295	79.5
62	250	303	79.5
65	251	310	77.0
66	256	312	78.6
68	250.5	300.5	78.6
70	260	319	72.5
71	257.5	324	78.6
72	252	310.5	77.0
72	258	312.5	76.2
75	265	323	76.2
77	264.5	323	75.0
82	268	330	75.8
82	269	330.5	72.7

(Marschik and Breiner, *Leipz. Monatsch. Textilind.*, **1913**: 219.)

TENSILE STRENGTHS OF WORSTED YARNS AT DIFFERENT RELATIVE HUMIDITIES

Relative humidity at 70°F, %	Tensile strength, g
45	234
55	231
65	220
75	216
85	191

EFFECT OF MOISTURE ON STRENGTH OF LINEN SAIL CLOTH[1]

Moisture, %	Strength, kg	Moisture, %	Strength, kg
0.0	180	12.0	350
2.2	190	15.0	402
5.5	232	19.1	417
9.0	288	35.0	425

[1] Brun, *Chem. Zeit.*, 1893.

EFFECT OF STEAMING ON TENSILE STRENGTH OF WOOLEN CLOTH[1]

Steaming at 100°C, hr	Relative strength		
	Warp	Filling	Mean
Original cloth	100	100	100
3	86	78	82
6	80	75	77
12	75	69	72
24	68	53	60
36	62	37	50
48	40	32	36
60	29	23	26

[1] Scheurer, *Bull. Soc. Ind. Mulh.*, 1893.

EFFECT OF MOISTURE ON COTTON YARN IN FINISHING

Moisture in yarn, %	Breaking strain
2.89 (dry)	39.9
8.93 (usual)	64.0
17.36 (moist)	69.2

REGAIN

REGAINS IN CONDITIONING VARIOUS FIBERS FIXED BY THE INTERNATIONAL CONGRESS AT TURIN

	%
Silk	11
Wool (tops)	18¼
Wool (yarn)	17
Cotton	8½
Linen	12
Hemp	12
Jute	13¾
New Zealand hemp	13¾

PERCENTAGE OF MOISTURE IN TEXTILE MATERIALS CORRESPONDING TO PERCENTAGE OF REGAIN

Regain, %	Moisture, %	Regain, %	Moisture, %
5	4.76	12.5	11.11
6	5.66	13	11.50
7	6.54	14	12.28
7.5	6.98	15	13.04
8	7.41	16	13.79
8.5	7.83	17	14.53
9	8.26	18	15.25
10	9.09	19	15.97
11	9.91	20	16.67
12	10.71		

TABLE OF REGAIN FOR COTTON AT VARIOUS TEMPERATURES AND PERCENTAGES OF HUMIDITY

Humidity, %	°F					
	50	60	70	80	90	100
40	5.90	5.79	5.65	5.47	5.25	5.05
50	6.89	6.78	6.63	6.45	6.18	5.86
60	8.00	7.87	7.69	7.44	7.13	6.80
70	9.14	9.00	8.79	8.58	8.32	8.05
80	10.58	10.42	10.23	9.95	9.70	9.60
90	12.28	12.10	11.85	11.56	11.43	11.85
100	14.12	14.00	13.80	13.65	13.70	14.50

REGAIN IN WORSTED TOPS AT 70°F AT DIFFERENT RELATIVE HUMIDITIES OF THE AIR

Relative humidity, %	Regain, %
45	13.33
55	14.51
65	15.37
75	16.38
85	18.92

HEAT CONDUCTIVITY

HEAT CONDUCTING POWERS OF TEXTILE MATERIALS

	Relative values
Slag wool	100
Hair felt	117
Cotton felt	122
Sheep's wool	126
Air space	280

Comparative Values of Fibers as Non-Conductors of Heat[1]

A mass of the non-conducting material 1 in. thick was placed on a flat surface of iron kept heated to 310°F; the amount of heat transmitted per hr through the non-conductor was measured in lb. of water heated 10°F, the unit of area being 1 sq. ft. of covering:

Substance	Lb. water heated 10°F	Solid matter in 1 sq. ft., 1 in. thick, parts in 1000	Air occluded, parts in 1000
Loose wool	8.1	56	944
Goose feathers	9.6	50	950
Carded cotton	10.4	20	980
Hair felt	10.3	185	815
Fine asbestos	49.0	81	919
Air alone	48.0	0	1000

[1] Ordway, Eng. Min. J., **1890**, 650.

Heat Retaining Value of Clothing Materials

Count Rumford heated a large thermometer to 70°R and then ascertained the length of time required for the thermometer to fall to 10°R when surrounded with various textile materials, as follows:

	Sec
Air	576
Raw silk	1284
Sheep's wool	118
Cotton	1046
Fine lint (linen?)	1032
Beaver's fur	1296
Hare's fur	1315
Eiderdown	1305

In another series of experiments, however, using the same materials differently arranged, different results were obtained, as follows:

	Sec
Sheep's wool, loosely arranged	1118
Woolen thread, wound round bulb	934
Cotton, loose	1046
Cotton thread, wound round bulb	852
Lint, loose	1032
Linen thread, wound round bulb	873
Linen cloth, wound round bulb	786

From these experiments, Rumford showed that the heat-retaining value of clothing depends more on its texture than on its actual material.

FIREPROOFING

Minimum Quantity of Chemical Substances Required to Render 100 Parts of Cotton Non-inflammable (Duhem)

Reagent	Parts by weight
Tungstate of ammonium	12
Sulfate of ammonium	4½
Phosphate of sodium	30
Chloride of sodium (common salt)	35
Phosphate of calcium	30
Phosphate of magnesium	30
Chloride of magnesium	4–5
Phosphate of zinc	20
Sulfate of zinc	4½
Borate of aluminum	24
Aluminum hydrate	3
Chloride of ammonium	4¼
Phosphate of ammonium	4½
Silicate of sodium	50
Borax	8½
Chloride of calcium	4½
Sulfate of magnesium	15
Chloride of potassium	45
Borate of zinc	20
Phosphate of aluminium	30
Boric acid	10
Silicic acid	30

LITERATURE

(For a key to the periodicals see end of volume)

For much additional material on textile fibers and a fairly complete bibliography, *see* Matthews, *The Textile Fibers.* 4th ed., New York, Wiley, 1924.

TANNINS AND VEGETABLE TANNING MATERIALS

John Arthur Wilson

and

Arthur W. Thomas

The tabulation of the properties of tanning substances of vegetable origin is complicated by the facts that the chemistry of these exceedingly complex substances is still in its infancy, the literature is not always clear, due to confusion in terminology, and the authenticity of the specimen studied is often uncertain. Formulas, especially those reported in the literature before 1910, are of little value, except as they indicate the relative percentages of C, H and O.

CLASSIFICATION

The earlier classification, based upon color reactions with ferric salts, is of no present value. Two systems are now used: Perkin (34) and Freudenberg (13).

Perkin's classification: α, Gallotannins (Depsides); β, Ellagitannins (Diphenylmethylolids); γ, Catecholtannins (Phlobatannins). These are characterized by the following reactions: *$FeCl_3$:* α, blue; γ, green. *Boiling dilute H_2SO_4:* α, gallic acid is formed; β, ellagic acid ppts.; γ, phlobaphenes or "reds" ppt. *Br:* γ give a ppt. *HCl and pine wood:* γ give phloroglucinol reaction, while α and β do not. *$C_6H_5N{:}NCl$:* γ give a ppt., indicating the presence of phloroglucinol or resorcinol groups, while α and β do not. *Fusion with alkali:* α yield gallic acid and a little pyrogallol; γ yield protocatechuic acid. *Heating in glycerol:* α form pyrogallol; γ form catechol. *HCHO and HCl:* γ give complete precipitation, the others do not. *Lead acetate in CH_3CO_2H:* α are pptd., γ are not.

Freudenberg's classification: A. Hydrolyzable tannins in which the benzene nucleus is united to a larger complex through the O atoms. **A1.** Mutual esters of phenolcarboxylic acids or with other hydroxy-acids (Depsides). **A2.** Esters of phenolcarboxylic acids with polyatomic alcohols and sugars. **A3.** Glucosides. In this group gallic acid predominates as the phenolic component. There is also the extraordinary distribution of combined caffeic acid and the presence of a new phenolcarboxylic acid in chebulinic acid. The ellagic acid glucosides also belong here. The most important criterion for the inclusion in this group is the splitting into simple components by hydrolyzing enzymes, especially tannase and emulsin.

B. Condensed tannins in which C linkages hold the nuclei together. These are not decomposed into simple components by enzymes. They are generally, not always, precipitated by bromine and under the influence of oxidizing agents or strong acids condense to high molecular weight tannins or "reds." By drastic treatment, preferably by alkalis, the C skeleton is broken up and phloroglucinol, if present, is dissolved out while the remainder of the molecule is transformed mainly into phenolcarboxylic acids. **B1.** Simple ketones such as hydroxybenzophenones and hydroxyphenylstyryl ketones. The phloroglucinol and benzene nuclei are present in equimolecular proportions. **B2.** This group is more complicated. The phloroglucinol and benzene nuclei are present in equimolecular proportions. This class embraces the catechols with their corresponding tannins and "reds." This is the most important class of technically used tannins. **B3.** There is practically nothing that can be said about this class of condensed tannins. It is even impossible to state whether they are really jointly condensed systems. In common with the first class of the condensed tannin group, they are precipitated by bromine and are transformed into "reds." On the other hand, they contain no phloroglucinol nucleus. It is possible that the hydroxycinnamic acids are characteristic components of this class; caffeic acid itself is readily transformed into condensation products of the nature of "reds."

In the following tables, the information is given in the following order: Name; classification (Perkin's being indicated by Greek letters, Freudenberg's by the above combinations of letters and figures); (1), source; (2) color and form in which it is isolated; (3) formula; (4) solvents; (5) specific rotatory power; (6) color with ferric salts; (7) remarks as to constitution, etc.

	Sec
Sheep's wool, loosely arranged	1118
Woolen thread, wound round bulb	934
Cotton, loose	1046
Cotton thread, wound round bulb	852
Lint, loose	1032
Linen thread, wound round bulb	873
Linen cloth, wound round bulb	786

From these experiments, Rumford showed that the heat-retaining value of clothing depends more on its texture than on its actual material.

FIREPROOFING

MINIMUM QUANTITY OF CHEMICAL SUBSTANCES REQUIRED TO RENDER 100 PARTS OF COTTON NON-INFLAMMABLE (Duhem)

Reagent	Parts by weight
Tungstate of ammonium	12
Sulfate of ammonium	4½
Phosphate of sodium	30
Chloride of sodium (common salt)	35
Phosphate of calcium	30
Phosphate of magnesium	30
Chloride of magnesium	4–5
Phosphate of zinc	20
Sulfate of zinc	4½
Borate of aluminum	24
Aluminum hydrate	3
Chloride of ammonium	4¼
Phosphate of ammonium	4½
Silicate of sodium	50
Borax	8½
Chloride of calcium	4½
Sulfate of magnesium	15
Chloride of potassium	45
Borate of zinc	20
Phosphate of aluminium	30
Boric acid	10
Silicic acid	30

LITERATURE

(For a key to the periodicals see end of volume)

For much additional material on textile fibers and a fairly complete bibliography, *see* Matthews, *The Textile Fibers.* 4th ed., New York, Wiley, 1924.

TANNINS AND VEGETABLE TANNING MATERIALS

JOHN ARTHUR WILSON

AND

ARTHUR W. THOMAS

The tabulation of the properties of tanning substances of vegetable origin is complicated by the facts that the chemistry of these exceedingly complex substances is still in its infancy, the literature is not always clear, due to confusion in terminology, and the authenticity of the specimen studied is often uncertain. Formulas, especially those reported in the literature before 1910, are of little value, except as they indicate the relative percentages of C, H and O.

CLASSIFICATION

The earlier classification, based upon color reactions with ferric salts, is of no present value. Two systems are now used: Perkin (34) and Freudenberg (13).

Perkin's classification: α, Gallotannins (Depsides); β, Ellagitannins (Diphenylmethylolids); γ, Catecholtannins (Phlobatannins). These are characterized by the following reactions: *$FeCl_3$:* α, blue; γ, green. *Boiling dilute H_2SO_4:* α, gallic acid is formed; β, ellagic acid ppts.; γ, phlobaphenes or "reds" ppt. *Br:* γ give a ppt. *HCl and pine wood:* γ give phloroglucinol reaction, while α and β do not. *$C_6H_5N{:}NCl$:* γ give a ppt., indicating the presence of phloroglucinol or resorcinol groups, while α and β do not. *Fusion with alkali:* α yield gallic acid and a little pyrogallol; γ yield protocatechuic acid. *Heating in glycerol:* α form pyrogallol; γ form catechol. *HCHO and HCl*: γ give complete precipitation, the others do not. *Lead acetate in CH_3CO_2H:* α are pptd., γ are not.

Freudenberg's classification: **A.** Hydrolyzable tannins in which the benzene nucleus is united to a larger complex through the O atoms. **A1.** Mutual esters of phenolcarboxylic acids or with other hydroxy-acids (Depsides). **A2.** Esters of phenolcarboxylic acids with polyatomic alcohols and sugars. **A3.** Glucosides. In this group gallic acid predominates as the phenolic component. There is also the extraordinary distribution of combined caffeic acid and the presence of a new phenolcarboxylic acid in chebulinic acid. The ellagic acid glucosides also belong here. The most important criterion for the inclusion in this group is the splitting into simple components by hydrolyzing enzymes, especially tannase and emulsin.

B. Condensed tannins in which C linkages hold the nuclei together. These are not decomposed into simple components by enzymes. They are generally, not always, precipitated by bromine and under the influence of oxidizing agents or strong acids condense to high molecular weight tannins or "reds." By drastic treatment, preferably by alkalis, the C skeleton is broken up and phloroglucinol, if present, is dissolved out while the remainder of the molecule is transformed mainly into phenolcarboxylic acids. **B1.** Simple ketones such as hydroxybenzophenones and hydroxyphenylstyryl ketones. The phloroglucinol and benzene nuclei are present in equimolecular proportions. **B2.** This group is more complicated. The phloroglucinol and benzene nuclei are present in equimolecular proportions. This class embraces the catechols with their corresponding tannins and "reds." This is the most important class of technically used tannins. **B3.** There is practically nothing that can be said about this class of condensed tannins. It is even impossible to state whether they are really jointly condensed systems. In common with the first class of the condensed tannin group, they are precipitated by bromine and are transformed into "reds." On the other hand, they contain no phloroglucinol nucleus. It is possible that the hydroxycinnamic acids are characteristic components of this class; caffeic acid itself is readily transformed into condensation products of the nature of "reds."

In the following tables, the information is given in the following order: Name; classification (Perkin's being indicated by Greek letters, Freudenberg's by the above combinations of letters and figures); (1), source; (2) color and form in which it is isolated; (3) formula; (4) solvents; (5) specific rotatory power; (6) color with ferric salts; (7) remarks as to constitution, etc.

I. Natural Tannins

Beech tannin. γ. (1) Bark of red beech. (3) $C_{20}H_{22}O_9$ (34).

Caffetannic acid. γ. (1) Coffee berries as Ca and Mg salts; cainia root, *Chiococca brachiata; Nux vomica;* St. Ignatius beans; Paraguay tea, *Ilex paraguensis.* (2) Amorphous powder. (4) H_2O, C_2H_5OH. (6) Dark green (34).

Callutannic acid. γ. (1) Heather, *Calluna vulgaris.* (2) Amber colored powder. (6) Dark green (34).

Canaigre tannin. γ. **B3.** (1) Tuberous roots of the sorrel, *Rumex hymenosepalus.* (2) Bright yellow powder. (3) C, 58.10; H, 5.33 (34). (4) H_2O, C_2H_5OH. (6) Green (13, 34).

Catechol. γ. **B2.** (6) Green. *See* Table 3.

Chebulinic acid, Eutannin. α. **A2.** (1) Myrobalans, fruit of the *Terminalia chebula.* (2) Rhombic prisms, also colorless needles (34). (3) C, 50.60; H, 3.65. Probably $C_{34}H_{30}O_{23}$ (16). Air-dry substance contains 16.5% H_2O of crystn., which is lost at 100° (2). Mol. wt. by titration and by boiling point elevation in acetone, 806 (16). (4) Hot H_2O, C_2H_5OH, acetone, ethyl acetate (13). (5) α_D, +61.7° to 66.9° (H_2O) (5). α_D^{18}, +85° ±4° (abs. C_2H_5OH) (11); α_D^{22}, −60 (acetone, 1%) (2). α_D +59° to 67° (C_2H_5OH, 1–2%)(13). (6) Blue-black. (7) Apparently union between di-gallolyl-glucose and the dibasic acid, $C_{14}H_{14}O_{11}$ with elimination of $2H_2O$ (11, 16). D. at 234° (34).

Cherry bark tannin. γ. (1) Bark of *Prunus cerasus.* (3) $C_{21}H_{20}O_{10}.0.5H_2O$. (6) Green (34).

Chestnut tannin. α. **A3.** (1) Leaves, bark and wood of Spanish chestnut, *Castanea vesca.* (3) Purified tannin, C, 50.79; H, 3.32. Mol. wt. 400 or multiple as detd. by titration (24). (4) H_2O. (6) Dark green to blue. (7) Tannin from leaves, wood and bark identical. Raw tannin is mixture containing quercetin, sugar, ellagic and gallic acids. Contains no phloroglucinol. Probably similar to tannin of German native oak (24).

Chinese tannin. *See* Gallotannin.

Chlorogenic acid. **A1.** (1) Monopotassium salt combined with one molecule of caffein in coffee beans. (2) Cryst. (3) $C_{16}H_{18}O_9.0.5H_2O$. (4) Hot H_2O, C_2H_5OH, acetone, ethyl acetate. (5) α_D, −33.1° (H_2O, 1–3%). (6) Green ppt. (7) 3, 4-Dihydroxy-cinnamoyl-quinic acid (13).

Cinchona tannin, quinotannic acid. γ. **B3.** (1) Cinchona bark. (2) Light yellow powder. (3) $C_{14}H_{16}O_9$(?) (34). (4) H_2O, C_2H_5OH (13). (6) Green ppt. (7) Very hygroscopic.

Cocatannic acid. γ. (1) Leaves of *Erythroxylon coca.* (2) Yellow micro. cryst. (3) $C_{17}H_{22}O_{10}.2H_2O$(?) (6) Green (34).

Colatein. γ. **B2.** (1) Cola nuts, *Cola acuminata.* (4) Hot H_2O, C_2H_5OH, acetone. (6) Green. (7) M. P. 257°–288° (13).

Colatin, Colatannin. γ. **B2.** (1) Cola nuts, *Cola acuminata.* (2) Cryst. (13). Light red amorphous powder (34). (3) $C_{16}H_{20}O_8$ (34). (4) C_2H_5OH, acetone, ethyl acetate. (5) Inactive. (6) Green. (7) M. P. 148° (13).

Cortepinitannic acid. γ. (1) Bark of Scotch fir, *Pinus sylvestris.* (2) Bright red powder. (3) $C_{32}H_{34}O_{17}$. (6) Intense green (34).

Cyanomaclurin. **B2.** (1) Wood of *Artocarpus integrifolia.* (2) Cryst. (3) $C_{15}H_{12}O_6$. (6) Violet. (7) M. P. above 290° (13).

***m*-Digallic acid.** α. **A1.** (1) Esterified with glucose in Chinese tannin; also synthetic. *See* Table 2.

Ellagic acid. β. (1) From many tannins containing ellagitannin by boiling with dilute H_2SO_4. Divi-divi, myrobalans and valonia best sources; also synthetic. *See* Table 2.

Filitannin. γ. **B2.** (1) Fern-root, *Aspidium filix-mas.* (2) Red-brown powder (34). (3) $C_{41}H_{36}NO_{18}$(?) (29, 34). (4) C_2H_5OH, H_2O (29). (5) Inactive (13). (6) Olive-green. (7) Heated at 125°, loses water and becomes insoluble (13).

Fraxitannic acid. γ. (1) Leaves of ash tree, *Fraxinus excelsior.* (2) Brownish-yellow deliquescent powder. (3) $C_{26}H_{32}O_{14}$ (?) (29, 34). (4) H_2O, C_2H_5OH (29, 34). (6) Dark green ppt. (7) Heated at 100°, loses water and becomes practically insoluble. Yields quinone upon oxidation by permanganate (29, 34).

Galitannic acid. γ. (1) Bark of *Galium verum.* (3) $C_{14}H_{16}O_{10}.H_2O$. (6) Green (34).

Gallotannin, Gallotannic acid, Tannin, Tannic acid. α. **A2.** (1) From galls on leaves and buds of various species of oak, especially *Quercus infectoria* and *Q. lusitania* ("Turkish tannin") due to puncture by insects of the genus *Cynips.* From galls on leaves and buds of a species of sumach, *Rhus semialata* ("Chinese tannin") due to puncture of insect, *Aphis chinensis.* (2) Light yellow-brown powder. (3) Average of several specimens, C, 52.59 to 53.70; H, 3.24 to 3.40 (6). $C_{76}H_{52}O_{46}$ (E. Fischer). Mol. wt., 1247–1636 by boiling point elevation in acetone. (4) H_2O, C_2H_5OH, ethyl acetate. (5) α_D^{20}, +58° to +70° (different specimens, H_2O); α_D^{20}, +18° (one specimen, C_2H_5OH) (1, 6); α_D^{22}, +12.9° (acetone); α_D^{22}, +17.6° (purified specimen, C_2H_5OH) (1, 3). (6) Bluish-black. (7) Hydrolysis of purified specimen by dil. H_2SO_4 yields 93.6% gallic acid and 6.8% glucose (1, 3). Undoubtedly a mixture of at least two individuals (34). The tannin, according to E. Fischer, is penta-*m*-digalloylglucose. Nierenstein objects, asserting that gallotannin is probably a glucoside of polydigalloyl-leucodigallic acid anhydride or of its free acid (31).

Gallotannin, Chinese Tannin. α. **A2.** (1) *See* Gallotannin above. (2) Amorphous yellow to light brown powder. (3) Penta-*m*-digallolyglucose. Mol wt., 1700 (13). (4) *See* Gallotannin above. (5) α_D^{26}, +73° (purified specimen, H_2O, 1%) (1, 7); α_D, +45° to +53° (H_2O, 20%), rising rapidly on dilution to +135° to +140° (H_2O, 1.2%) (13); α_D in formamide, +13°; acetone, +14°; C_2H_5OH, +18°, glacial acetic acid, +25°; pyridine, +40°. These all showed high and low α_D fractions in water; were alike in organic solvents. Colloidal forms and impurities markedly affect α_D in water (23). Two fractions—(a) α_D, +30° to +40° (H_2O); +40° to +41° (pyridine); (b) α_D, +150° to +158° (H_2O); +50° to +51° (pyridine) (27). Purified tannin, after removing part difficultly soluble in water, α_D, +13.9° (C_2H_5OH, 3%); +14.9° (C_2H_5OH, 10%); +13.1° (acetone, 10%) (1, 4). Potassium salt, containing 10.2% K, α_D^{18}, +46.3° (H_2O, 1%) (1, 4). (6) Bluish-black. (7) Upon hydrolysis with dil. H_2SO_4 there is produced 88.6% gallic acid and 11.4% glucose (13). This tannin is a mixture of deka-, nona-, and octa-gallolyl-glucoses averaging 8 to 9 gallic acid radicals to 1 molecule glucose. The fractions of lower α_D contain more depside-like gallic acid (27). *See also* gallotannin above.

Gallotannin, Turkish Tannin. α. **A2.** (1) *See* Gallotannin above. Aleppo galls. (2) Amorphous yellow to light brown powder. (3) C, 52.5; H, 3.5 (13). (4) *See* Gallotannin above. (5) α_D^{17}, 2.5° (H_2O, 7%); α_D, +5° (H_2O, 7% and less); α_D^{14} +23.2° to +24.2° (acetone, 10%) (1, 8). (6) Bluish-black. (7) Hydrolysis of purified specimens with dil. H_2SO_4: 81.8 to 84.8% gallic acid; 2.7 to 3.8% ellagic acid; 11.5 to 13.8% glucose; 2.0 to 4.1% tannin residue (1, 8). Hydrolysis and fractionation give a series of fractions of increasing α_D in alcohol from 15.7° to 43.7°. Concomitantly there is a decrease in ellagic and increase in gallic acid content. The ellagic acid is a part of the tannin molecule. At least 25% of the gallic acid is in depside form, partly directly bound in ester form to the sugar hydroxyl groups (28).

Gallnut Tannin. α. **A2.** (1) Galls on acorn cups of *Quercus robur* and *Q. pedunculata.* (3) C, 52.0; H, 3.3 (13). (7) Undoubtedly identical with gallotannin.

Hamamelitannin. α. **A2.** (1) Bark of *Hamamelis virginica.* (2) Fine white needles (13). (3) C, 49.9; H, 4.0; H_2O of crystn. 17.9%, approximating $C_{20}H_{20}O_{14}.6H_2O$ (10, 18). (4) Hot H_2O, C_2H_5OH, acetone, ethyl acetate (13). (5) α_D^{23}, +29° (H_2O, 2.35%); α_D^{23}, +33° (H_2O, 1.24%); α_D^{20}, +35.6° (another specimen, H_2O, 1.2%) (10). (7) Contains no free carboxyl group. Acidity, equal to that of pyrogallol, is due to phenolic hydroxyls (10, 18). Upon hydrolysis with dil. H_2SO_4: gallic acid, 70%; sugar, 30%. Upon hydrolysis with tannase: gallic acid, 66%; sugar, 34% (13). M. P., 115°–117° (air-dry); 203° (dried at 100°) (34).

Hemlock tannin. γ. (1) Hemlock bark, *Tsuga* (*Abies*) *canadensis.* (3) $C_{20}H_{18}O_{10}$ (?). (7) Probably related to quercitannic acid of the oak (29, 34).

Horsechestnut tannin. γ. (1) Nearly all parts of the *Aesculus hippocastanum* and in root bark of apple tree. (2) Nearly colorless powder. (3) $C_{26}H_{24}O_{12}$. (6) Green (34).

Ipecacuanhic acid. γ. (1) Roots of *Psychotria ipecacuanha.* (2) Reddish-brown hygroscopic substance. (3) $C_{14}H_{18}O_7$. (6) Green (34).

Larch tannin. γ. (1) Bark of the larch, *Larix europea.* (6) Green (34).

Maclurin. B1. (1) Wood of "old fustic," *Chlorophora tinctoria;* also synthetic. (2) Yellow crystals (13). Colorless needles when pure (34). (3) $C_{13}H_{10}O_6$. (4) 14°, 1 part in 190 parts H_2O (13). (6) Green. (7) 2, 4, 6, 3′, 4′-Pentahydroxybenzophenone, M. P. 200° (anhydrous form) (34).

Maletto tannin. γ. **B2.** Bark of *Eucalyptus occidentalis* and other species of *Eucalyptus.* (2) Brown powder. (3) $(C_{19}H_{20}O_9)_n$ (29, 34). (4) H_2O, abs. C_2H_5OH (from which it is precipitated by ether) (13). (7) Similar to quebracho tannin (13, 34).

Mangrove tannin. γ. **B2.** (1) *Rhizophora mangle*, *R. mucronata*, *Ceriops candolleana*, *C. roxburghiana.* (2) Amorphous red powder. (3) $C_{24}H_{26}O_{12}$ (29). (6) Green. (7) Closely resembles catechutannic acid (34).

Mimosa tannin. γ. (1) Various species of *Mimoseae* such as *Acacia arabica* of Egypt and the "wattles" of Australia. (6) Bluish-violet. (7) With the exception of the reaction with ferric salts, gives all the ordinary reactions of the phlobatannins (34).

Oak tannin. B3 (36). (1) Leaves and buds of German oak, *Quercus pedunculata.* (2) Amorphous reddish-yellow powder (22). (3) C, 49.9; H, 4.2. (4) H_2O, C_2H_5OH, acetone (22, 36). (4) $\alpha_{\mathrm{Hg\ yellow}}$, −39° ± 10° ($H_2O$); −30° ± 4° ($CH_3OH$) (21). (7) Tannin from leaves of *Quercus sessiflora* identical (21). Molecule contains 18–25% bound ellagic acid; 3–7% bound glucose; and the rest is an amorphous acid, "Quercus acid," C, 50.2; H, 3.6. Titration equivalent about 400 (21, 22).

Oak tannin, Quercitannic acid. γ. **B2.** (1) Bark of various species of *Quercus* (34); Bark of *Quercus robur* (13). (2) Reddish-white powder (34). Light brown powder (13). (3) $C_{20}H_{20}O_4$ (?): C, 59.79; H, 5.0 (34). C, 56.8; H, 4.4. C, 55.4; H, 4.1 (13). (6) Green (34). Black-blue (13).

Oak tannin, Quercin, Quercic acid, Quercinic acid. γ. **B2.** (1) Wood of various species of *Quercus.* (2) Light brownish-yellow (34). (3) $C_{15}H_{12}O_9.2H_2O$ (29, 34). C, 48.3; H, 4.5 (13). (6) Blue.

Paullinio tannin, Guarana tannin. γ. **B2.** (1) "Guarana paste" from seeds of *Paullinia cupana.* (2) Small colorless crystals (34). Gray needles (30). (3) $C_{37}H_{35}O_{18}.COOH.2H_2O$ (30). (4) H_2O, C_2H_5OH, ethyl acetate, glacial acetic acid (30). (5) α_D^{20}, −74.4° (H_2O, 10%); α_D^{18}, −39.1° (C_2H_5OH, 8%); −48.1° (acetone, 6%); α_D^{20}, −56.8° (initial rotation in pyridine, 8%. By mutarotation falls to constant value of −8.6°) (30). (7) M. P. 199°–201° with evolution of CO_2. Loses two mol. H_2O of crystn. at 130°. M. P. of anhydrous form 259°–261° with evolution of CO_2 (30). Paullinia catechol isolated from paullinia tannin is identical with "acacatechin" in crystal form and chemical properties. Chemically it is identical with gambier-catechin (13).

Pinicortannic acid. γ. (1) Bark of Scotch fir, *Pinus sylvestris.* (2) Reddish-brown powder. (3) $(C_{16}H_{18}O_{11})_2.H_2O$. (6) Green (34).

Pistachio tannin. γ. **B2.** (1) Leaves of mastic tree, *Pistachia lentiscus.* (2) Pale brown brittle mass (34). (4) H_2O, C_2H_5OH, ethyl acetate (13). (6) Blue-black. (7) Often sold for sumach (34).

Pomegranate tannin, Ellagitannin. β. **A3.** (1) Root bark of *Punica granatum.* (2) Amorphous greenish-yellow powder. (3) $C_{20}H_{16}O_{13}$ (34). Two fractions: A (sol. in H_2O), C, 50.9; H, 3.4. B (insol. in H_2O), C, 52.4; H, 3.4 (13). (4) Fraction A: H_2O, C_2H_5OH, ethyl acetate (13). (6) Blue-black. (7) Glucoside of ellagic acid and hexose (13).

Quebracho tannin. γ. **B2.** (1) Wood of *Quebracho colorado*, *Schinopsis lorentzii* and *Balsanae.* (2) Red powder. (3) C, 62.5; H, 5.4. (4) Hot H_2O, C_2H_5OH, ethyl acetate, acetone (13). (6) Green. (7) Tannin is mixture of products insol. in H_2O and sparingly sol. in cold H_2O. A benzoyl derivative, C, 73.0; H, 4.2, showed a mol. wt. in benzene of about 2300.

Rhatany tannin. γ. Bark of root of rhatany, *Krameria triandra.* (2) Light yellow powder. (4) H_2O. (6) Green (34).

Rheotannic acid, Rhubarb tannin. γ. **B2.** (1) Rhubarb. (2) Yellowish-brown powder. (3) $C_{26}H_{26}O_{14}$ (34). (4) H_2O. (6) Black-green ppt. (7) Contains two glucosides, glucogallin ($C_{13}H_{16}O_{10}$) and tetrarin ($C_{32}H_{32}O_{10}$) (34). Catechin also present which is probably identical with gambier-catechin (13).

Rubitannic acid. γ. (1) Leaves of *Rubia tinctorum.* (3) $C_{14}H_{22}O_{12}.0.5H_2O$. (6) Green (34).

Sequiatannic acid. γ. (1) Cones of *Sequoia gigantea.* (2) Reddish-brown powder. (3) $C_{21}H_{20}O_{10}$ (29, 34). (4) H_2O, C_2H_5OH. (6) Brown-black ppt.

Spruce bark tannin. γ. (1) Bark of spruce. (3) $C_{21}H_{20}O_{10}$ (?) (34).

Sumach tannin. α. **A2.** (1) From leaves of many species of *Rhus.* Also *Coriaria myrtifolia* (French), *Colpoon compressum* (Cape), *Arctostaphylos* (Russian). (2) Yellow powder. (3) C, 52.3; H, 3.5. (*Rhus coriaria*) (13). (4) H_2O, C_2H_5OH, ethyl acetate. (7) Similar to Turkish tannin.

Tannecortepinic acid. γ. (1) Bark of young Scotch firs in spring time. (3) $C_{28}H_{26}O_{12}$. (6) Green (34).

Tannic acid. *See* Gallotannin.

Tea tannin. γ. **A2.** (1) Leaves of black tea. (4) H_2O, ethyl acetate. (5) α_D, −177.3° (29). (7) Probably identical with quercitannic acid (29, 34). A gallotannin (13).

Tormentilla tannin. γ. (1) Root of *Potentilla tormentilla.* (2) Amorphous reddish powder. (3) $C_{26}H_{22}O_{11}$. (6) Blue-green (34).

Turkish tannin. *See* Gallotannin.

Willow bark tannin. γ. (1) Bark of *Salix triandra.* (6) Green. (7) Glucoside tannin (34).

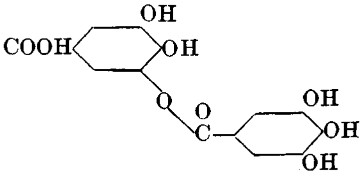
II. SYNTHESIZED TANNINS

***m*-Digallic acid.** α. A1. (2) Fine needles. (3) I (13). (4) CH_3OH, C_2H_5OH, $C_5H_{11}OH$. 23°, 1 part in 950 parts H_2O; 1 part in 350 parts ethyl acetate; 1 part in 2000 parts ether (1, 5). 25°, 1 part in 1900 parts H_2O. 100°, 1 part in 50–60 parts H_2O (13). (5) Inactive. (6) Blue-black. (7) Found esterified with glucose in Chinese tannin. When hot aq. solution is chilled, it jellifies (13). M. P., 275° (282° corr.) with foaming and decomposition (1, 5).

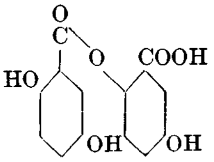
Digalloyl-levoglucosan. A2. (2) Micro-needles. (3) $C_{20}H_{18}O_{13}$. (4) H_2O, C_2H_5OH, acetone. (5) α_D^{18}, −27.9° (C_2H_5OH, 1.8%). (6) $FeCl_3$ gives blue-black ppt. in C_2H_5OH solution. (7) Decomposes 220°, carbonizes 270° (26).

Digentisic acid. α. (2) Fine needles. (3) II. (4) 0°, 1 part in 900 parts H_2O. (5) Inactive. (6) Fugitive blue and ppt. (1, 5). (7) Dry form melts 204°–205° (208°–209° corr.) with sintering.

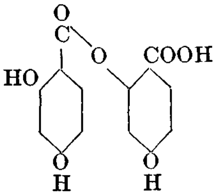
Diprotocatechuic acid. α. (2) Fine needles. (3) $(OH)_2C_6H_3$-$CO.O.C_6H_3(OH)COOH$. (4) Acetone, CH_3OH. 1 part in 2500 parts H_2O. (5) Inactive. (6) Blue-green. (7) M. P., 237°–239° (corr.) (1, 5).



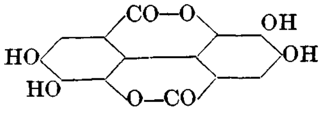
I. *m*-Digallic acid



II. Digentisic acid



III. Di-β-resorcylic acid



IV. Ellagic acid

Di-β-resorcylic acid. α. (2) Micro-needles. (3) III. Isomeric with digentisic acid. (4) C_2H_5OH, acetone, ethyl acetate, hot H_2O, ether. (5) Inactive. (6) Violet red. (7) Foams and decomposes at about 210° (215° corr.) (1, 5).

Ellagic acid. β. (2) Cryst. from pyridine in prismatic needles which are converted by C_2H_5OH to a pale yellow cryst. powder. (3) $C_{14}H_6O_8.2H_2O$. IV. (5) Inactive. (7) Above 360° sublimes with carbonization (34). Not a true tannin. *See* Table 1.

Hexagalloyl mannite. **A2.** (2) Amorphous brown powder. (3) $C_6H_8O_6[CO.C_6H_2(OH)_3]_6$. (4) H_2O, C_2H_5OH, acetone, ethyl acetate. (5) α_D^{18}, +27.0° (C_2H_5OH, 2%). (6) Dark blue (1, 4).

Maclurin. **B1.** *See* Table 1.

Penta-*m*-digalloyl-α-glucose. **A2.** (2) Light brown amorphous mass. (3) $C_{76}H_{52}O_{46}$. (4) 18°, 1 part in 200 parts H_2O. (5) Prepared by alkaline hydrolysis of acetates: α_D^{18}, +36°(C_2H_5OH, 10%); +40° to 41° (acetone, 10%); 43.8° (H_2O, 1%) (1, 3). Prepared from acetates by CH_3OH and HCl: α_D^{18}, +41.3° (C_2H_5OH, 5%); +44.6° (acetone, 5%); +51° (H_2O, 0.5%) (1, 4). (6) Blue-black. (7) Potassium salt containing 10.3% K, α_D^{18} +56.6° (H_2O, 5%) (1, 4).

Penta-*m*-digalloyl-β-glucose. **A2.** (2) Light brown amorphous mass. (3) $C_{76}H_{52}O_{46}$. (4) 20°, 1 part in 1000 parts H_2O. (5) Prepared by alkaline hydrolysis of acetates: α_D^{18}, +14.9° (C_2H_5OH, 10%); +13.1° (acetone, 10%); +42.3° (H_2O, 1%) (1, 3). Prepared from acetates by CH_3OH and HCl: α_D^{18}, +10.8° (C_2H_5OH, 5%); +10.8° (acetone, 5%); +21° (H_2O, 0.1%) (1, 4). (6) Blue-black. (7) Apparently identical with Chinese tannin. Potassium salt containing 10.3% K, α_D^{18}, +33.7° (H_2O, 0.5%) (1, 4).

Pentagalloyl-α-glucose. **A2.** (2) Yellow mass. (3) $[(OH)_3C_6H_2CO]_5C_6H_7O_6$. (4) H_2O, C_2H_5OH, ether (1, 3). (5) α_D^{18}, +66.5° (H_2O, 1%). α_D^{23}, 65.4° (H_2O, 1%). α_D^{20}, +77.0° (C_2H_5OH, 3%). α_D^{18}, 76.4° (C_2H_5OH, 2%) (1, 3). α_D^{16}, +60° (H_2O, 1%); +81.5° (C_2H_5OH, 2%) (1, 4). (6) Blue-black.

Pentagalloyl-β-glucose. **A2.** (2) Yellow mass. (3) $[(OH)_3C_6H_2CO]_5C_6H_7O_6$. (4) H_2O, C_2H_5OH (1, 3). (5) α_D^{18}, +13.1° (H_2O, 1%); +13.6° (H_2O, 10%); +23.3° (C_2H_5OH, 2%) (1, 3). α_D^{18}, +15° (H_2O, 1%); +24° (C_2H_5OH, 2%). (6) Blue-black. (7) Potassium salt contains 10.1% K.

Pentapyrogallol-carboyl-glucose. **A2.** (2) Amorphous powder. (3) $[(OH)_3C_6H_2CO]_5C_6H_7O_6$. (4) Hot H_2O, C_2H_5OH, acetone. (5) α_D^{18}, +69° (H_2O, 2.5%). (6) Dark blue (1, 9). (7) Sinters at 160° and melts at about 200° with decomposition.

Tetragalloyl-erythrite. **A2.** (2) Cryst. (3) $[(OH)_3C_6H_2CO]_4C_4H_6O_4$. (4) Hot H_2O, C_2H_5OH, acetone, mixtures of H_2O and C_2H_5OH. (7) Decomposes at about 308° (1, 4).

Tetragalloyl-α-methylglucoside. **A2.** (3) $C_{35}H_{30}O_{22}$. (4) Identical with pentagalloyl-glucoses. (5) α_D^{20}, +26.4° (H_2O, 4%). (6) Identical with pentagalloyl-glucoses in reactions. (7) M. P. 130°–140° with decomposition (1, 6).

Trigalloyl-acetone-glucose. **A2.** (2) Amorphous light brown mass. (3) $[C_6H_2(OH)_3CO]_3C_6H_7O_6(C_3H_6)$. (4) Warm H_2O, CH_3OH, C_2H_5OH, acetone, ethyl acetate. (5) α_D^{20}, −93° (dry acetone, 4%). (6) Blue-violet (1, 2).

Trigalloyl-glucose. **A2.** (2) Amorphous yellowish brown mass. (3) $[C_6H_2(OH)_3CO]_2C_6H_9O_6$. (4) Cold H_2O, CH_3OH, C_2H_5OH, acetone, ethyl acetate, pyridine. (5) α_D^{20}, −118° (dry acetone, 2.5%). (6) Deep violet (1, 2).

Trigalloyl-glycerol. **A2.** (2) Amorphous yellowish brown mass. (3) $[(OH)_3C_6H_2CO]_3C_3H_5O_3$. (4) H_2O, acetone, ethyl acetate, warm ether. (6) Deep blue (1, 4).

α-Trigalloyl-levoglucosan. A2. (2) Micro. hexagonal crystals. (3) $C_{27}H_{22}O_{17}$. (4) Hot acetone. (5) α_D^{18}, −18.0° (C_2H_5OH, 19%). (6) $FeCl_3$ gives blue-black ppt. in C_2H_5OH solution. (7) Decomposes 250°–300°, carbonizes 320° (26).

β-Trigalloyl-levoglucosan. **A2.** (2) Micro-needles. (3) $C_{27}H_{22}O_{17}$. (5) α_D^{18}, −21.0° (C_2H_5OH, 1%). (6) $FeCl_3$ gives blue-violet ppt. in C_2H_5OH solution. (7) Decomposes 270°, carbonizes 320° (26).

III. Catechols or Catechins

d-**Catechol.** (1) Acacia and gambier catechus. (2) Thin needles. (3) $C_{15}H_{14}O_6.4H_2O$ (20). (4) C_2H_5OH, ethyl acetate, pure ether. Anhydrous form almost insoluble in latter two. (5) α_{578}, +17° (50% acetone, 9%) (14, 15, 19, 20). α_{578}, ±0° (C_2H_5OH) (20). α_D, −2° (C_2H_5OH) (20). α_D^{18}, −0.47° ±0.03° (C_2H_5OH, 9%); +3.7° ± 0.5° (50% C_2H_5OH, 9%). α_D^{20}, +18.4° ± 0.9° (H_2O, 0.9%, increasing markedly with temperature decrease) (14). (7) For discussion of structural formula *see* (20, 29, 33). M. P. 93°–95°; anhyd., 174–5°.

l-**Catechol.** (1) Isolated from acacia and gambier catechus. (2) Thin needles. (3) $C_{15}H_{14}O_6.4H_2O$. (5) α_{578}, ±0° (C_2H_5OH); α_{578}, −16.8° (50% acetone, 3%) (20). (7) M. P. 93°–95°; anhyd., 174°–175° (19, 20).

dl-**Catechol.** (1) Principal constituent of catechol separated from acacia catechu. (2) Thin needles. (3) $C_{15}H_{14}O_6.3H_2O$. (7) Is "acacatechin" (19). Sinters at 100°, melts 214°–216° with decomposition (19, 20).

Catechol-a. (1) Acacia catechu (33, 35). (3) $C_{15}H_{14}O_6.3H_2O$ (35). (7) Is *dl*-catechol (14). Methylated "acacatechin" has same melting point and crystal form as synthetic methyl compound (14). M. P. 204°–205° (35).

Catechol-b, Gambier catechol. (1) Gambier catechu (33, 35). (7) Identical with *d*-catechol in crystal form, melting point, solubility, and constitution.

Catechol-c. (1) Gambier catechu. (2) Small pale yellow prisms (35). (3) $C_{15}H_{14}O_6$. (7) Identified as *d*-epicatechol (20). M. P. 235°–237° (35).

Chinese rhubarb catechol. (5) α_{578}, +18° (50% acetone) (15).

Mahogany catechol. (5) α_D, +23° (50% acetone). α_{578}, +16° (50% acetone); +15° (C_2H_5OH) (15).

Paullinia catechol. (5) Inactive in C_2H_5OH. α_D, +3.7° (50% acetone) (15).

d-**Epicatechol.** (2) Thick prisms. (3) $C_{15}H_{14}O_6.4H_2O$. (5) α_{578}, +68.9° (C_2H_5OH, 7%); +59.9° (50% acetone, 4%). (7) M. P. 245° (20).

l-**Epicatechol.** (1) Gambier and acacia catechus (19). (2) Thick prisms. (3) $C_{15}H_{14}O_6.4H_2O$ (19, 20). (5) α_{578}, −68.2° (C_2H_5OH, 6%): −59.0° (50% acetone, 4%) (19, 20). (7) M. P. 245°.

***dl*-Epicatechol.** (1) Gambier and acacia catechus (19). (2) Exists both as prisms and needles. (3) $C_{15}H_{14}O_6.4H_2O$. (7) M. P. of prisms, 224°–226° (20).

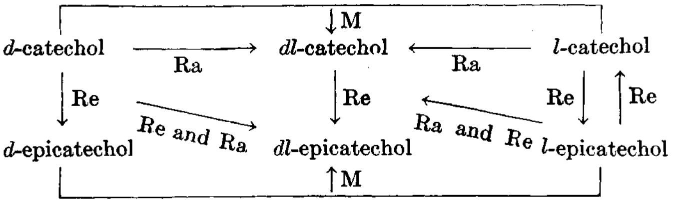
***d*-β-Gambier catechol-carboxylic acid.** (2) Micro-needles. (3) $C_{16}H_{14}O_8$. (5) α_D^{20}, +12.6° (H_2O, 5%); +17.6° (C_2H_5OH, 7%). (7) M. P. 249°–251° with evolution of CO_2 (30).

***l*-β-Gambier catechol-carboxylic acid.** (2) Large needles. (3) $C_{16}H_{14}O_8$. (5) α_D^{18}, −22.4° (H_2O, 5%). α_D^{17}, −31.6° (C_2H_5OH, 6%). (7) M. P. 258°–261° with evolution of CO_2 (30).

***dl*-β-Gambier catechol-carboxylic acid.** (3) $C_{16}H_{14}O_8$. (7) M. P. 252°–253° with evolution of CO_2 (30).

The relationship between the catechols and epicatechols is shown as follows:

M = mixing; Ra = racemizing; Re = rearrangement (20).



LITERATURE

(For a key to the periodicals see end of volume)

(1) Fischer, *Untersuchungen über Depside und Gerbstoffe*, 1919. (2) Fischer and Bergmann, *25*, **51**: 298; 18. (3) *Idem.*, *25*, **51**: 1760; 18. (4) *Idem.*, *25*, **52**: 829; 19. (5) Fischer and Freudenberg, *8*, **384**: 225; 11. (6) *Idem.*, *25*, **45**: 915; 12. (7) *Idem.*, *25*, **45**: 2709; 12. (8) *Idem.*, *25*, **47**: 2485; 14. (9) Fischer and Rapaport, *25*, **46**: 2389; 13.

(10) Freudenberg, *25*, **52B**: 177; 19. (11) *Idem.*, *25*, **52B**: 1238; 19. (12) *Idem*, *25*, **53B**: 1416; 20. (13) *Idem.*, *Die Chemie der natürlichen Gerbstoffe*, 1920. (14) Freudenberg, Böhme and Beckendorf, *25*, **54B**: 1204; 21. (15) Freudenberg, Böhme and Purrmann, *25*, **55B**: 1734; 22. (16) Freudenberg and Fick, *25*, **53B**: 1728; 20. (17) Freudenberg, Orthner and Fekentscher, *8*, **436**: 286; 24. (18) Freudenberg and Peters, *25*, **53B**: 953; 20. (19) Freudenberg and Purrmann, *25*, **56B**: 1185; 23.

(20) Freudenberg and Purrmann, *8*, **437**: 274; 24. (21) Freudenberg and Vollbrecht, *8*, **429**: 284; 22. (22) *Idem.*, *25*, **55B**: 2420; 22. (23) Freudenberg and Scilasi, *25*, **55B**: 2813; 22. (24) Freudenberg and Walpuski, *25*, **54B**: 1695; 21. (25) Iljin, *52*, **82**: 422; 10. (26) Karrer and Salomon, *37*, **5**: 108; 22. (27) Karrer, Salomon and Peyer, *37*, **6**: 3; 23. (28) Karrer, Widmer and Staub, *8*, **433**: 288; 23. (29) Nierenstein, *Abderhalden's Biochemisches Handlexikon*, vol. 7, 1912.

(30) Nierenstein, *4*, **121**: 23; 22. (31) *Idem.*, *54*, **41**: 29; 22. (32) *Idem.*, *1*, **46**: 2793; 24. (33) Perkin, *4*, **87**: 398; 05. (34) Perkin and Everest, *The Natural Organic Coloring Matters*, 1918. (35) Perkin and Yoshitake, *4*, **81**: 1160; 02. (36) Vollbrecht, *259*, **1921**: 1.

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS

The names and tannin contents listed were taken from the literature at large for what they may be worth; in some cases the information given may be considerably in error. The place grown may indicate either the place where the sample analyzed was grown or the place where the material grows in abundance. In the majority of cases, at least, the tannin contents are supposedly those of the air-dried material.

In using the tannin figures, it should be recognized that they are not true tannin contents, but merely figures obtained by methods open to very serious question. A number of slightly different methods were used, but all conformed roughly to the following general scheme. A solution of the tanning material of concentration confined to certain limits was treated with lightly chrome-tanned hide powder until no tannin was left in solution; *i.e.*, the solution no longer gave a precipitate with gelatin solution. The decrease in concentration of all matters in solution was then taken as the measure of the tannin content. Obviously all substances of a slightly acid nature would be removed to some extent by the hide powder and hence all figures must be high where these are present.

The probable magnitude of the error was shown by Wilson and Kern for a number of the commoner tanning extracts. By first freeing the tannin solution of tannin by shaking with hide powder and then freeing the hide powder from nontannin by washing, they were able to estimate the tannin by the increase in weight of the dried hide powder. The tannin contents so obtained differed in many cases by startling amounts from those obtained by the methods generally accepted as official.

The comparison is with the official method of the American Leather Chemists' Association, which is similar in principle to the methods employed in other countries.[1]

Tanning material	Per cent tannin found	
	A. L. C. A. method	Wilson-Kern method
Chestnut wood extract	25.80	11.90
Gambier extract	24.95	7.79
Hemlock bark	10.06	6.17
Hemlock bark extract	26.68	23.38
Oak bark extract	24.20	12.88
Osage orange extract	39.87	13.37
Quebracho extract	68.01	47.41
Spruce bark extract	22.14	11.71
Sumac extract	25.51	16.29
Sumac leaves	25.56	9.61
Wattle bark extract	33.55	24.16

Many of the tanning materials are leached on a large scale by extract manufacturers and the concentrated extracts are available on the market showing a tannin content by the A. L. C. A. and similar methods of from 20 to 35% for liquid extracts and from 45 to 70% for solid extracts.

It may be assumed that nearly every form of plant life contains some tannin. The following list is not complete but is intended to serve as a guide to those whose interests might be directed into these fields of work.

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[1] For a detailed comparison of the methods and their interpretation, see J. A Wilson, *The Chemistry of Leather Manufacture*, p. 215–31 (The Chemical Catalog Co., New York, 1923).

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS

Botanical name	Common name	Place grown	Per cent tannin
Abies alba	White spruce	Northern America	Bark 7–13
Abies canadensis	Hemlock fir	Northern America	Bark 8–15
Abies dumosa	Hemlock spruce	Northern America	Bark 10
Abies excelsa	Norway spruce	Northern Europe	Bark 7–13
Abies grandis	Lowland fir	California	Bark 9
Abies pectinata	Silver fir	Europe	Bark 6–15
Acacia acuminata	Raspberry jam wood	Australia	Bark 7–15
Acacia angica	Angica	Brazil	Bark 20–25
Acacia anema	Mulga	New South Wales	Bark 5–9
Acacia arabica	Babul	India	Bark 12–20 Pods 20–42
Acacia binervata	Black wattle	Australia	Bark 30
Acacia catechu	Cutch	India	Wood ext. 60
Acacia cavenia	Espinillo	South America	Pods 18–21 Bark 6
Acacia cebil	Red cebil	Argentina	Bark 10–15 Leaves 6–7
Acacia cunninghamii		Queensland	Bark 9
Acacia curupi	Curupy	South America	Bark 18
Acacia dealbata	Wattle	Africa and Asia	Bark 17–23
Acacia decurrens	Wattle	Australia	Bark 18–51
Acacia granulosa		New Caledonia	Bark 12
Acacia homalophylla	Yarran	New South Wales	Bark 9
Acacia horrida	Doornbosch	Cape Good Hope	Bark 8–18
Acacia koa	Koa tree	Hawaii	Bark 18
Acacia leptocarpa		Queensland	Bark 10
Acacia longifolia		Cyprus	Bark 15
Acacia melanoxylon	Blackwood	New South Wales	Bark 11 Leaves 3
Acacia microbotrya	Manna wattle	Australia	Bark 18–27 Leaves and twigs 20
Acacia mollissima	Green wattle	Australia	Bark 12–47
Acacia neriifolia		Australia	Bark 14
Acacia oswaldi	Miljie	Australia	Bark 10
Acacia penninervis	Hickory	Europe	Bark 14–38
Acacia podalyriaefolia		Queensland	Bark 12
Acacia polystachya		Queensland	Bark 18
Acacia pycnantha	Golden wattle	Australia	Bark 40–50
Acacia salicina		Australia	Bark 6–8
Acacia sentis		New South Wales	Bark 6
Acacia seyal	Talh	Sudan	Bark 18
Acacia sp.	Gallol	Somaliland	Bark 24
Acacia spiralis	Guaic	New Caledonia	Bark 17
Acer campbellii	Himalayan maple	India	Bark 3
Acer campestre	Field maple	Europe	Bark 4
Alchornea triplinervia	Tapia gwazu-ih	Paraguay	Bark 12
Allophylus edulis	Koku	Paraguay	Bark 10
Alnus firma	Minibari	Japan	Fruits 25
Alnus glutinosa	Alder	Europe	Bark 16–20
Alnus incana	Grey alder	Europe	Bark 10
Alnus maritima	Hannoki	Japan	Fruits 25
Alnus oregona	Red alder	Pacific states	Bark 9
Anacardium occidentale	Kashew nut	India	Bark 9
Anogeissus acuminata	Yon	India	Bark 10
Anogeissus latifolia	Dhawa	India	Bark 16 Leaves 10–18 Shoots 20–30 Red tips 54
Anogeissus pendula		India	Bark 9
Apuleia praecox	Yhvihra-pere	Paraguay	Bark 11
Arctostaphylos uva-ursi	Bearberry	Russia	Leaves and twigs 14
Areca catechu	Betelnut palm	India	Fruits 10–15
Aspidiosperma polyneuron	Palo rosa	Paraguay	Bark 3

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Aspidiosperma quebracho-blanco	White quebracho	Argentina	Leaves 27–28 Bark 4 Wood 3
Banksia integrifolia	Coast honeysuckle	Queensland	Bark 11
Banksia serrata	Heath honeysuckle	Australia	Bark 11–23
Bauhinia vahlii	Muhurain bark	India	Bark 9
Betula alba	White birch	Northern Europe	Bark 2–18
Betula lenta	Black birch	Northern America	Bark 3–18
Boswellia serrata	Salai bark	India	Bark 13
Bruguiera gymnorrhiza	Mangrove	East Africa	Bark 22–52
Bruguiera parviflora	Hagalay	Philippines	Bark 7–13
Bruguiera rhumphii	Mangrove	New Caledonia	Bark 27–42 Root bark 6 Root wood 9
Bumelia obtusifolia	Pihkasurembiu	Paraguay	Bark 8
Byrsonima cydoniaefolia	Mureci	Bolivia	Bark 20
Byrsonima spicata	Tamwood	South America	Bark 44
Cabralea sp	Cancharana	Paraguay	Bark 5
Caesalpinia brevifolia	Algarobilla	Chile	Pods 43–67
Caesalpinia cacolaco	Cascalote	Mexico	Pods 40–55
Caesalpinia coriaria	Divi-divi	Central America	Pods 30–50
Caesalpinia digyna	Tari	India and Burma	Pod cases 40–60
Caesalpinia melanocarpa	Guyacan	Argentina	Pods 15–23 Wood 8
Caesalpinia tinctoria	Celavinia	Central America	Pods 30–32
Callitris calcarata	Australian fir	Australia	Bark 17–31
Callitris glauca	Australian fir	Australia	Bark 12–15
Camellia thea	Tea	Asia and Africa	Leaves 5–10
Carissa spinarum		India	Leaves 8–12
Cassia auriculata	Tarwar	India	Bark 16–22
Cassia fistula	Amaltas	South India	Bark 11–15 Pod husk 17
Castanea pubinervis	Japanese chestnut	Japan	Bark 6 Wood 7
Castanea cesva	Spanish chestnut	Southern Europe Southern U. S.	Bark 6–8 Wood 7–11
Castanopsis chrysophylla	Western chinquapin	Pacific states	Bark 8
Castanopsis sinensis	Gie-gay	Indo-China	Bark 12
Casuarina	Ironwood	New Caledonia	Bark 10
Casuarina equisetifolia	Casagha pine	Southern Asia	Bark 11–18
Casuarina glauca	Bull oak	New South Wales	Bark 12
Ceanothus velutina	Snow bush	Western U. S.	Leaves 17
Ceriops candolleana	Bahau	India and Africa	Bark 24–42
Ceriops roxburghiana	Goran	India	Bark 13
Ceriops tagal	Tangal	Philippines	Bark 24–37
Cleistanthus collinus	Kodarsi		Bark 33
Cocos romanzoffiana	Pindo	Paraguay	Bark 7
Copaifera lansdorfii	Kupaih	Paraguay	Bark 17
Coriaria myrtifolia	French sumac	France	Leaves 15
Coriaria nepalensis		India	Leaves 20
Coriaria ruscifolia	Tutu	New Zealand	Bark 16–17
Corylus avellana	Hazel	Europe	Bark 5
Coulteria tinctoria	Tara	Algeria and Peru	Pods 43–51
Crossostylis multiflora	Bush mangrove	New Caledonia	Wood 21 Bark 3
Cryptomeria japonica	Japanese cedar	Japan	Bark 6
Cupania sp	Cedrillo	Paraguay	Bark 16
Cupania uraguensis	Kambuata	Paraguay	Bark 18
Cupania vernalis	Yaguarataih	Paraguay	Bark 15
Dalbergia sp	Yhsapih-ih	Paraguay	Bark 6
Dioscorea atropurpurea	Cu-nao	Indo-China	Tubers 20
Elaeocarpus grandis	Blue fig bark	New South Wales	Bark 10
Elephantorrhiza burchellii	Elephant roots	Africa	Root 6–22
Enterolobium timbouva	Timbo	Paraguay	Bark 22

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Eremophila longifolia	Emu bush	New South Wales	Bark 5 Leaves 10
Eucalyptus accedens	Spotted gum	Australia	Bark 18
Eucalyptus alba	Mountain gum	Australia	Bark 30–32
Eucalyptus amygdalina	Ribbon gum	New South Wales	Gum 58–65
Eucalyptus corymbosa	Bloodwood	New South Wales	Gum 28 Leaves 18 Bark 6
Eucalyptus diversicolor	Karri	Australia	Bark 16–20
Eucalyptus erythronema	White mallet	Australia	Bark 30
Eucalyptus falcata	Silver mallet	Australia	Bark 5–32
Eucalyptus globulus	Eucalyptus	Australia	Sap 28
Eucalyptus gunnii	Red gum	New South Wales	Leaves 17 Bark 11
Eucalyptus longifolia	Woolly-butt	Australia	Bark 8
Eucalyptus maculata	Spotted gum	New South Wales	Gum 45 Bark 10 Leaves 5
Eucalyptus loxophleba	York gum	Australia	Bark 5–10
Eucalyptus obliqua	Stringy bark	New South Wales	Bark 17
Eucalyptus occidentalis	Black mallet	Australia	Bark 20–26
Eucalyptus occidentalis astringens	Red mallet	Australia	Bark 40–50
Eucalyptus odorata	White box	New South Wales	Leaves 7
Eucalyptus piperita	Messmate	New South Wales	Gum 32–62 Leaves 13
Eucalyptus platypus	Round leaf moort	Australia	Bark 25
Eucalyptus redunca	Wandoo	Australia	Bark 16–20
Eucalyptus redunca oxymitra	Blue leaf mallet	Australia	Bark 22–30
Eucalyptus robusta	Mahogany	Florida	Leaves 12–17
Eucalyptus rostrata	Blue gum	Australia	Bark 16
Eucalyptus salmonophloia	Salmon gum	Australia	Bark 8–13
Eucalyptus salubris	Gimlet	Australia	Bark 16–19
Eucalyptus siderophloia	Red iron bark	New South Wales	Gum 35–73 Bark 10 Leaves 6
Eucalyptus sieberiana	Cabbage gum	New South Wales	Bark 37
Eucalyptus spathulata	Swamp mallet	Australia	Bark 26
Eucalyptus stellulata	Black gum	New South Wales	Bark 13 Leaves 17
Eucalyptus stuartiana	Apple	New South Wales	Bark 5 Leaves 10
Eucalyptus torquata	Flowering gum	Australia	Bark 17
Eucalyptus viminalis	Manna gum	New South Wales	Bark 8 Leaves 4
Eugenia braziliensis	Yhva-poroitih	Paraguay	Bark 43 Leaves 17 Wood 12
Eugenia jambolana	Java plum	India	Bark 19
Eugenia jambos		Brazil	Bark 12
Eugenia maire		New Zealand	Bark 16–17
Eugenia michellii	Nangapirih gwazu	Paraguay	Bark 29
Eugenia pungens	Yhva viyu	Paraguay	Bark 11
Eugenia smithii		Australia	Bark 17
Eugenia sp	Yhvajhay puihta gwazu	Paraguay	Bark 16–29
Exocarpus cupressiformis	Native cherry	Australia	Bark 15–16
Fiscus sp	Kili bark	Sudan	Bark 19
Fusanus acuminatus	Quandony	Australia	Bark 19
Garicinia mangostana	Mangoustan	Cochin-China	Fruit shells 14
Grevillia striata	Beefwood	Australia	Bark 18
Guarea sp	Guare	Paraguay	Bark 10
Hakea glabella		Australia	Bark 18
Hakea leucoptera	Needle bark	New South Wales	Bark 11
Heritiera fomes	Sundri bark	India	Bark 7

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Hopea odorata		India	Bark 14–15 Leaves 11 Wood 10
Hopea parviflora	Ironwood	India	Bark 17–22
Hydnora longicollis	Ganib	Africa	Roots 32
Inga affinis	Inga gwazu	Paraguay	Bark 26
Inga feuillei	Paypay	Peru	Pods 12–15
Juniperus recurva	Weeping blue	Japan	Bark 8
Krameria triandria	Rhatany	Peru	Root bark 20
Larix dahurica	Larch	Japan	Bark 9
Larix europaea	Larch	Europe	Bark 9–10
Larix occidentalis	Western larch	N. W. United States	Bark 11 Wood 7
Laurus lingue		Chile	Bark 17–19
Leuceadendron argenteum	Silver tree	Cape Good Hope	Bark 9–16
Leucospermum conocarpum	Knotted tree	Cape Good Hope	Bark 10–22
Ludwigia caparossa	Caparossa	Brazil	Bark 20–25
Lysiloma candida	Palo blanco	Lower California	Bark 26
Maclura pomifera	Osage orange	Texas	Wood 11
Malpighia faginea	Nance	Mexico	Bark 26
Malpighia punicifolia	Mangrutta	Nicaragua	Bark 20–30
Mimosa farinosa	Mimosa	Argentina	Bark 4
Mimosa pudica	Mimosa	India	Roots 10
Mimosa sp	Yukeri gwazu	Paraguay	Bark 11
Myrica asplenifolia	Sweet fern	Michigan	Leaves 4–5 Roots 4–6
Myrica nagi	Box myrtle	India	Bark 13–27
Nauclea gambir	Gambier	East Indies	Leaves and twigs 5–6
Ocotea bullata		South Africa	Bark 6
Ocotea sp	Yhva-iha	Paraguay	Bark 11
Osyris abyssinica		Transvaal	Leaves and twigs 13–25
Osyris arborea		Northern India	Leaves 20
Osyris compressa	Cape sumac	Cape Good Hope	Leaves 17–23
Oxalis gigantea		Chile	Bark 25
Paullinia sorbilis	Guara	Brazil	Fruit 43–55
Peltophorium dubium	Yhvihra puihta	Paraguay	Bark 31
Pentacme suavis		India	Leaves 12–24 Bark 7–13 Wood 4
Phyllanthus emblica	Amla	India	Stoned fruit 26–35 Leaves 23–28 Bark 15–24
Phyllocladus asplenifolia	Celery-topped pine	Tasmania	Bark 23
Phyllocladus rhomboidalis		Tasmania	Bark 21
Phyllocladus trichomanoides		New Zealand	Bark 28–30
Picea glehni	Red yezomatsu	Japan	Bark 19
Picea sitchensis	Sitka spruce	Pacific states	Bark 12–18
Pinus cembra	Pine	Alpine Europe	Bark 3–5
Pinus densiflora	Red pine	Japan	Bark 6
Pinus halepensis	Aleppo pine	Mediterranean coasts	Bark 10–15
Pinus Khasya	Pine	Burma	Bark 7–10
Pinus longifolia	Long-leaved pine	India	Bark 11–14
Pinus muricata	Swamp pine	California	Bark 13
Pinus radiata	Monterey pine	California	Bark 14
Pinus sylvestris	Scotch fir	Northern Europe	Bark 4–5
Pinus thunbergii	Black pine	Japan	Bark 6
Piptadenia cebil		Argentina	Bark 15
Piptadenia rigida	Kurupaih-ra puihta	Paraguay	Bark 28
Pistacia lentiscus	Pistacio	Mediterranean	Leaves 12–19
Pistacia orientalis	Pistacio	India	Galls 30–40
Pithecolobium dulce	Camanchile	Mexico	Bark 15–25
Polygonum amphibium		Missouri	Roots 22 Branches 17
Polygonum bistorta	Snakeweed	England	Roots 16–21

SOURCE AND TANNIN CONTENT OF VEGETABLE TANNING MATERIALS.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Populus tremula	Poplar	Europe	Bark 3
Prosopis oblonga	Abu-surug	Sudan	Bark 14
Protea grandiflora		Cape Good Hope	Bark 15–16
Protea mellifera	Sugarbush	Cape Good Hope	Bark 18–25
Pseudotsuga taxifolia	Douglas fir	Pacific states	Bark 7
Punica granatum	Pomegranate	India	Fruit rind 27–30 Kernel 32 Bark 18–22
Quebrachia lorentzii	Quebracho	South America	Wood 20–30 Bark 6–8
Quercus aegilops	Valonia	Mediterranean	Acorns 17–40
Quercus agrifolia	Live oak	California	Bark 19
Quercus alba	White oak	Northern America	Bark 7
Quercus californica	Black oak	California	Bark 10
Quercus cerris	Turkey oak	Southern Europe	Galls 35
Quercus chrysolepis	Maul oak	Pacific states	Bark 7–12
Quercus coccifera	Kermes oak	Mediterranean	Bark 10–18
Quercus coccinea	Scarlet oak	United States	Bark 8
Quercus densiflora	Tanbark oak	California	Bark 10–29
Quercus dentata	Japanese oak	Japan	Bark 11 Wood 7
Quercus fenestrata		Northern India	Bark 10–16
Quercus garryana	Pacific post oak	Pacific states	Bark 6–7
Quercus grosseserrata	Water oak	Japan	Bark 9 Wood 2
Quercus ilex	Evergreen oak	Southern Europe	Bark 5–11
Quercus incana		India	Bark 22
Quercus infectoria	Aleppo	Turkey	Galls 24–60
Quercus lamellosa		Northern India	Bark 8–10
Quercus lineata		Northern India	Bark 11
Quercus lobata	White oak	California	Bark 12
Quercus mirbechi		Algeria	Bark 8
Quercus pachyphylla	Sungra katus	Northern India	Acorn cups 13–15 Bark 12–13 Leaves 10
Quercus prinus	Chestnut oak	United States	Bark 9–12
Quercus pseudocornea	Gie-quang	Indo-China	Bark 16
Quercus robur	Common oak	Europe and U. S.	Bark 9–12 Wood 2–4
Quercus rubra	Red oak	Northern America	Twig galls 35 Bark 4–6
Quercus spp	Gie-bob	Indo-China	Bark 11
Quercus suber	Cork oak	Europe	Bark 12–19
Quercus tozae		Southern France	Bark 14
Quercus velutina	Black oak	United States	Bark 6–12
Quercus wislizeni	Highland oak	California	Bark 7–8
Rheedia braziliensis	Pakuri	Paraguay	Bark 22
Rhizophora conjugata	Mangrove	Philippines	Bark 26–32
Rhizophora mangle	Mangrove	Tropical coasts	Bark 15–42 Leaves 22
Rhizophora mucronata	Mangrove	Asia and Africa	Bark 21–48
Rhus copallina	Sumac	United States	Leaves 17–38
Rhus coriaria	Sicilian sumac	Sicily	Leaves 25–32
Rhus cotinus	Venetian sumac	Italy	Leaves 17
Rhus cotinoides	Sumac	United States	Leaves 21
Rhus glabra	White sumac	United States	Leaves 15–25
Rhus metopium	Sumac	United States	Leaves 8
Rhus mysorensis		Southern India	Bark 20
Rhus pentaphylla	Tizra sumac	Morocco	Roots 29 Wood 23
Rhus rhodanthema	Deep yellow wood	New South Wales	Bark 23
Rhus semialata	Sumac	America and Asia	Leaves 5 Chinese galls 70

Source and Tannin Content of Vegetable Tanning Materials.—(*Continued*)

Botanical name	Common name	Place grown	Per cent tannin
Rhus succedanea	Sumac	India	Leaves 20
Rhus thunbergii		Cape Good Hope	Bark 28
Rhus typhina	Virginian sumac	Virginia	Leaves 10–18
Robinia pseudacacia	Black locust	Europe	Bark 2–7 Wood 3–4
Rollinia sp	Aratiku gwazu	Paraguay	Bark 4
Rumex hymenosepalum	Canaigre	Mexico	Roots 25–30
Rumex maritima	Docks	Europe	Roots 22
Sabal palmetto	Cabbage palmetto	Florida	Roots 10–18
Sabal serrulata	Saw palmetto	Florida	Leaves 13
Salix alba	White willow		Bark 9
Salix arenaria	Willow	Russia	Bark 13
Salix caproea	Willow	Japan	Bark 8–12
Salix fragilis	Willow		Bark 9–12
Salix lasiandra	Yellow willow	California	Bark 2
Salix purpurea	Willow	Japan	Bark 8
Salix viminalis	Willow	Russia	Bark 7–10
Schinus molle	Molle	Argentina	Leaves 19
Sequoia sempervirens	Redwood	Pacific states	Heartwood 4–12 Sapwood 1–2 Bark 1–3
Shorea obtusa		India	Bark 9 Wood 6–7
Shorea robusta	Sal bark	India	Bark 6–15
Sonneratia pagatpat	Pagatpat	Philippines	Bark 11–12
Spermolepsis gummifera	Oak gum	New Caledonia	Bark 17 Resin 43–80
Statice coriaria	Marsh rosemary	Southern Russia	Roots 20–22
Stryphnodendron barbatimao	Barbatimao	Brazil	Bark 18–27
Tamarix africana	Tamarisk	Mediterranean	Galls 26–56 Twigs 9 Leaves 9
Tamarix articulata	Tamarisk	Morocco	Galls 43–56
Tamarix dioica	Jhao	India	Bark 10
Taxus cuspidata	Yew	Japan	Bark 10
Terminalia arjuna	Kahua	India	Bark 18–24
Terminalia belerica	Bedda	India	Nuts 12
Terminalia catappa	Badamier	India	Bark 12–25
Terminalia chebula	Myrobalan	India	Nuts 30–40
Terminalia glabra	Kumbuk	Ceylon	Bark 27–32
Terminalia mauritiana	Jamrosa	India	Bark 30
Terminalia oliveri	Thann	Malay	Bark 31 Leaves 14
Tormentilla erecta		Europe	Roots 20–46
Trichilia catigua	Kaatigua puihta	Paraguay	Bark 21
Trichilia hieronymi	Kaatigua moroti	Paraguay	Bark 23
Tsuga canadensis	Hemlock	Northern America	Bark 7–12
Tsuga heterophylla	Western hemlock	Pacific states	Bark 9–16
Umbellularia californica	California laurel	California	Bark 16
Vateria indica		India	Fruit 25
Weimannia glabra	Curtidor	Venezuela	Bark 10–13
Woodfordia floribunda	Itcha	India	Bark 27 Leaves 15
Ximenia americana	Alimu	Sudan	Bark 17
Xylia dolabriformis	Jamba	Burma and India	Bark 9–19 Wood 4
Xylocarpus granatum	Piagao	Africa and Asia	Bark 21–48
Xylocarpus obovatus	Tabique	Philippines	Bark 22–25
Zizyphus nummularia	Ber	India	Bark 10
Zizyphus xylopyra	Gothar	India	Fruit flesh 23

LITERATURE

(For a key to the periodicals see end of volume)

The following periodicals, reports and books were used in the above compilation: *45*; *54*; *157*; *257*; *258*; *259*; *260*; *261*; *262*; *263*; *264*; *265*; *Reports*, Freiberg Experiment Station; *Reports*, Australian Institute of Science and Industry; U. S. Department of Commerce, *Reports;* H. R. Procter, *Principles of Leather Manufacture*, New York, 1922; J. Dekker, *Die Gerbstoffe*, Berlin, 1913; A. Harvey, *Tanning Materials*, London, 1921; J. A. Wilson, *The Chemistry of Leather Manufacture*, New York, 1923.

Electrical Potential Difference (P. D.) between Tannin Particles and Solutions of Tanning Extracts

1. Extracts from Different Sources

Extract of	Concn. g dry solids per l	P. D. (volts)
Gambier	18.7	−0.005
Oak bark	17.0	−0.009
Chestnut wood	17.8	−0.009
Hemlock bark	16.7	−0.010
Sumac leaves	19.6	−0.014
Spruce bark	19.5	−0.018
Osage orange wood	13.7	−0.018 (?)
Quebracho wood	11.0	−0.028

2. Effect of Removal of Nontannin by Dialysis

Extract of	Initial concn. g dry solids per l	Hours dialyzed	Final concn. g dry solids per l	P. D. (volts)
Gambier	32.8	24	21.0	−0.029
Hemlock bark		24		−0.024
Sumac leaves	16.0	24	8.6	−0.026
Osage orange	16.0	24	10.9	−0.024
Quebracho wood	16.0	60	9.6	−0.033

3. Effect of Concentration of Quebracho Extract

Concn. g dry solids per l	P. D. (volts)
4.0	−0.030
8.0	−0.029
16.0	−0.028
32.0	−0.024

4. Effect of Addition of Acid

(16 g solid quebracho extract per l)

0.1*N* HCl added per l	P. D. (volts)
0.0	−0.024
10.0	−0.014
15.0	−0.010
20.0	approx. zero

LITERATURE

Thomas and Foster, *45*, **14:** 191; 22. **15:** 707; 23.

LEATHER

John Arthur Wilson

Ind. No.	Type	Genres de cuirs	Die untersuchten Lederarten	Tipi di pelle
1.	Colored, vegetable-tanned calf.	Veau teint, tanné au végétal.	Farbiges lohgares Kalbleder.	Vitello al tannino, colorato.
2.	Colored, chrome-tanned calf.	Veau teint, tanné au chrôme.	Farbiges Chromkalbleder.	Vitello al cromo, colorato.
3.	Black, chrome-tanned, glazed kid.	Chevreau verni, noir, tanné au chrôme.	Schwarzes Chromchevreaux.	Cuoio morbido di montone; glacé tinto in nero al cromo.
4.	Black, chrome-tanned kangaroo.	Kangourou noir, tanné au chrôme.	Schwarzes chromgares Känguruhleder.	Pelle di canguro al cromo, tinta in nero.
5.	Black, vegetable-tanned horse butt (Cordovan).	Croupon de cheval, tanné au végétal (Cordovan).	Schwarzer lohgare Rosspiegel (Cordovan).	Culatta di cavallo al tannino tinta in nero (Cordovano).
6.	Colored, chrome-tanned, buffed and split cow hide (buck).	Cuir de vache teint, tanné au chrôme, refendu et effleuré (façon daim).	Farbige chromgare, gebuffte Rindernarbenspalte (buck).	Pelle di vacca al cromo, spaccata, scamosciata, colorata.
7.	Colored, chrome-tanned side (split cow hide).	Bande entière de vache (refendue) teinte, tannée au chrôme.	Farbige chromgare Rindspalte.	Fianco di vacca (spaccata) al cromo, colorato.

LITERATURE

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4.	Black, chrome-tanned kangaroo.	Kangourou noir, tanné au chrôme.	Schwarzes chromgares Känguruhleder.	Pelle di canguro al cromo, tinta in nero.
5.	Black, vegetable-tanned horse butt (Cordovan).	Croupon de cheval, tanné au végétal (Cordovan).	Schwarzer lohgare Rosspiegel (Cordovan).	Culatta di cavallo al tannino tinta in nero (Cordovano).
6.	Colored, chrome-tanned, buffed and split cow hide (buck).	Cuir de vache teint, tanné au chrôme, refendu et effleuré (façon daim).	Farbige chromgare, gebuffte Rindernarbenspalte (buck).	Pelle di vacca al cromo, spaccata, scamosciata, colorata.
7.	Colored, chrome-tanned side (split cow hide).	Bande entière de vache (refendue) teinte, tannée au chrôme.	Farbige chromgare Rindspalte.	Fianco di vacca (spaccata) al cromo, colorato.

8. Black, chrome-tanned slink calf (suede).	Veau mort-né noir, tanné au chrôme (façon suède).	Schwarzes chromgare Kalbleder (suède).	Pelle di vitello (feto) al cromo, tinta in nero (tipo svedese).
9. Uncolored, vegetable-tanned calf (shoe lining).	Veau naturel, tanné au végétal (doublure de chaussure).	Ungefärbtes lohgare Kalbleder (Schuhfutterleder).	Vitello al tannino in color naturale (fodera da calzature).
10. Uncolored, vegetable-tanned sheep (shoe lining).	Mouton naturel, tanné au végétal (doublure de chaussure).	Ungefärbtes lohgare Schafleder (Schuhfutterleder).	Montone al tannino in color naturale (fodera da calzature).
11. Black, vegetable-tanned shark.	Requin noir, tanné au végétal.	Schwarzes lohgare Haifischleder.	Pelle di squalo al tannino, tinta in nero.
12. Patent, chrome-tanned side (split cow hide).	Bande entière de vache (refendue), vernie, tannée au chrôme.	Chromgares Rindspaltlackleder.	Fianco di vacca (spaccata) al cromo, brevettato.
13. Patent, chrome-tanned kid.	Chevreau verni, tanné au chrôme.	Chromchevreauxlackleder.	Cuoio morbido di montone al cromo, brevettato.
14. Patent, chrome-tanned colt.	Poulain verni, tanné au chrôme.	Chromgares Rosslackleder.	Puledro al cromo, brevettato.
15. Heavy, black, chrome-tanned cow hide.	Cuir de vache, fort, noir, tanné au chrôme.	Schweres schwarzes Chromrindleder.	Pelle di vacca al cromo tinta in nero, pesante.
16. Chrome-re-tan, army upper leather (split cow hide).	Cuir d'empeigne pour l'armée, semi-chrôme (peau de vache refendue chrômé, puis retanné au végétal).	Nachchromiertes Militäroberleder (Rindspalte).	Cuoio di vacca (spaccata) superiore per l'esercito, riconciato al cromo.
17. Vegetable-tanned steer hide (sole leather).	Cuir de génisse, tanné au végétal (cuir de semelles).	Lohgares Rindleder (Sohlenleder).	Pelle di giovenco al tannino (cuoio da suola).
18. Chrome-tanned steer hide (sole leather).	Cuir de génisse, tanné au chrôme (cuir de semelles).	Chromgares Rindleder (Sohlenleder).	Pelle di giovenco al cromo (cuoio da suola).

Each analysis was made on one representative skin of each type. The same 18 skins were used to make all measurements listed in this section, thus making all properties of any one type directly comparable and related to chemical composition.

Chaque analyse a été effectuée sur une peau représentative de chaque genre de cuir. On a utilisé les mêmes 18 peaux pour faire toutes les mesures mentionnées dans cette section. De la sorte, toutes les propriétés de chaque genre de cuir sont directement comparables et en relation avec la composition chimique.

Jede Analyse wurde an einem besonderem Vertreter einer Hauttype gemacht. Dieselben 18 Häute sind für alle Messungen die in diesem Abschnitt angeführt werden, verwendet worden. Es werden dadurch alle Eigenschaften jeder einzelnen Type direkt vergleichbar und in Beziehung zur chemischen Zusammensetzung gebracht.

Ogni analisi fu fatta sopra un campione rappresentante ciascun tipo di pelle. Gli stessi 18 campioni furono usati per eseguire tutte le misure indicate in questa sezione, risultando così tutte le proprietà di ogni singolo tipo direttamente paragonabili ed in rapporto alla composizione chimica.

COMPOSITION, % AT 50% RELATIVE HUMIDITY (¹)

Ind. No.	H_2O	Skin protein	Fat	H_2SO_4	Na_2SO_4	HCl	NaCl	CaO	$MgSO_4$	Al_2O_3	Fe_2O_3	Cr_2O_3	Organic water soluble	Collodion	Combined tannin by diff.	Other organic matter by diff.
1	13.6	41.0	12.0	0.3						0.4	0.1		9.1		23.5	
2	16.3	62.6	4.6	3.4	0.4	0.3	0.5			1.2	0.3	5.4				5.0
3	13.7	65.3	6.6	1.0	0.9	0.5	0.2	0.2		0.2	0.3	4.5				6.6
4	12.0	62.7	11.3	1.8	0.2	0.3	0.1	0.3		0.1	0.1	6.0				5.1
5	10.0	40.1	18.6	0.6				0.1			0.1		8.7		21.8	
6	14.1	69.6	2.1	3.2	0.3			0.2		1.0	0.6	5.3				3.6
7	16.3	66.8	5.8	3.6	1.0		0.3	0.1		0.2	0.2	3.6				2.1
8	12.7	55.1	7.1	0.8	0.4	0.2	0.1	0.2		1.0	1.2	5.4				15.8
9	11.9	46.0	7.6	0.1				0.2		0.1			12.3		21.8	
10	10.9	50.0	6.1	1.7		0.6		0.1		0.1	0.1		13.0		17.4	
11	12.2	45.4	6.9	1.5				0.1			0.1		5.4		28.4	
12	10.1	50.5	10.0	1.8	0.6	0.1		0.1		0.1	0.4	2.9		9.0		14.4
13	11.8	54.0	6.6	2.1	0.3			0.2		0.2	0.6	3.6		8.4		12.2
14	12.0	60.4	5.1	2.3	0.5	0.1	0.1	0.3		0.1	0.3	3.6		6.1		9.1
15	14.4	57.0	14.2	4.4	0.4	0.1	0.4	$CaSO_4$			0.7	5.5				2.9
16	15.1	44.6	20.4	1.1	0.3		0.4			0.3	0.2	2.4				15.2
17	14.6	29.7	3.2	0.8					0.8		0.7		35.6		14.6	
18	16.3	29.4	25.4	5.9	12.3	0.8	0.9	2.3	0.5	2.6	0.5	1.7				1.4

TENSILE STRENGTH, STRETCH AND STITCH TEAR (¹)

Each value recorded is the average of 3 determinations. The strips for strength and stretch were cut with a die 2.54 × 15.24 cm and the jaws of the testing machine were initially 10.16 cm apart. The 3 strips from each skin were cut with their lengths parallel to the backbone and spaced equally between head and tail end along a line midway between backbone and belly edge. The leather was in equilibrium with an atmosphere of 50% relative humidity. The stitch tear was made with Irish flax shoe thread No. 6 slipped through a hole 2 mm from the leather edge.

l = average thickness; TS = tensile strength in kg per cm² of original cross section; S = stretch (*a*) at 13.6 kg per 2.54 cm width, (*b*) at 225 kg per cm²; ST = stitch tear.

Ind. No.	l mm	TS kg/cm²	% S (*a*)	% S (*b*)	ST kg
1	1.19	422	5	17	13
2	1.00	327	7	22	10
3	0.76	409	20	34	8
4	0.52	508	16	24	9
5	1.12	113	14	53	7
6	0.92	201	9	34	5
7	1.22	213	11	36	10
8	0.63	156	19	36	1
9	0.93	310	11	27	8
10	0.87	200	13	35	6
11	0.80	118	35	84	5
12	1.09	90	10	69	3
13	0.96	217	17	42	7
14	1.43	228	13	46	8
15	2.94	182	8	54	27
16	2.48	346	6	29	28
17	6.28	191	1	23	38
18	4.80	100	1	70	21

Area Change with Relative Humidity

Measurements were made after 30 days contact at 25°C. The samples were kept in desiccators over sulfuric acid solutions of 37.5, 17.6, 13.6, 11.8, 10.2, 6.6, and 0.0 normalities to maintain the relative humidities at 0, 20, 40, 50, 60, 80 and 100% respectively.

Ind. No.	% increase in area with increasing relative humidity					
	Relative humidity					
	20	40	50	60	80	100
1	3.6	4.2	4.5	4.8	5.5	5.7
2	7.7	10.0	10.3	11.5	12.4	16.0
3	3.4	4.6	4.8	5.5	7.5	15.6
4	5.7	6.9	6.9	7.5	10.9	19.0
5	2.0	3.0	3.0	3.2	3.4	4.0
6	6.7	7.5	7.7	8.8	10.5	14.7
7	6.7	7.7	8.0	9.2	10.5	15.8
8	8.0	10.7	10.9	11.7	11.9	13.8
9	5.3	6.5	6.7	6.9	7.5	9.2
10	4.2	5.5	5.5	5.9	8.2	9.4
11	4.0	4.9	5.1	5.3	5.7	8.0
12	5.5	6.3	6.3	6.9	8.6	10.5
13	5.3	5.9	6.1	6.5	7.1	9.6
14	4.5	6.3	6.3	6.5	8.2	13.0
15	7.1	8.0	8.0	9.2	10.9	16.9
16	6.5	7.7	8.0	8.4	9.0	11.5
17	1.0	1.4	2.7	3.0	3.0	5.5
18	3.8	4.5	5.9	6.3	7.7	13.0

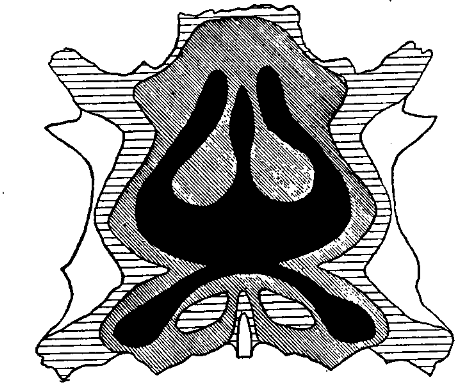

FIG. 1.—Variations in strength and resistance to stretch for calf leather from different parts of the skin (³).

Tensile strength given in kg per cm².
Percentage stretch measured under load of 225 kg per cm².

☐ Tensile strength less than 170 kg. Stretch greater than 60 %.

▤ Tensile strength 170 to 260 kg. Stretch 60 to 26 %.

▨ Tensile strength 260 to 350 kg. Stretch 26 to 20 %.

■ Tensile strength greater than 350 kg. Stretch less than 20 %.

Water Content at Different Relative Humidities (¹, ²)

Ind. No.	g water per 100 g dry leather after 30 days at relative humidity of %						
	0	20	40	50	60	80	100
1	1.4	10.8	14.0	15.7	17.9	21.2	39.6
2	2.1	12.4	18.1	19.5	21.0	27.9	53.4
3	2.9	10.6	14.2	15.9	18.1	27.3	62.2
4	0.4	9.3	12.6	13.6	15.4	22.8	51.7
5	1.8	7.0	9.8	11.1	11.8	15.6	22.9
6	2.2	11.7	15.4	16.4	17.4	25.1	47.8
7	1.8	12.1	17.2	19.5	20.8	25.9	54.5
8	0.3	9.4	13.4	14.5	15.8	20.9	59.5
9	0.9	8.8	12.1	13.5	16.1	19.6	32.0
10	1.1	8.2	11.3	12.2	14.6	19.6	48.4
11	2.4	10.2	12.7	13.9	14.3	17.1	38.1
12	0.7	8.5	10.4	11.2	12.6	18.5	36.9
13	1.9	10.5	12.7	13.4	14.6	20.7	39.5
14	2.0	9.6	12.4	13.6	15.1	22.7	57.5
15	1.2	12.9	15.1	16.8	17.7	21.9	49.6
16	4.4	12.5	16.4	17.8	18.4	21.1	37.8
17	3.4	12.2	17.0	17.1	18.3	21.7	43.6
18	8.6	14.9	18.1	19.5	20.6	24.5	50.4

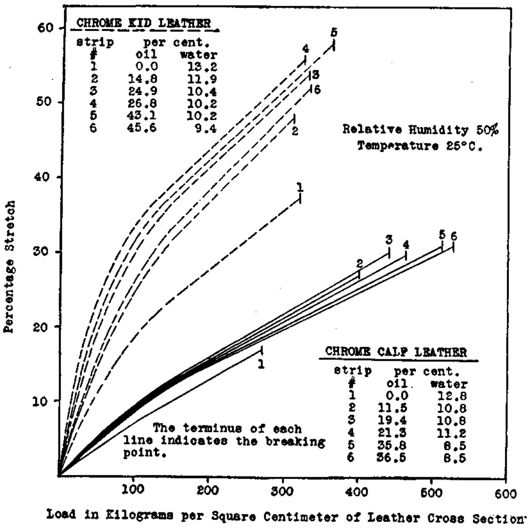

FIG. 2.—Effect of oil content (⁴).

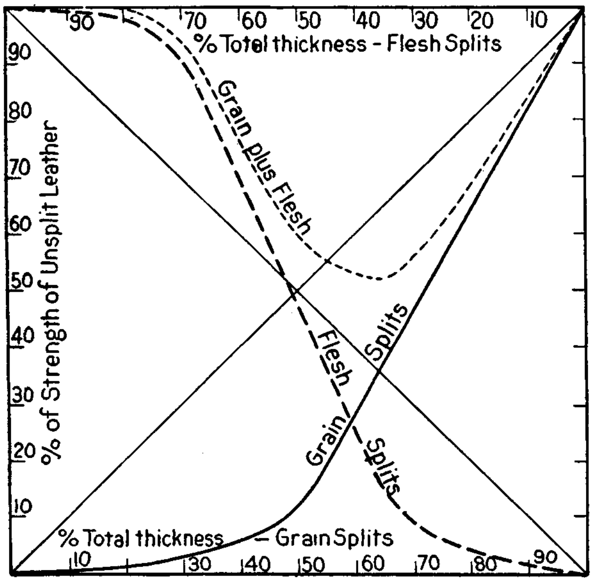

FIG. 3.—Relative strengths of splits of vegetable-tanned calf leather compared with unsplit leather. Average tensile strength of skin 324 kg/cm²; average thickness 0.91 mm. Strengths in chart are given per unit width, not cross section (⁵).

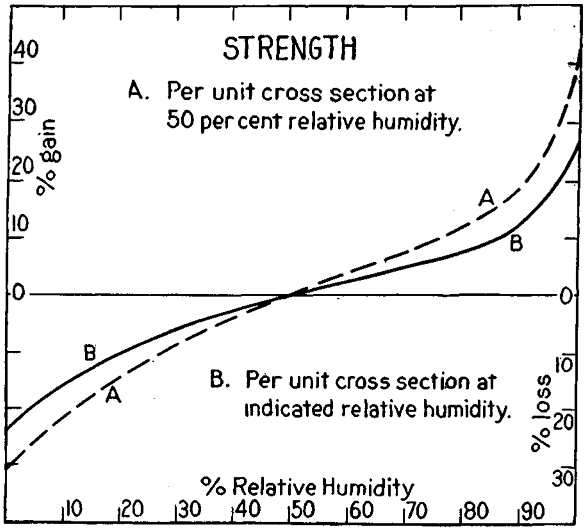

Fig. 4.—Percentage gain or loss in strength per unit cross section of chrome calf leather with change of relative humidity. The difference between the two curves reflects the volume change in the leather with relative humidity. Leather with high fat content shows much less change in strength with relative humidity (8).

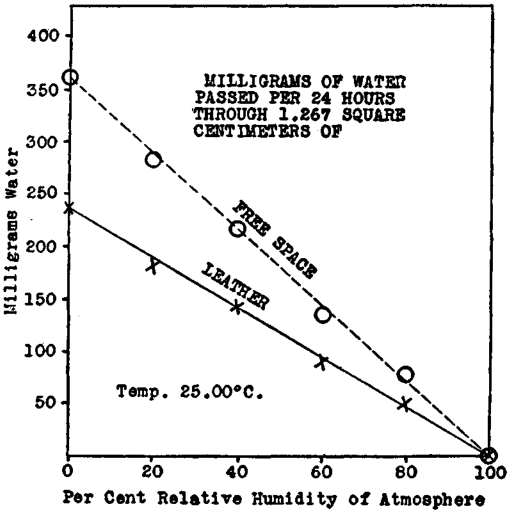

Fig. 5.—Effect of relative humidity of 1 atmosphere upon passage of water into it from an atmosphere kept at 100 % relative humidity through vegetable-tanned calf leather and through free space (6).

Ventilating Properties

Effect of kind of skin and tannage (1)

Ind. No.	1	2	3	4	5	6	7	8	9
1 mm	1.08	1.00	0.73	0.53	1.15	0.88	1.22	0.60	0.88
P_W*, %	70	70	70	65	54	95	74	97	79
P_A†	197	67	249	185	41	1183	369	1820	246

Ind. No.	10	11	12	13	14	15	16	17	18
1 mm	0.88	0.89	1.01	0.99	1.37	2.59	2.31	6.28	4.80
P_W*, %	78	89	6	9	5	38	49	34	4
P_A†	251	1416	0	0	0	45	179	43	0

* P_W, % permeability to water vapor, is defined as 100 times the ratio of the rate of passage of water from an atmosphere of 100% relative humidity to one of zero humidity through a given area of the leather sample, of thickness, 1, to the rate of a similar passage of water through an equal area of free space at the same temperature. In these measurements, the area chosen was 1.267 cm² and the temperature 25°C.

† P_A, permeability to air, is defined as the rate of flow of air (cm³/min per cm² of leather) through thickness 1, under the pressure difference, atmospheric to 35 mm Hg.

Effect of temperature, Fig. 6; effect of relative humidity, Fig. 5.

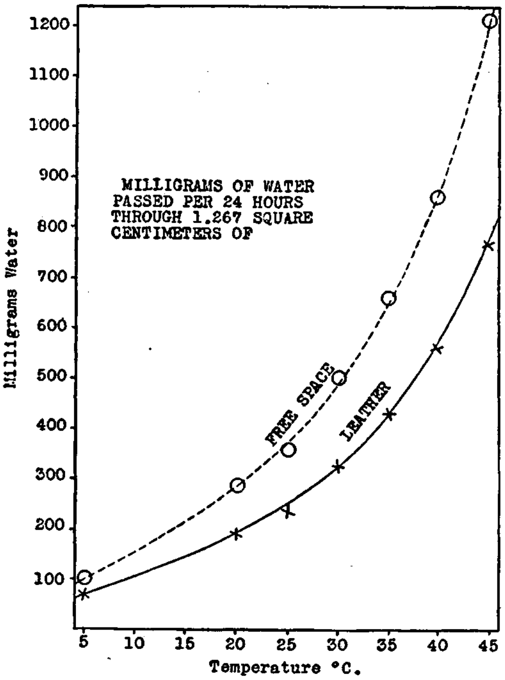

Fig. 6.—Effect of temperature upon passage of water from an atmosphere of 100 % relative humidity to one of zero relative humidity through vegetable-tanned calf leather and through free space (6).

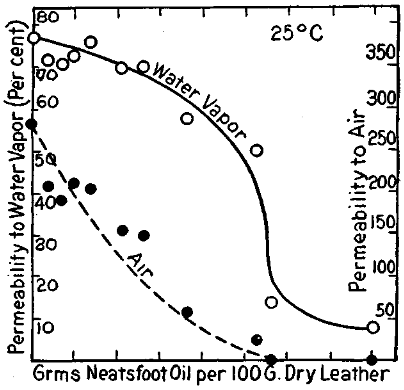

Fig. 7.—Effect of oil content of leather (6).

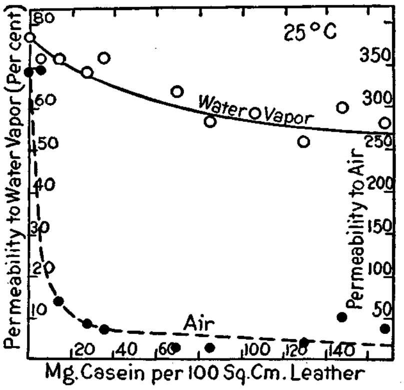

Fig. 8.—Effect of quantity of casein used as finishing material (6).

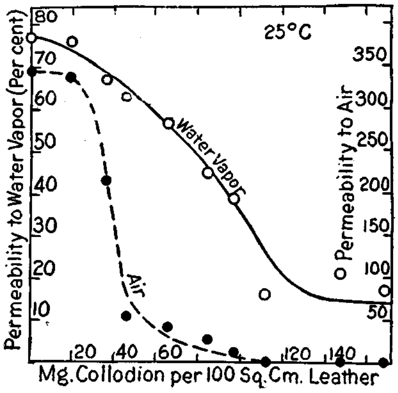

Fig. 9.—Effect of quantity of collodion used as finishing material (6).

Relative resilience is defined as the percentage rebound of a brass plunger (weighing 48.5 g and having a contact area of 0.70 cm^2) when dropped from a height of 60 cm upon a thickness of 3 mm of leather backed by a solid maple block. Relative humidity 50%.

The relative resilience is decreased by an increasing content of either water or oil.

RESILIENCE (1, 7)

Ind. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Rel. resilience	22	26	28	24	16	23	21	21	22	21	23	19	22	23	17	11	39	17

LITERATURE

(For a key to the periodicals see end of volume)

(1) Wilson *et. al.*, *261*, **21**: 193, 198, 241; 26. (2) Wilson and Gallun, *45*, **16**: 268; 24. (3) Wilson, *45*, **17**: 829; 25. (4) Wilson and Gallun, *45*, **16**: 1147; 24. (5) Wilson and Kern, *45*, **18**: 312; 26. (6) Wilson and Lines, *45*, **17**: 570; 25. (7) Wilson, *261*, **20**: 576; 25. (8) Wilson and Kern, *261*, **21**: 250; 26.

RUBBER, GUTTA-PERCHA AND BALATA

G. Stafford Whitby

ABBREVIATIONS

T_B	Breaking load expressed unless otherwise stated as kg per cm^2 unstrained cross section
E_B	Ultimate elongation (percentage of unstrained length)
T_x	Stiffness, expressed as the load (kg/cm^2 unstrained cross section) required to produce an increase in length x times the unstrained length
E_T	Stiffness, expressed as the percentage elongation produced by a load T kg/cm^2 unstrained cross section
V. C.	Vulcanization coefficient
D_{30}	Plasticity expressed as the thickness of a disc (0.4 g) after 30 min in a Williams' plastometer at 100° under a load of 5 kg
ΔD	Plasticity expressed as D_{25}–D_{35}
Cure	Unless otherwise indicated, the period of vulcanization required to give an optimum or standard "cure."
η	Viscosity, expressed unless otherwise indicated as the time of flow of a 1% solution in benzene relative to the time of flow of the pure solvent.

Relative resilience is defined as the percentage rebound of a brass plunger (weighing 48.5 g and having a contact area of 0.70 cm²) when dropped from a height of 60 cm upon a thickness of 3 mm of leather backed by a solid maple block. Relative humidity 50%.

The relative resilience is decreased by an increasing content of either water or oil.

RESILIENCE (1, 7)

Ind. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Rel. resilience	22	26	28	24	16	23	21	21	22	21	23	19	22	23	17	11	39	17

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LATEX

Specific Gravity

Average Undiluted Latex.—0.97 to 0.98 (197).

Serum from Normal Latex.—1.016 to 1.025 (197).

Globules in Latex.—0.914 (181).

TABLE 1.—VARIATION WITH RUBBER CONTENT OF ORIGINAL UNDILUTED LATEX (197)

g rubber/100 cm³	50	45	40	35	30	25	20	17	15	10
d_t^t	0.9620	0.9678	0.9736	0.9794	0.9852	0.9910	0.9968	1.0003	1.0026	1.0084

TABLE 2.—TEMPERATURE COEFFICIENT OF SPECIFIC GRAVITY OF LATEX (81)

Sp. gr.	0.9950	0.9900	0.9850	0.9800	0.9750
Corr. 1°	0.00030	0.00034	0.00038	0.00042	0.00046

Viscosity

TABLE 3.—VISCOSITY OF ORIGINAL LATEX WITH AND WITHOUT NH_3 (191)

% rubber content		35	30	25	20	15
η/η_w at 30°	Without NH_3	12–15	8	5–6	4	
	With NH_3*		4–5.5	3–4	2.5	2

* Viscosity falls on keeping.

TABLE 4.—INFLUENCE OF DILUTION ON VISCOSITY OF AMMONIATED LATEX (94)

Ratio		% solids	d_4^{20}	200 cm³ in Engler viscosimeter	
Latex	Water			Sec	Deg. Engler
5	0	48.5	0.963	110	2.1
4	1	37.5	0.972	75	1.42
2.5	2.5	24.25	0.981	65	1.23
2	3	18.7	0.983	60	1.15
1	4	9.4	0.992	50	1.0

Surface Tension (10)

Drop No.—(*a*) water, 31; (*b*) latex diluted with equal volume of water, 37 to 40; (*c*) 2% NH_3, 37 to 38; (*d*) *c* after 2 months, 49 to 50.

Miscellaneous

Fresh Latex.—pH: 5.8 to 6.4 (10), 6.2 to 6.6 (20); acidity: 0.02 to 0.04*N* (phenolphthalein) (190); alkalinity: 0.002 to 0.008*N* (methyl red) (190).

Potential Difference between Surface of Particles and Surrounding Liquid (Ammoniated Latex).— −35 millivolts (145).

Size and Shape of Globules (19, 66, 225).

Rubber Content

TABLE 5.—DISTRIBUTION OF RUBBER CONTENT IN LATEX FROM 245 7-YR OLD TREES (211)

Mean: 36.58 ± 0.25%

g/100 cm³	23	24–5	26–7	28–9	30–1	32–3	34–5	36–7	38–9	40–1	42–3	44–5	46–7	48–9	50–1	52–3	54–5
Number of trees	4	2	7	11	16	27	44	35	23	12	17	12	5	1	4	3	2

Influence of severity of tapping (181) and of resting trees (179, 181) on rubber content of latex; *cf.* Tables 7, 8.

Chemical Composition

Acetaldehyde in Latex.—0.006 g/l (91). Trace of NH_3 present (91).

Heat-Coagulable Protein in Serum.—After coagulation by acetic acid, 0.15% (rubber content of latex, 40%) (11); 0.115% (203); after coagulation by alcohol, 0.19% (203).

TABLE 6

Sample Component	a(7)	b(7)	c(7)	d(130)	e(71)
Total solids	30.0	22.0	25.8	32.4	
Rubber by coagulation				29.0	37.0
Solids in serum				3.4	2.91
Solids in dialysate	2.6	1.65	1.54	3.2	
Protein (non-diffusible, N × 6.25)	1.26	0.87	1.04		
Diffusible N:					
Total	0.048	0.054	0.043	0.072	
Ammoniacal				0.0096	

Total N (mean of 3 samples): 0.29 for f(11).

Dialysates from samples a, b, c (mean values)

	Sugars*	Ash	SO_3	P_2O_5	CaO	MgO	K_2O
% latex	0.18	0.31	0.008	0.09	0.01	0.016	0.17
% ash			2.6	29.1	3.2	5.2	54.8

* After inversion.

Serum solids from sample e, NH_3 also present

	Ash	Protein (N × 6.25)	Sugars	Quebrachitol
g/100 cm³	0.53	0.34	0.25	1.45

Deposit Which Forms in Ammoniated Latex

Composition of deposit (*ca.* 0 to 7% of the latex) (37), %: Of this deposit *ca.* 30% is volatile in steam in the presence of MgO.

	Sample 3*	Sample 5*
Rubber	*ca.* 30	*ca.* 30
Acetone extract	11.6	6.4
N insol. in Me_2CO	2.4	1.6
Fe_2O_3	9.0	15.1
MgO	16.0	13.1
P_2O_5	28.0	23.6
K_2SO_4	Tr.	Tr.

* *See* Table 9.

Deposit consisting of NH_4MgPO_4, 0.3 to 1.1 g/l (190).

Oxidases

Present.—Peroxidase (the chief oxidase; fatal temperature, 80 to 85°); oxidase; catalase; tyrosinase (fatal temperature, 70°). Optimum pH, 4.65 to 4.95, using citrate buffer solution; 8.13 to 8.28, using borax buffer solution. Inhibitory pH, 1.03; very sensitive to alkali (21).

Activators.—Ca and Mg salts (21, 207).

TABLE 7.—RUBBER CONTENT OF LATEX AND SOLID CONTENT OF SERUM UNDER DIFFERENT TAPPING SYSTEMS (203)

Tapping system	1 cut on $\frac{1}{3}$	2 cuts on $\frac{1}{4}$	2 cuts on $\frac{1}{2}$	2 cuts on $\frac{3}{4}$	2 cuts on $\frac{1}{1}$
Rubber content*	34.2	31.65	28.2	22.75	22.4
Solid content†	8.8	9.5	10.1	8.6	11.6

* g/100 cm³ by coagulation. † Expressed on rubber %.

TABLE 8.—INFLUENCE OF RESTING TREES ON RUBBER CONTENT OF LATEX AND SOLID CONTENT OF SERUM (6)

Days after tapping began following long rest	1	3	12	18	22	33
Rubber content by coagulation (%)	43.0	39.3	31.5	35.8	21.8	14.8
Serum solids (% of rubber)	4.9	7.1	10.15	13.2	13.8	16.9

Ammoniated Latex

0.33% NH_3 will preserve latex in liquid condition, while 0.5%, giving an alkalinity of 0.25*N* (methyl red), is absolutely reliable (190).

TABLE 9.—COAGULATION OF AMMONIATED LATEX IN EUROPE (37)

Sample	Rubber content, %	NH_3 content (% rubber)		% CH_3CO_2H*
		Added (in Ceylon)	Found (In Europe)	
1	33.2	0.89	0.82	4.4
2	33.0	1.19	1.00	4.46
3	32.5	1.80	1.57	8.75
4	31.8	2.40	2.17	12.2
5	32.6	2.92	2.73	15.8

* Per cent of acetic acid necessary for coagulation in excess of the acid equivalent to the NH_3 present.

TABLE 10.—VULCANIZING PROPERTIES OF RUBBER BY CH_3CO_2H COAGULATION FROM LATEX PRESERVED WITH DIFFERENT PROPORTIONS OF NH_3 (37)

Pure gum mixture (ring-shaped test pieces)

Sample, *cf.* Table 9	Cure, min	T_B	E_B	E_{104}	Slope
1	115	164	855	777	35
2	130	157	859	781	36
3	126	144	842	786	37
4	125	147	840	771	36
5	125	164	874	784	36

TABLE 11.—INFLUENCE OF AGE OF AMMONIATED LATEX ON VULCANIZING PROPERTIES OF RUBBER (201)

Undiluted latex containing 0.72% NH_3; coagulated by CH_3CO_2H; stock: rubber, 92.5; S, 7.5%; vulcanized at 148°

	Aqueous extract, %	Acetone extract, %	Cure, min	T_B	η		
					Orig.	After 14 mo	Orig. in acid C_6H_6
Control	0.44	3.0	110	128	31	29	16
Ammoniated:							
Same day	0.37	2.9	90	135	31	30	15.5
Next day	0.54	3.2	70	143	27	30	17
After 1 mo	0.23	3.2	105	143	53	22.5	19
After 3 mo	0.22	3.9	100	124	56	28	18

TABLE 12.—AMMONIATED LATEX CREAMED BY CENTRIFUGATION (129)

Stock: rubber, 92.5; S, 7.5; vulcanized for 90 min at 147°; coagulated by CH_3CO_2H

	Composition of rubber by evaporation, %						S*
	Rubber	H_2O	Acetone extract	Ash	Protein	Aqueous extract	
Orig. latex	17.6	2.0	2.3	1.0	4.0	3.4	4.7
Cream	48.0	0.6	1.8	0.4	1.8	0.4	3.9
Skimmed latex	9.7	4.1	2.9	2.0	7.4	13.1	5.2

* Per cent combined S.

Latex with NaOH

0.5 to 1% NaOH will preserve latex in a liquid condition; 1.3% or more causes the separation of a paste or coagulation, the resulting rubber being of poor quality and becoming tacky on keeping (198).

TABLE 13.—INFLUENCE OF AGE OF NaOH LATEX ON RUBBER (CREPE) BY CH_3CO_2H COAGULATION (198)

Stock: rubber, 92.5; S, 7.5; vulcanized at 148° (ring-shaped test pieces)

Period after addition	Ash, %	Aqueous extract, %	Acetone extract, %	N, %	Cure, min	T_B	Slope	η
Control*	0.40	1.11	2.6	0.55	<35	133	39.5	24.5
Same day	0.31	0.37	3.0	0.52	<45	145	40	33
Next day	0.29	0.21	3.1	0.43	80	122	36.5	40.5
1.5 mo	0.40	0.28	3.7	0.42	60	122	37	36
3.5 mo	0.46	0.30	2.9	0.38	50	137	33	31
6 mo	0.34	0.38	3.4	0.50	110	132	38.5	33

* Same day, no NaOH.

TABLE 14.—RUBBER FROM CREAMED NaOH LATEX (198)

Latex containing 1.1% NaOH allowed to stand 2 yr; layers coagulated by CH_3CO_2H; crepe; stock: rubber, 92.5; S, 7.5; vulcanized at 148°.

	Cream	2nd layer	3rd layer	4th layer	Residue
% rubber content	62.8	50.0	45.8	26.8	4.4
% H_2O	0.67	0.95	1.72	1.66	1.68
% ash	0.55	0.58	0.65	0.73	1.22
% N	0.09	0.10	0.13	0.18	0.48
Cure, min	55	45	>25	35	
T_B	130	135	130	120	
Slope	34	34	34	34	
η (ordin.)	13	30	41	48	78
η (acid)	7	15	17.5	18.5	26
Plasticity:					
D_{30}	0.88	1.15	1.36	1.29	1.16
ΔD	0.085	0.11	0.08	0.10	0.11

Vulcanization of Latex

TABLE 15.—INFLUENCE OF PERIOD OF VULCANIZATION AND OF CHARACTER OF THE S ON THE COMBINED S (43)

Composition of mixture: 100 cm³ latex; 50 cm³ H_2O; 2 g S (rubber coagulated by acetone). Latex No. 1: rubber, 32.9%; NH_3, 0.6%. Latex No. 2: rubber, 30.15%; NH_3, 0.43%. Vulcanizing conditions: rise to 141°, 10 min; blow-off, 20 min.

Time at 141°, min	Combined sulfur, %			
	Latex No. 1	Latex No. 2		
	Flowers	Flowers	Pptd.	Colloidal
0	0.18	0.13	0.23	0.47
20	0.59		0.85	1.56
30		0.46	1.04	1.87
60	0.91	0.55	1.47	2.44
120	1.07			2.64

TABLE 16.—INFLUENCE OF CONCENTRATION OF S (43)

Composition of mixture: 100 cm³ latex (30.7% rubber; 0.43% NH_3); 50 cm³ H_2O; 1% S (calculated on rubber + S). Vulcanizing conditions: 10 min rise; 30 min at 141°; 20 min at blow-off.

S		Comb. S, %	E_{60} (films)
g	% on rubber		
1	3.26	0.64	1000
2	6.51	1.02	954
4	13.02	1.42	951
6	19.53	1.65	886

TABLE 17.—VULCANIZATION WITH SODIUM POLYSULFIDE (43)

Composition of mixture: 120 cm³ latex (32.9% rubber, 0.6% NH_3); 10 cm³ sodium polysulfide (21.0% S on pptn.). Vulcanizing conditions: 10 min rise to 141°; 20 min blow-off.

Period at 141°, min	0	20	30	60	120
Combined S, %	0.31	0.85	1.02	1.42	1.88

Coagulation

Acidity Necessary for Coagulation.—By addition of acid, pH = 4.3 to 4.8 (10, 20). By addition of acid to ammoniated latex (dialyzed or undialyzed), pH *ca.* 5.5 (103). For spontaneous coagulation, pH = 4.8 to 5.6 (20).

CH_3CO_2H, ACETIC ACID

TABLE 18.—PROPORTION OF CH_3CO_2H USED IN PLANTATION PRACTICE (189)

Rubber	15%		25%	
For coagulation on	Same day	Next day	Same day	Next day
CH_3CO_2H(g/l)	1–1.25	0.75	1.5	1

TABLE 19.—CONCENTRATION OF CH_3CO_2H REQUIRED TO COAGULATE LATEX DILUTED TO DIFFERENT EXTENTS (189), *cf.* (188)

% rubber content	Ratio, acid: rubber	% rubber content	Ratio, acid: rubber
30	1:303	6	1:83.5
24	1:190	3	1:91
18	1:115	1.5	1:125
15	1:100	0.75	1:83.5
12	1:89		

Influence of excess CH_3CO_2H on properties of crepe: Double the minimum quantity increases time of cure 0 to 5 min; decreases viscosity 0 to 4. Four times minimum quantity increases time of cure 5 to 10 min for the stock: rubber, 92.5; S, 7.5, at 148°; decreases viscosity 2 to 7 (176).

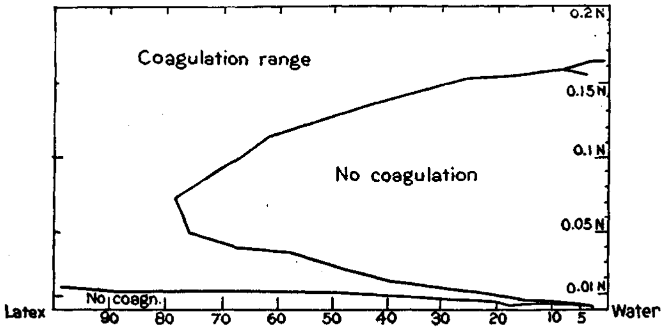

FIG. 1.—Concentrations of hydrochloric acid producing coagulation in latex (31.8 % rubber, *ca.* 35 % total solids) diluted to different extents (188).

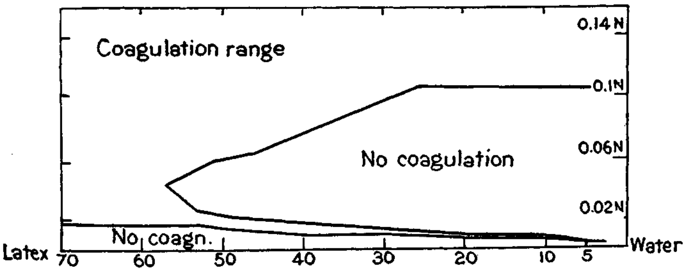

FIG. 2.—Concentrations of nitric acid producing coagulation in latex (28 % rubber) diluted to different extents (188).

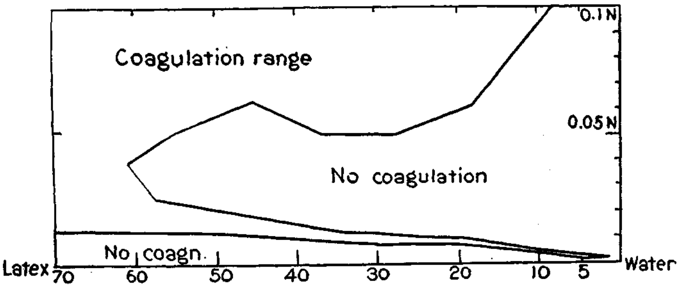

FIG. 3.—Concentrations of sulfuric acid producing coagulation in latex (28 % rubber) diluted to different extents (188).

H_2SO_4, SULFURIC ACID

Proportion H_2SO_4 Used in Practice.—0.45 to 0.6 g/l latex (15% rubber).

TABLE 20.—VULCANIZING PROPERTIES OF CREPE RUBBER PREPARED BY H_2SO_4 (182)
Stock: rubber, 92.5; S, 7.5; vulcanized at 148° (ring-shaped test pieces)

Normal proportion				Double the normal proportion			
Cure, min	T_B	Slope	η	Cure, min	T_B	Slope	η
125	140	38	35	150	136	38.5	27

ALUM

Minimum Effective Proportions.—3 to 4 g/l.

TABLE 21.—EFFECT OF ALUM (COMPARED WITH CH_3CO_2H) ON PROPERTIES OF CREPE (182)

Alum (g/l)	3–4	10	20
Increase in time of cure, min	$\nless 15$	$\nless 30$	$\nless 85$
Decrease in viscosity	4–7	7–12	10–12

HCO_2H, FORMIC ACID

The proportion of HCO_2H necessary for coagulation is about half the quantity of CH_3CO_2H (130); *cf.* Tables 18, 19.

TABLE 22.—COMPARISON OF HCO_2H AND CH_3CO_2H (101)
Stock: rubber, 92.5; S, 7.5 %; vulcanized at 150° (ring-shaped test pieces, 11 samples)

Description	Cure, min	T_B	Slope	η
Smoked sheet:				
CH_3CO_2H	105	143	36.7	31
HCO_2H	109	141.5	36.7	35.5
Pale crepe:				
CH_3CO_2H	110	143.5	35.6	33
HCO_2H	113	143	35.5	33

Stock: rubber, 100; S, 3; ZnO, 30; $(CH_2)_6N_4$, hexamethylenetetramine, 1; vulcanized at 150° (ring-shaped test pieces)

Vulcanization time in min	T_B	E_B	E_{130}	T_B	E_B	E_{130}
	Smoked sheet, CH_3CO_2H			Smoked sheet, HCO_2H		
40	185	784	693	173	784	714
50	173	751	678	173	766	695
60	176	763	688	174	769	693
70	146	738	712	167	763	698
80	146	772	748	131	764	762
	Pale crepe, CH_3CO_2H			Pale crepe, HCO_2H		
40	165	803	750	168	811	752
50	182	785	712	179	776	708
60	176	778	714	179	782	714
70	167	765	714	168	771	717
80	157	779	738	151	776	743

Stock: rubber, 100; S, 5; PbO, 10; vulcanized at 150° (ring-shaped test pieces)

Vulcanization time in min	T_B	E_B	E_{100}	T_B	E_B	E_{100}
	Smoked sheet, CH_3CO_2H			Smoked sheet, HCO_2H		
30	106	895	883	102	905	900
60	106	944	932	100	935	935
90	97	989	997	87	977	1000
120	79	1000	1056	84	1014	1060
	Pale crepe, CH_3CO_2H			Pale crepe, HCO_2H		
30	125	931	887	118	923	891
60	124	977	933	119	964	929
90	105	1014	1003	105	1006	995
120	94	1027	1042	99	1039	1040

TABLE 23.—CHEMICAL COMPOSITION, %

	H_2O	Ash	Water extract	Acetone extract	N
Smoked sheet, CH_3CO_2H	0.75	0.35	0.75	3.4	0.49
Smoked sheet, HCO_2H	0.72	0.30	0.58	3.4	0.47
Pale crepe, CH_3CO_2H	0.33	0.23	0.16	3.0	0.36
Pale crepe, HCO_2H	0.37	0.17	0.21	3.0	0.36

TABLE 24.—AGING

Raw crepe rubber

	Cure, min	T_B	Slope	η		Plasticity	
				C_6H_6	HCl + C_6H_6	D_{30}	ΔD
Initial, CH_3CO_2H	110	141	34	32	17	1.52	0.065
Initial, HCO_2H	<120	134	35	31	16.5	1.41	0.07
After 1 yr, CH_3CO_2H	120	141	35	27	16.5	1.58	0.07
After 1 yr, HCO_2H	>120	145	35	26	16.5	1.58	0.06

TABLE 24.—AGING.—(*Continued*)

Vulcanized rubber; stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

Cure, min	T_B		Change in
	Initial	After 1 yr	E_{130}
75, CH_3CO_2H	86	119	*ca.* 170
75, HCO_2H	86	118	*ca.* 170
120, CH_3CO_2H	133	17	
120, HCO_2H	140	16	

OTHER COAGULANTS

Hydrofluoric (57), citric (57), oxalic (57), tartaric (57), lactic (202), sulfurous acids (178); calcium chloride (208); alcohol (40); pyroligneous acid (58); freezing (58); electrolysis (187).

CHEMICAL COMPOSITION OF RAW RUBBER

TABLE 25.—COMPOSITION OF HEVEA RUBBERS

	Number of samples	H_2O, %		Ash, %		Acetone extract, %		Protein, % (N × 6.25)		Water extract, %	Lit.
		Mean	Limits	Mean	Limits	Mean	Limits	Mean	Limits		
Latex crepe	102	0.61	0.30–1.08	0.30	0.15–0.87	2.88	2.26–3.45	2.82	2.17–3.76		(130)
Smoked sheet	35	0.42	0.18–0.90	0.38	0.25–0.85	2.89	1.52–3.50	2.82	2.18–3.50		(130)
Unsmoked sheet	25	0.58	0.32–1.30*	0.23	0.15–0.31	2.88	2.30–3.47	2.31	2.04–2.68		(35)
Fine hard Para				0.3		3		2.3		0.5	(183)
Latex sprayed				1.10		4.25		4.2		6.50	(86)
				1.5		4.7		4.2		7.1	(158)
		1.2		1.5		5.1		4.3		7.7	(128)
Kerbosch rubber			2.5 –4.5		1.6 –2.2	2.2		5.0		1.5	(194)
		4.2		1.9		2.5		4.5		4.1	(128)

* % loss on washing.

TABLE 26.—MOISTURE CONTENT OF RAW RUBBER

	Number of samples	Moisture content, %	
		Mean	Limits
In the tropics (177)			
Latex crepe	54	0.67	0.34–1.01
Smoked sheet	96	0.76	0.43–1.16
Lump crepe	17	1.05	0.65–1.80
Scum or skimmings crepe	3	0.43	0.35–0.53
Washings crepe	6	0.55	0.27–0.78
Scrap crepe	15	1.16	0.68–1.64
Dark crepe	3	1.07	0.90–1.33
Earth crepe	2	0.70	0.60–0.81
In Europe (130)			
Latex crepe	102	0.42	0.18–0.90
Smoked sheet	35	0.61	0.30–1.08
Fine hard Para, washed and air-dried			0.56
Caucho			0.31

TABLE 27.—RESIN CONTENT

Hevea.—*v.* Table 29.

Castilloa, %.—16.7, 18.9 (130); 5.4–52 (17 samples) (26).

Ceara (*Manicoba*), %.—3.4, 6.8 (130); 2.0 (206).

Congo, %.—2.0, 4.4, 5.2 (130).

Kassai, Red.—3.8 (206).

Kassai, Black.—4.0 (206).

Jelutong.—76–81 (3 samples) (55).

TABLE 28.—OPTICAL ACTIVITY OF RESIN FROM VARIOUS RUBBERS (85)

Source	$[\alpha]_D^{20}$	Source	$[\alpha]_D^{20}$
Upper Congo	12–13°	Padang	28–30°
Manaos	16–18°	Guayule	11–15°
Peruvian	29–31°	Kassai	29–30°
Jelutong	49–50°		

TABLE 29.—SAPONIFIABILITY (130)

Rubber	Resin, %	Unsaponifiable, %	
		Of the rubber	Of the resin
Fine hard Para	3.0	0.8	25.4
Hevea sheet	1.8	0.9	48.3
Hevea crepe	3.2	0.7	22.0
Castilloa	18.9	14.0	73.7
Congo	4.4	3.0	68.3
Jelutong	38.1	31.7	83.2
Jelutong crepe	7.2	5.6	77.8

TABLE 30.—NITROGENOUS CONSTITUENTS

Average N content of crepe and sheet, 0.45%; of slab, 0.21–0.30% (57).

A sample of crepe contained 0.40% N, representing 61.5% of the total N (0.11%) of the latex (57).

Properties of Rubber Proteins.—*v.* (11, 12, 150).

Nitrogen in Acetone Extract.—Crepe (2 samples), 0.04; sheet, 0.014; fine hard Para, 0.053; Manicoba, 0.069; Manihot, 0.041; Castilloa, 0.027; hard Congo, 0.013; soft Congo, 0.15% (130).

TABLE 31.—CONSTITUENTS IDENTIFIED IN THE RESIN OF HEVEA RUBBER

Constituent	M. P., °C	$[\alpha]^t_D$	Approximate % of the raw rubber
Smoked sheet and latex crepe (215)*			
Phytosterol ester	83	−11.0° (24°)	0.075
Sitosterol *d*-glucoside	285–90 d	−41.7° (23°)	0.175
Phytosterol	125	−24.6° (23.5°)	0.225
d-Valine	*ca.* 260 d	26.5° (16°)	0.015
Quebrachitol	190	−80.3° (20°)	Tr.
Stearic acid			0.15
Oleic + linoleic acids			1.25

* In slab (matured) rubber (28) acetic and valeric acids have been identified (probably as the NH_4 salt or amide); also valeramide, M. P. 102–3°, and palmitic and stearic acids (0.5–0.7 %).

TABLE 32.—ACID CONTENT

Water-soluble acids* by cold extraction for 24 hr (130)

Sheet				Crepe			
Number of samples	Mean	Maximum	Minimum	Number of samples	Mean	Maximum	Minimum
35	0.03	0.078	0.006	102	0.006	0.024	0.006

* Results expressed as % acetic acid.

By extraction with boiling water (8, 50, 136). Pale crepe, 0–0.1%; smoked sheet, 0.055–0.25%.

Acetone-soluble acids

Kind of rubber	a (213, 214, 222)				b (28)			
	Number of samples	Acid number*			Number of samples	Acid number*		
		Mean	Maximum	Minimum		Mean	Maximum	Minimum
Hevea smoked sheet	19	275	314	234		292	300	284
Hevea latex crepe	12	282	296	272				
Fine hard Para	12	218	384	100		215		
Hevea scrap (brown) crepe	3	151	223	92				
Latex sprayed	3	453	534	301	2	273.5		
Slab (matured rubber):								
Unwashed					3	851	896	818
Outside	1	256						
Interior	1	459						
Washed	1	224			2	237.5	240	235
Palembang "plain sheet"					3		366	336
Caucho	1	57						
Kassai	1	75						
Massai					2	182	182	166

c (34). Acid number:* Fine hard Para, 294; Kassai, 32; Guayule, 240; Ceara, 172; Upper Congo, 43; Benguella, 60; Peruvian, 18; Accra lumps, 75.5.

* Acid number = mg KOH required to neutralize the acid in the acetone or alcohol extract from 100 g rubber.

TABLE 33.—MANGANESE CONTENT (29)

	Number of samples	g Mn/100 kg	
		Mean	Limits
Sound rubber (fine hard Para, sheet, crepe, slab)	11	0.16	0.125–0.625
Very tacky rubber (sheet, brown crepe)	5	20.0	

PHYSICAL PROPERTIES OF RAW RUBBER

Coefficient of cubical expansion: under no load, $\frac{10^6}{V}\frac{dV}{dt}$ = at 10°, 657; 20°, 665; 30°, 670 (133). At constant length practically the same values hold as for no load (99, 105, 133).

TABLE 34

	d_4^{20}	V_M^{20}	n_D^t	M_D
Purified rubber (106)	0.9237		1.5219^{20}	22.46
Smoked sheet (106)	0.9217	73.8	1.5208^{20}	22.44
Pale crepe (164), *cf.* (42)			1.525^{15}	
Synthetic methyl rubber (106)	0.9292	88.23	1.525^{20}	27.03

Viscosity of Raw Rubber and Its Solutions

RUBBER

TABLE 34*A*

Unmilled.—ca. 10^{20} poise at 15.5° (1). (By extrapolation from values for solutions.)

Milled (77).

Period of milling, min	10	22	32	39
$10^{-7}\ \eta$ at 100°	9.3	5.0	3.2	2.4

Heavily Milled.—$\eta = 22.4 \times 10^5$ at 10°; 2.29×10^5 at 60° (1).

UNMILLED RUBBER SOLUTIONS

Ostwald viscosimeter used unless otherwise indicated

TABLE 35.—CASTILLOA RUBBER (65)

Number of samples	Resin content, %	Relative viscosity in benzene					
		0.25%		0.5%		1.0%	
		Mean	Limits	Mean	Limits	Mean	Limits
13	18.9–37.0	3.0	2.0–3.5	6.7	3.5–9.0	26.0	9.2–36.5

For viscosity of 1 % solution in benzene of typical samples of Hevea rubber *v.* Tables 49, 57, 58.

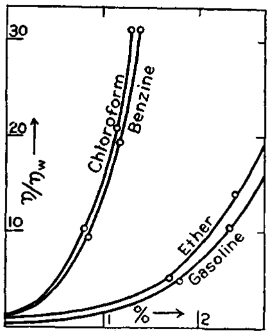

FIG. 4.—Viscosity of plantation rubber in various solvents (67).

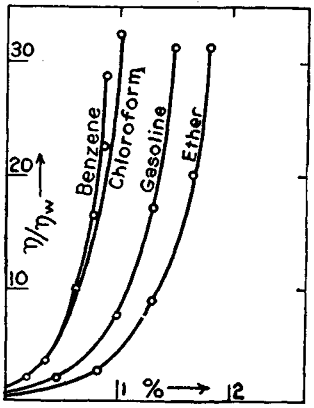

FIG. 5.—Viscosity of fine hard Para rubber in various solvents (67).

TABLE 36.—CONCENTRATED SOLUTIONS IN BENZENE (1)

Falling sphere method

Concentration, %	2	3	4	5	6
η at 15°, poise	5.04	35.63	162.8	464.4	1577

TABLE 37.—ONE PER CENT SOLUTION IN CHLOROFORM (113)

	Number of samples	η/η_0 at 25°, centipoise	
		Mean	Limits
Pale crepe	5	32.7	22.5–41.6
Smoked sheet	12	22.9	16.3–26.6

TABLE 38.—COMPARISON OF VISCOSITY IN C_6H_6, C_7H_8 AND CCl_4 (130)

Extreme samples in a series of 5 samples

Solvent	Sample No. 1			Sample No. 5		
	C_6H_6	C_7H_8	CCl_4	C_6H_6	C_7H_8	CCl_4
Concn	0.998	0.998	0.997	0.993	0.991	0.993
η/η_0	20.26	20.94	29.95	53.5	68.1	119.5
$\eta/\eta_{C_6H_6\ soln.}$	1.00	1.04	1.48		1.29	2.24

TABLE 39.—VISCOSITY IN VARIOUS SOLVENTS AT VARIOUS CONCENTRATIONS (92)

Solvent \ g/100 cm³ solvent	0.5	1	2	3
Benzine	1.9	4.3		94.0
Benzene	2.1	4.7	23.5	97.3
Carbon tetrachloride	2.6	7.5		211.3
Tetrachloroethane	2.5	6.9		168
Pentachloroethane	3.0	8.7	46.0	213.5

Variations of viscosity with concentration: (1) $\eta_x = k^x$, where η_x = the viscosity at concentration x; k = a constant (67). (2) Log $\eta/\eta_0 = \theta C$, where η = viscosity of solution, η_0 = viscosity of solvent, C = concentration (147).

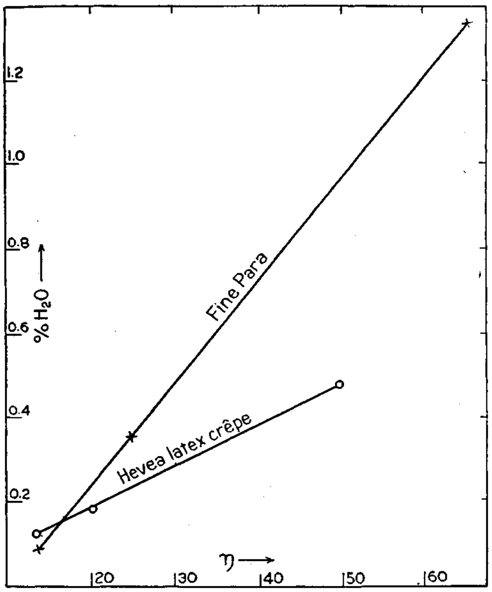

FIG. 6.—Influence of water on viscosity of benzene solutions (92).

TABLE 40.—INFLUENCE OF HEATING ON VISCOSITY (67)

Toluene solution at 40°

Period of heating, days	0	6	12
Time of efflux, sec	260	150	129

Xylene solutions at 80°

Period of heating \ g/100 cm³	Time of efflux, sec					
	0.4	0.48	0.54	0.60	0.73	0.82
0	61.5	73.0	87.0	104.5	138.0	187.0
30 min	53.0	62.0	74.0	89.5	120.0	161.0
1 hr	51.0	60.0	70.0	81.5	111.5	148.0
2 hr	46.5	57.0	64.0	73.5	105.0	132.0
3 hr	44.0	56.0	62.0	69.0	98.0	124.5

Xylene solutions heated 2 hr at 100°

Rubber	Number of samples	Time of efflux, sec	
		Initial	After heating
Fine hard Para	3	111–103	48–46
Plantation Hevea	3	115–108	72–65
Fine hard Para (45 min in cold)	1	118	81
Funtumia	3	104–100	81–70
Castilloa	2	111, 107	80.5, 78
Ceara	1	118	90

Law of diminution of viscosity with time of heating: $x = a + b \log t$, where x = diminution in time t; a = diminution in first unit of time; b = increment of diminution with time (67).

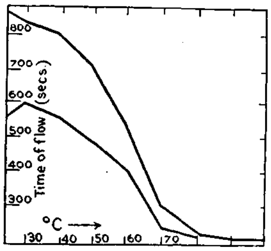

FIG. 7.—Viscosities at 18° of 0.5 % solutions in xylene of two samples of plantation rubber heated for two hours at various temperatures (13).

TABLE 41.—INFLUENCE OF ULTRA-VIOLET LIGHT* (13)

	Plantation					Fine Para				
Min exposed	0	15	30	45	60	0	15	30	45	60
Viscosity†	90	57	30	25	15	180	109	32	25	15

* Three per cent solution in xylene exposed at distance of 12 cm from quartz lamp (110 volts, 2.5 amp.).

† Frank-Mackwald viscosimeter.

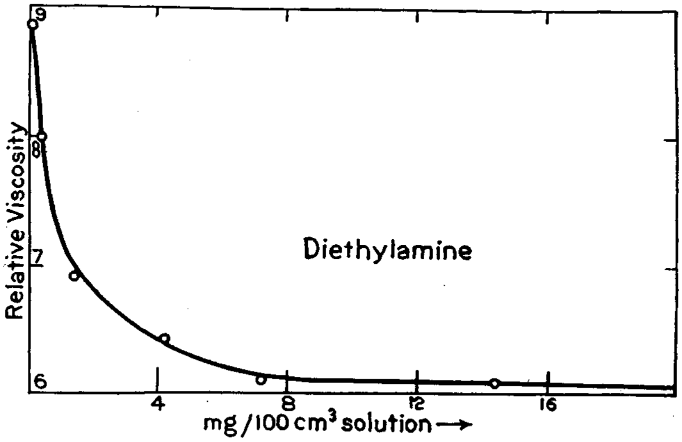

FIG. 8.—Influence of diethylamine on the viscosity of a benzene solution of rubber (218).

MILLED RUBBER SOLUTIONS

TABLE 42.—INFLUENCE OF MILLING. 2% SOLUTION IN C_6H_6 (13)

Milling period, min	25	5	10	15	20	30	40	50	60
Time of flow, sec	1900	540	150	100	90	70	65	60	59

TABLE 43.—EFFECT OF TEMPERATURE ON VISCOSITY AND DENSITY

Falling sphere method; heavily milled smoked sheet (10 g/100 cm³ solution in C_6H_6) (1)

°C	11.3	14.6	20.0	30.0	42.0	50.0	62.0
d_4^t	0.890	0.887	0.881	0.871	0.859	0.851	0.840
η*	3.97	3.77	3.42	2.92	2.57	2.32	1.95

* Expressed in poises.

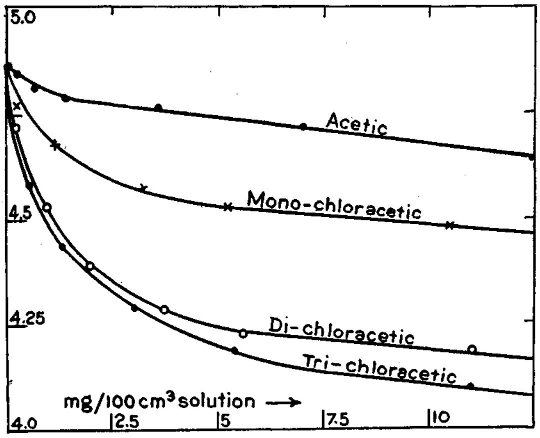

FIG. 9.—Influence of acetic and the chloroacetic acids on the viscosity of a benzene solution of resin-free rubber ([218]); *cf.* ([60, 150, 192]).

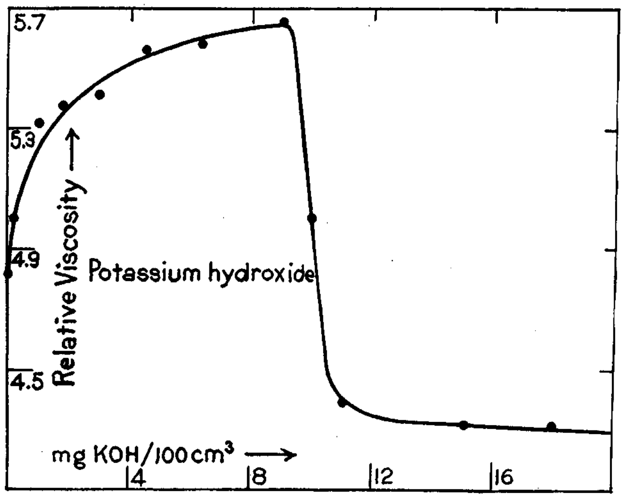

FIG. 10.—Influence of KOH on the viscosity of a benzene solution of a resin-free rubber (0.4961 g per 100 cm³) ([218]).

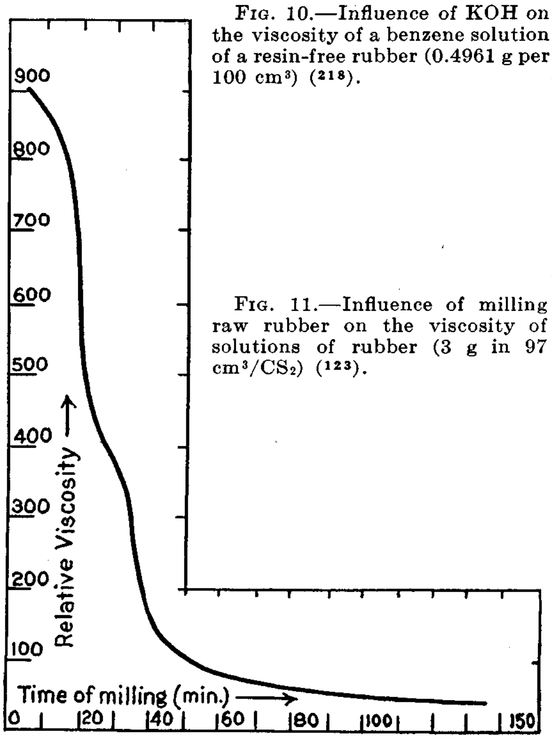

FIG. 11.—Influence of milling raw rubber on the viscosity of solutions of rubber (3 g in 97 cm³/CS_2) ([123]).

TABLE 44.—VISCOSITY OF BENZENE SOLUTIONS OF HEAVILY MILLED RUBBER AT LOW CONCENTRATIONS ([1])

Same sample as in Table 43 and Fig. 12

Concn.	0	0.5	1.0	2.0	3.0
η, poises	0.0063	0.0124	0.021	0.055	0.131

Relation between viscosity and concentration ([1]): $\eta_c = Ke^{k\sqrt{c}}$, for $c = 1 - 40$, where c = concn.; K and k are constants; e = base Naperian logs.

TABLE 45.—INFLUENCE OF LIGHT ([123])

Solutions of milled rubber in benzene exposed to light through a screen of benzene: (a) 3 g/97 cm³ benzene. (b) a + 0.06 g Sudan III/100 cm³.

	(a) exposed	(b) exposed	(b) protected
Initial viscosity	548.7	548.7	548.7
After 30 days	52.5	457.0	473.2
After 60 days	30.2	339.0	393.2

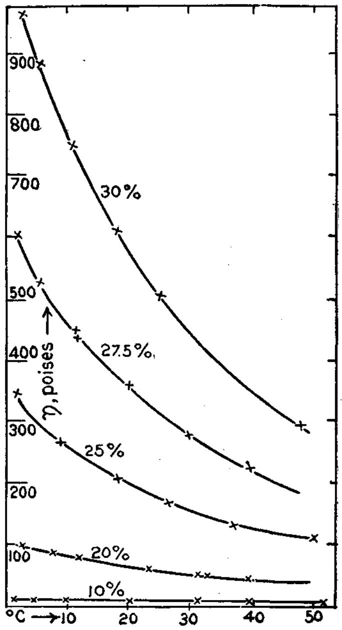

FIG. 12.—Viscosity of rubber solutions in C_6H_6; variation with temperature and concentration (falling sphere method) ([1]).

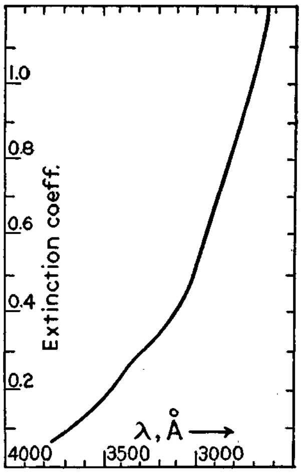

FIG. 13.—Ultra-violet absorption spectrum curve of ether solution of caoutchouc calculated on a 3% solution in a 1 cm cell ([102]).

Tensile Properties

TABLE 46

At room temperature: unmilled sheet (16 samples from a single sheet), T_B: 10.4 (limits: 7.8–18.1); E_B: 527 (limits: 423–616) ([130]).

At low temperature: rubber calendered and then allowed to age before testing (cross section of test pieces not stated) ([101]).

	Crepe					Fine hard Para			
°C	−13	−21	−34	−50	−55	−13	−23	−37	−51
E_5	425	320	275	120	50			290	250
Breaking load, kg	8	20	40	40	20	3	4	40	20
E_B	530	610	670	710	570	360	280	650	705
	Fine weak Para					Congo			
°C	−14	−23	−40	−53		−15	−26	−42	−55
E_5	510	460	440	120			520	440	20
Breaking load, kg	5	20	30	16		2	5	25	20
E_B	510	700	790	610		500	520	850	640

TABLE 46.—(*Continued*)

At optimum temperature; E (%) for (a) crepe and (b) fine hard Para (101)

Load, kg	1	2	3	4	5	6	7	8	9
(a) at −34°	0	0	50	200	275	320	370	400	430
(b) at −37°	0	10	110	220	290	350	400	440	460

Load, kg	10	12	14	16	18	20	25	30	40
(a) at −34°	460	490	510	540	560	580	610	640	670
(b) at −37°	470	490	520	540	560	570	610	630	650

VARIOUS TYPES OF HEVEA

Vulcanizing Properties, Etc., of Various Types and Grades of Hevea Rubber

LATEX CREPE AND SMOKED SHEET

TABLE 47

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

Type of rubber	Number of samples	Cure, min	T_B	Slope	η/η_0§	Lit.
Pale crepe*	1293	108.7 ± 7.6	142.4	35.4	33.5	(195)
Smoked sheet*	853	105.9 ± 12.5	143.5	36.7	33.9	(195)
Pale crepe*†	101	109.2 ± 7.2	140.8	36.0	34.7	(195)
Smoked sheet*†	149	104.6 ± 11.7	142.7	37.9	33.5	(195)
Pale crepe‡	1668	110.5	140.3	35.2	32.3	(192)
Smoked sheet‡	1647	97.5	140.7	36.4	32.6	(192)

* Prepared 1921–23. † *Ca.* 100 plantations sampled. ‡ Prepared 1917–23. § One per cent in C_6H_6.

Distribution as regards time of cure (195)

Type of rubber	Number of samples	Variation from medium value, %		
		< 10	< 20	> 20
Pale crepe	1293	83.5	99.5	0.5
Smoked sheet	853	60.5	91	9
Pale crepe	101	86	99	1
Smoked sheet	149	64.5	90	10

Stock: rubber, 90; S, 10; vulcanized at 140°. Mean for latex crepe: (cure = 195 min) T_B = 130. Mean for smoked sheet: (cure = 165 min) T_B = 146 (57).

TABLE 48.—VULCANIZATION COEFFICIENTS (110)

Data refer to a "standard" cure, *i.e.* T_{330} = 136 in the stock: rubber, 90; S, 10; vulcanized at 148°

Age of tree	10 year old trees*		20 year old trees*	
	Cure, min	V. C.	Cure, min	V. C.
Latex crepe	107	5.20 ± 0.16	126	5.00 ± 0.07
Sheet	61	5.47 ± 0.19	72	5.38 ± 0.10

* Six samples.

FINE HARD PARA

Mean Values.—Rubber, 92.5; S, 7.5; vulcanized at 150°. (Ring-shaped test pieces.) Cure (min), 100; T_B, 145; slope, 35.39; η, (1% in C_6H_6), 33 (182).

TABLE 50.—COMPARISON WITH SMOKED SHEET FROM SAME LATEX (209)

Stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces)

Type	Cure, hr	T_B	E_B	Slope
Brazilian from young trees	2.25	168	929	40
Smoked sheet from young trees	1.75	158.5	928	38
Brazilian from old trees	2.25	153	919	38
Smoked sheet from old trees	2.25	149.5	944	36

CEYLON BLANKET CREPE

TABLE 49 (154)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

	Air dried mean*	Heat dried mean†	Average (17 samples)		Thin crepe (for comparison)	
			Mean	Limits	Mean	Limits
Thickness, mm			11	4–22		
Moisture, %			0.4	0.24–0.62	0.6	0.35–1.0
Ash, %			0.2	0.12–0.33		
Vulcanization time in min	124	132	129	115–140	109	
T_B	146	140	142		142	
Slope	34	35.5	35	34–36	35.5	
η, 1% in C_6H_6‡	37	23	29	21–44	34	
η, 1% in acid C_6H_6‡	20	15	17	14.5–21.5		

* 6 samples. † 9 samples. ‡ Rate of flow compared with rate of flow of the solvent.

SLAB (MATURED RUBBER)

TABLE 51 (205)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

Thickness	Number of samples	% loss on washing	Cure, min	T_B	Slope
3 cm	11	22.0	35	155	32.2
1–1.5 cm	4	21.6	36	157	31.5

For stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces); cure, 75 min; T_B = 151 (mean values) (57).

TABLE 52.—VARIATION IN TIME OF CURE (COMPARED WITH CREPE AND SHEET) (205)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150°

Type	Cure, min		% deviation	
	Mean	Limits	Maximum	Mean
Slab (193 samples)*	35.5	15–57	118	18.8
1920–1924 samples of:				
Pale crepe	108.2	80–135	51	6.66
Smoked sheet	103.9	65–150	78	11.62

* By CH_3CO_2H and natural coagulation.

LATEX SPRAYED RUBBER

Comparison with sheet and crepe

TABLE 53 (86)

Stock: rubber, 100; S, 10; at 141°

Type	Number of samples	Cure, min	T_B
Latex sprayed	20	127	251
Smoked sheet	20	165	230
Latex crepe	20	183	227

TABLE 54 (38)

Stock: rubber, 90; S, 10; at 148° (ring-shaped test pieces); cure giving load-strain curve passing approx. through E_{775} = 104

Type	Number of samples	Cure, min	T_B	E_B	Slope
Latex sprayed	6	60	157.5	863	39
Smoked sheet	5	107	171	867	40
Latex crepe	5	136	155.5	854	37

TABLE 55 (38)

Stock: rubber, 90; ZnO, 90; S, 10; hexamethylenetetramine, 1

Type and number of samples	Cure giving					
	Load-strain curve through E_{480} = 104			Maximum breaking load		
	Min	T_B	E_B	Min	T_B	E_B
Latex sprayed, 3	23	184	607	47	193	392
Smoked sheet, 5	37	175	604	45	193	458
Latex crepe, 5	42	184	624	45	187	478

TABLE 56.—PLASTICITY OF UNMILLED LATEX SPRAYED RUBBER

Number of samples	D_{30}	ΔD	η		Lit.
			1 % in C_6H_6	1 % in HCl + C_6H_6	
6	1.94	0.08	*ca.* 40	17	(196)

OTHER TYPES LATEX RUBBER

Unsmoked Sheet.—Differs from smoked sheet only in vulcanizing in about 10 % less time (183).

Evaporated Latex.—Time of cure, 70 to 75 % that of crepe (203); 75 min in stock: rubber, 90; S, 10; at 141° (56).

Kerbosch Rubber.—Time of cure, 50 to 60 min in stock: rubber, 92.5; S, 7.5; at 150° (194). Deteriorates on aging.

TABLE 57.—LOWER PLANTATION GRADES (183)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

	Samples washed crepe	Cure, min		T_B		Slope		η, 1 % in C_6H_6	
		Mean	Limits	Mean	Limits	Mean	Limits	Mean	Limits
Lump (naturally coagulated clots)	90	104.5	7–130	133	107–150	37.3	33.5–40	30.5	10–58
Scum or skimmings (from tanks, etc.)	30	112.5	85–135	134	124–142	36.8	34 –40	28.5	20–59
Washings (diluted latex from cups, etc.)	25	118	95–145	127	106–145	39.1	35.5–46	22.6	15–31
Tree scrap	90	105	70–185	125	104–146	38.8	35.5–44.5	25.7	13–48
Bark scrap	25	111	90–140	108	82–136	42.9	38 –47.5	19.5	11–33
Earth rubber	28	97.5	70–130	126	106–138	37.6	34 –40	20.1	15–28

TABLE 58.—NATIVE RUBBER (155)

Stock: rubber, 92.5; S, 7.5; vulcanized at 150° (ring-shaped test pieces)

	Number of samples	% ash		Cure, min		T_B		η, 1 % in C_6H_6		η, 1 % in HC + C_6H_6	
		Mean	Limits	Mean	Limits	Mean	Limits	Mean	Limits	Mean	Limits
Crepe prepared in laboratory from native slab*	253			96	40–160	138		24.5		12.5	
Amber crepe prepared in native factories†	14	1.01	0.2–1.8	114	100–130	130	110–153	20	11–64	11	7–25
Amber crepe prepared from native rubber in Singapore	20	0.82	0.5–1.2	93	70–140	140	125–157	20	5–48		
First quality plantation latex crepe (for comparison)			0.2–0.4	107	80–130	143		33			

* Per cent washing loss = 10–50 (limits). † Plasticity: D_{30} = 1.30 (mean), 1.0–1.72 (limits); ΔD = 0.07 (mean), 0.04–0.13 (limits).

FACTORS IN THE PREPARATION OF HEVEA RUBBER

TABLE 59.—INFLUENCE OF DILUTION OF LATEX ON THE PROPERTIES OF RUBBER (192)

Ring-shaped test pieces

	Cure, min	T_B	Slope	η*
Undiluted latex				
Crepe milled same day	103.5	140	37.2	23.9
Crepe milled next day	84.5	142.5	36.7	27.2
Smoked sheet rolled next day	69	149	37.8	28.6
Diluted to 15 % rubber content				
Crepe milled same day	113.5	138.5	37.7	25.4
Crepe milled next day	100.5	140.5	38.0	23.6
Smoked sheet rolled next day	80	144.5	37.1	31.0

* One per cent in C_6H_6.

TABLE 60.—INFLUENCE OF AGE OF TREES ON PROPERTIES (192)

Ring-shaped test pieces

	Age, yr	Crepe		Sheet	
		Time, min	T_B	Time, min	T_B
First group of trees	3	77	123	59	127
	4.5	82	129	58	134
	7.5	97	138	64	145
Second group of trees	4.5	77	125	58	132.5
	8	96	137	68	144.5

Age, yr (184)	35	19	18	8
Vulcanization of crepe, min	145	130	135	110
η, 1% in C_6H_6	50	39	41	28

TABLE 61.—INFLUENCE OF RESTING TREES (203)

Change in rubber content of latex, vulcanizing properties, viscosity (1% in C_6H_6), after a period of rest

Days*	Rubber content, %	Cure, min†				η			
		Crepe		Sheet		Crepe		Sheet	
		A‡	B§	A‡	B§	A‡	B§	A‡	B§
1–2	51.3	<125	160	115	160	36.5	31.5	42.5	38
3	49.3	125	150	<105	<160	36.5	34	44.5	38.5
7	43.2	125	150	95	145	36.5	30.5	42	37
10	40.9	110	140	<95	125	32	28	40.5	30
14	38.5	<105	130	90	130	31.5	29	33	31
18	35.0	95	130	80	<110	28	23	30.5	25.5
23	32.4	95	<120		100	23	23	32	27.5
28	30.1	<85	115	<80	<100	28	25	29.5	32.5
35	29.0	90	115	75	90	26.5	21.5	32	31.5
39–56	28.4	89	104	69	81	26.9	23.4	30.3	29.5

* Days after tapping started again. † Stock: rubber, 92.5; S, 7.5; vulcanized at 148°. ‡ A, undiluted latex. § B, latex diluted to 15% rubber content.

TABLE 62.—INFLUENCE OF LENGTH OF REST ON RATE OF CURE (204)

Period of rest, mo	½	1	2	3	4
Increased time of cure, min*	2	10	20	20	40

* For early tappings (2–6 expts.).

TABLE 63.—INFLUENCE OF ANTICOAGULANTS ON THE PROPERTIES OF RUBBER

	$NaHSO_3$*		$Na_2SO_3.7H_2O$
Lit	(186)	(186)	(185)
g/l latex	0.5–1	2	1.2
Increase in T_B	0 – 5	0– 5	0– 3
Decrease in min of cure	5 –10	10–15	5–10
Decrease in slope	1 – 1.5	1– 1.5	1– 1.5
Increase in η (1% in C_6H_6)	1.5–10	3–10	1– 2

* Proportion necessary to inhibit action of latex oxidase: 1 part in 400 to 2400 parts latex (9).

NON-HEVEA RUBBERS

TABLE 64.—VULCANIZATION OF CAUCHO BALL WITH S ONLY (217)

Stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces)

Min	150	180	210	240
T_8	6.8	9.2	11.45	
T_B	34	46	57	62
E_B	1082	1045	1010	968

TABLE 65.—VULCANIZATION OF CAUCHO BALL WITH THE AID OF AN ACCELERATOR (217)

Stock: rubber, 100; S, 5; ZnO, 5; zinc pentamethylenedithiocarbamate, 0.5; vulcanized at 115° (ring-shaped test pieces)

Min	30	60	90	120
T_7	53.2	114	120	
T_B	130	152	138	27
E_B	861	769	737	

TABLE 66.—VULCANIZATION OF FICUS RUBBER WITH S ONLY (217)

Stock: rubber, 90; S, 10; vulcanized at 141° (ring-shaped test pieces)

Min	150	180	210
T_7	8.5	11.3	13.6
T_B	49	68	83
E_B	1112	1102	1074

TABLE 67.—VULCANIZATION OF FICUS RUBBER WITH THE AID OF AN ACCELERATOR (217)

Stock: rubber, 100; S, 5; ZnO, 5; zinc pentamethylenedithiocarbamate, 0.5; vulcanized at 115° (ring-shaped test pieces)

Min	60	90
T_7	77.5	96
T_B	187	163
E_B	853	794

VULCANIZED RUBBER

Hot Vulcanization with Sulfur

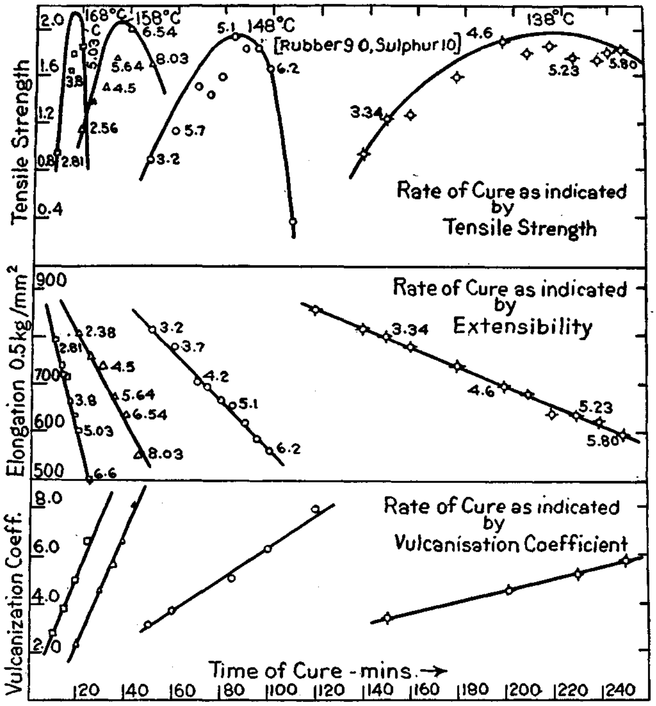

FIG. 14.—Vulcanization of simple rubber-S mixture (rubber, 90; S, 10) (165). Influence of temperature on rate of cure, ultimate tensile strength, stiffness, rate of combination of S and sharpness of tensile peak (ring-shaped test pieces).

LOAD-STRAIN RELATIONS OF VULCANIZED RUBBER

TABLE 68.—PROGRESSIVE CHANGE ON VULCANIZING A SIMPLE RUBBER-S MIXTURE

Stock: rubber, 92.5; S, 7.5, vulcanized at 148° (ring-shaped test pieces) (165)

Period vulcanized, min	T_B	Number of samples	E_B	E_{130}	V. C.
75	75 ±1.5	20	991±3.9	1110?	2.86
80	90 ±1.4	23	999±2.2	1063?	
85	102 ±1.4	29	990±2.6	1040?	3.58
90	114.5±0.8	58	992±1.4	1018	3.77
95	122 ±0.9	52	985±1.8	994	
100	131.5±0.9	39	969±1.8	966.5	4.24
105	134.5±0.8	38	957±1.9	950	4.27
110	139 ±0.8	58	944±1.6	932	4.65
115	140.5±0.7	50	928±1.5	913	4.85
120	142 ±0.6	60	916±1.0	898	5.07
125	141 ±0.8	34	901±1.5	885.5	5.30
130	139 ±0.9	28	885±1.0	771	5.49
140	137	4			
150	130	4			

TABLE 69.—MOST PROBABLE VALUES ON VULCANIZING 341 SAMPLES OF RUBBER-S MIXTURE (RUBBER, 92.5; S, 7.5) AT 148° (130), *cf.* (54, 152, 165, 175)

V. C.	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
T_4.......		12.4	13.9	15.4	16.9	18.4	19.9	21.4	22.9
$T_{8.5}$......	34.6	47.4	60.2	73.0	85.7	98.5	111.3	132.4	148.0
T_B.......	64.3	77.6	91.0	104.4	119.0	128.4	138.2	137.3	115.5
E_B.......	965	950	930	915	910	895	890	855	800

TABLE 70.—TEMPERATURE COEFFICIENT OF HOT VULCANIZATION WITH S (165), *cf.* (54, 130, 152, 175)

	Mixture A*	Mixture B†
Temperature range	128–168°	108–148°
Temperature coefficient based on:		
Combination of S..................	2.3	2.3
Extensibility of vulcanizate.........	2.3	2.5
Tensile strength of vulcanizate......	2.4	2.4

* Unaccelerated mixture: rubber, 90; S, 10.

† Accelerated mixture: rubber, 90; S, 10; aldehyde ammonia 0.125–1.0.

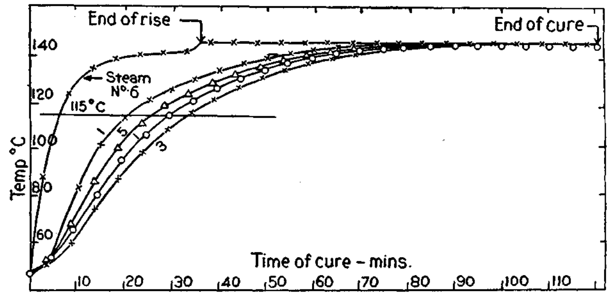

FIG. 15.—Temperature lag in vulcanization of a tire, vulcanized on air bags in steam autoclave for 2 hr at 146.3° (121). Temperatures at the following points in a 4-ply cord: (1) between second and third plies; (2) between second and third plies, under edge of the breaker; (3) same, under the center of the tread; (5) near the edge and on the top of the breaker.

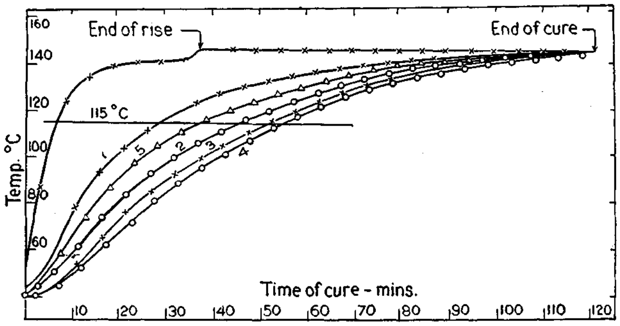

FIG. 16.—Vulcanized as in Fig. 15. Temperatures at following points in an 8-ply cover: (1) in the side between sixth and seventh plies; (2) between the sixth and seventh plies, under the edge of the breaker; (3) same, under the center of the tread; (4) same, under the edge of the breaker; (5) near the edge and on the top of the breaker.

TABLE 71.—INFLUENCE OF % OF S ON SIMPLE RUBBER-S MIXTURES

Mixtures vulcanized 90 min at 148° (130)

S, %	2.5	5	7.5	10	12.5	15	17.5	20
T_B....	29	63	99	124	57	23	25	62?
E_B....	900	894	894	766	431	198	183	384
V. C..	1.05	2.33	2.92	3.92	6.24	7.45	8.12	9.41

Vulcanized at 148° (199)

S, %	5	7	7.5	8	9	10
E_{50}................	1200	1000	965	925	870	790
T_B................	58	105	107	122	126	126
E_B................	1124	1016	984	964	911	840

TABLE 72.—INFLUENCE OF % OF S ON TIME OF CURE AT 148° AND ON TENSILE PROPERTIES AT OPTIMUM CURE (199)

S, %	Min	T_B	$T_{11.25}$	E_B	E_{120}	V. C.
7.5	75	133		911	891	
6	105	135		946	924	
5	120	135		1024	1001	4.41
3	120		40	>1125		2.81

Vulcanization by Other Means

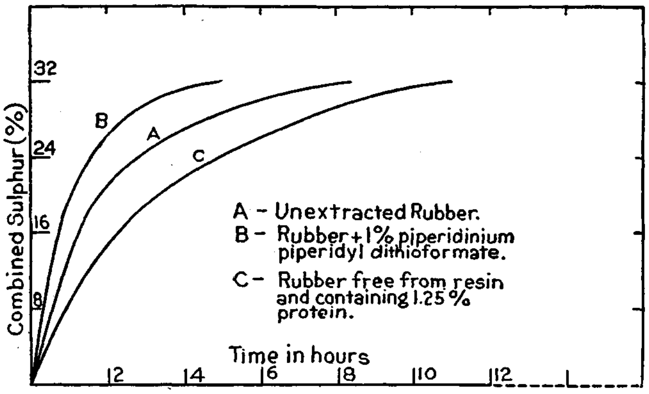

FIG. 17.—Vulcanization in solution. Rate of combination of S with (A) crepe, (B) crepe plus an accelerator and (C) crepe deprived of 52 % of its protein, on heating a 5 % solution in dichlorobenzene with 1000 % S (219); *cf.* (23, 84, 100, 157).

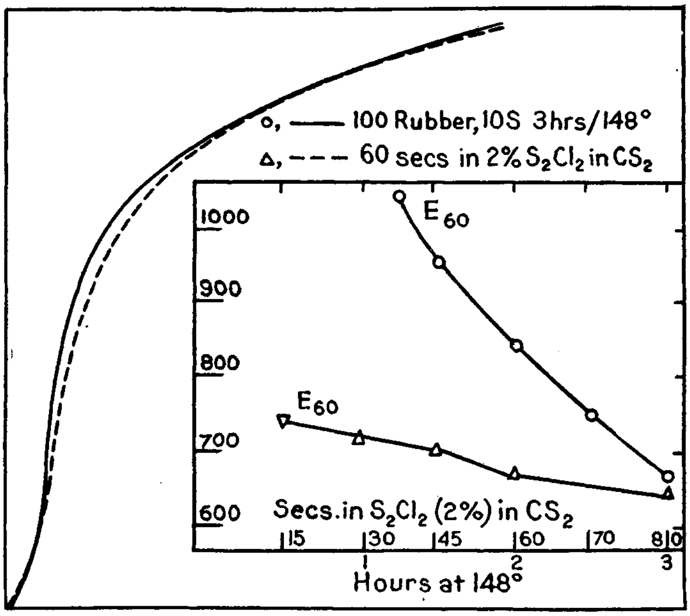

FIG. 18.—Comparison of the tensile properties (load-strain curve and stiffness) of rubber vulcanized by dipping in S_2Cl_2 solution and by heating with S (ring-shaped test pieces) (230).

SULFUR MONOCHLORIDE (130, 230)

Sheets of calendered latex crepe, 1 mm thick, dipped in solutions of S_2Cl_2 (1 – 5% in CS_2) for not more than 120 sec: T_B, 84 to 127; E_B, 800 to 1000 (ring-shaped test pieces) (230).

NITRO COMPOUNDS AND ORGANIC PEROXIDES

m-Dinitrobenzene. Stock: rubber, 100; PbO, 8; *m*-dinitrobenzene, 4; vulcanized 10 min at 147°: T_B, 103; E_B, 798 (30). Other nitro compounds and organic peroxides, *v.* (30).

TABLE 73.—MIXTURES OF SE AND S (228)

Composition of stock			Cure giving stiffest vulcanizate	
Crepe	S	Se	Time at 143°, min	T_{500}
94	6.00	0.00	270	375
94	5.11	2.19	180	430
94	4.51	3.69	210	370
94	3.73	5.6	240	315
94	0.00	14.80	No cure in 300 min	

ULTRA-VIOLET RAYS (83)

NITROGEN SULFIDE (126)

PHYSICAL PROPERTIES

Tensile Properties

FACTORS INFLUENCING TENSILE PROPERTIES

TABLE 74.—INFLUENCE OF SHAPE OF TEST PIECE AND DIRECTION OF ITS AXIS WITH REFERENCE TO THE CALENDER DIRECTION (32)

	T_B	E_B	T_B	E_B	T_B	E_B
Sample No	1		2		3	
Rings	151	635	119	675	74.5	525
Straight pieces:						
Longitudinal	192.5	630	146	640	84.5	480
Transverse	181.5	640	143.5	670	88.5	555
Sample No	4		5		6	
Rings	107	435	36	285	51.5	320
Straight pieces:						
Longitudina	130	410	48.5	320	62	315
Transverse	120	460	36	280	48.5	315

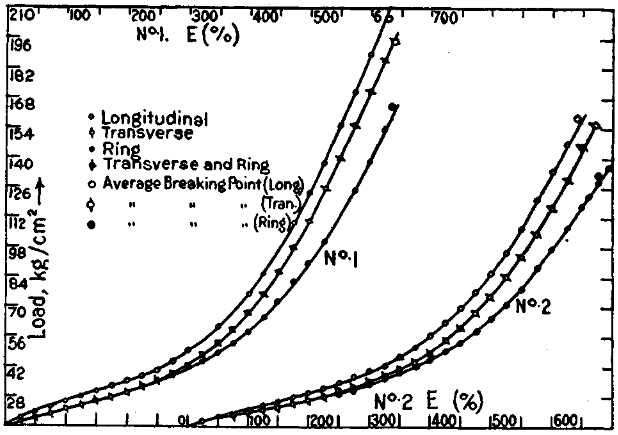

FIG. 19.—Load-strain curves of Samples 1 and 2 (Table 74) as determined by (*a*) ring test pieces, (*b*) straight test pieces cut longitudinally and (*c*) transversely (32).

TABLE 75.—INFLUENCE OF WIDTH OF STRAIGHT TEST PIECES (32)

Sample	Cover		Tube		Tube		Cover		Tube	
Width, mm	6.35	12.7	6.35	12.7	6.35	12.7	6.35	12.7	6.35	12.7
T_B	110	102	151	137	72	67	51.5	48.5	175	144
E_B	525	515	580	570	350	340	335	350	615	575

TABLE 76.—INFLUENCE OF WIDTH OF RING TEST PIECES (112)
Diameter, 44.6 mm; thickness, 4 mm

	Higher-grade rubber				Lower-grade rubber			
Sample No	1		2		3		4	
Width, mm	T_B	E_B	T_B	E_B	T_B	E_B	T_B	E_B
2	158.9	808	105.8	611	18.9	182	25.2	187
4	117.7	806	97.1	624	18.8	193	27.3	203
6	97.4	809	87.5	628	17.2	183	26.0	199

TABLE 77.—INFLUENCE OF RATE OF STRETCHING (32)
Straight test pieces

Rate of jaw separation (cm/min)	12.5	60	115	12.5	60	115
	Higher-grade rubber					
Sample No	5			2		
T_B	175	188.5	190.5	133	136	138
E_B	605	635	635	465	500	490
	Lower-grade rubber					
Sample No	3			4		
T_B	26.3	30.1	32.5	23.8	27.3	30.1
E_B	340	360	375	105	115	120

TABLE 78.—INFLUENCE OF TEMPERATURE ON THE STIFFNESS OF AN ACCELERATED STOCK (47)
Stock: smoked sheet, 100; S, 3; ZnO, 6; hexamethylenetetramine, 0.9; vulcanized 60 min at 141°

t, °C	21	24	27	30
T_7	85	80	74	67

TABLE 79.—INFLUENCE OF HIGH TEMPERATURES (131)
Stock: rubber, 92.5; S, 7.5; vulcanized to various extents at 147°

	t, °C	Time of heating prior to test, min	T_B	E_B	$T_{8.5}$
Sample No. 1 (vulcanized 60 min; V. C. = 2.1)	24		63	991	31
	70	15			22
	100	15			20
	130	15			19
	147	2			19
	147	5	13	700	
	147	15	14	678	
Sample No. 2 (vulcanized 90 min; V. C. = 3.2)	26		107	990	49
	70	15	104	1049	37
	100	15	18	595	
	130	1	12	460	
	130	5	13	500	
	147	1	12	465	
	147	5	14	512	
Sample No. 3 (vulcanized 120 min; V. C. = 4.2)	23		118	914	79
	70	1	15	453	
	70	5	17	491	
	100	1	14	423	
	100	5	13	395	
	130	1	12	381	
	130	5	12	379	
	147	1	13	384	

Load-Strain Curves for Vulcanized Rubber

Independently of state of cure, the load-strain curve for rubber-S stock is a conchoid expressed by

$$y = a - b \sin \alpha \qquad (1)$$
$$x = n\,(a \cot \alpha - b \cos \alpha)$$

where x = load; y = strain; a = distance between pole and asymptote; b = distance between origin and asymptote; and n =

a constant fraction of corresponding abscissae of parent conchoid (137).

$$y = cx + a \sin^2 bx \tag{2}$$

where y = strain; x = load; c, a, b = constants for the rubber specimen in question, characterizing respectively the initial, the middle, and the ultimate elongations (39).

$$x = A\left\{1 - \frac{2}{l - b}\right\} e^{h(p-l)^2} \tag{3}$$

where x = load; l = length; b = breadth $\left(\text{taken as } \frac{1}{\sqrt{l}}\right)$; h, p = constants for the rubber specimen in question (118).

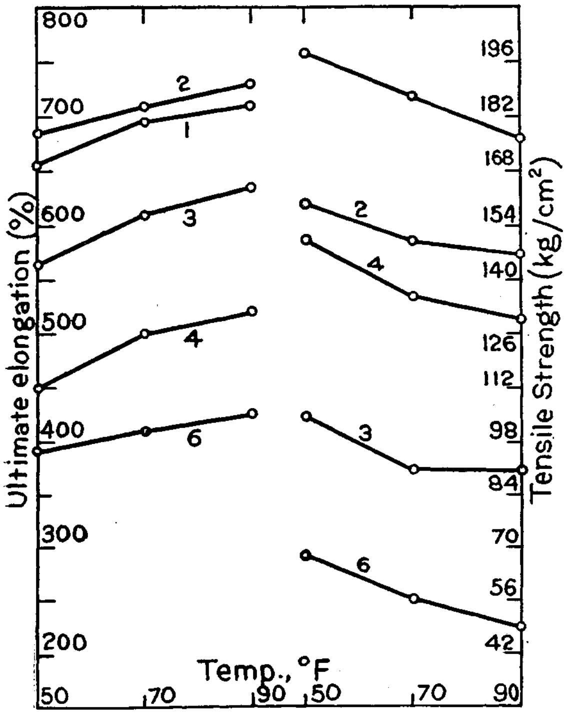

FIG. 20.—Influence of temperature on the tensile strength and ultimate elongation of five samples (32).

Stress-Strain Curve for Vulcanized Rubber

$$y = \frac{ax}{b + x} \tag{1}$$

where y = strain; x = load referred to unstrained cross section; a = distance of asymptote from axis; b = intercept cut off by tangent at origin on the asymptote.

The curve is a rectangular hyperbola, with asymptotes parallel to the axes, with the equations

$$y = a,\ x = -b.$$

Making the asymptotes the axes

$$x'y' = -ab \ (82)$$

$$\text{Stress} = Ee + e/B^{\frac{l}{k}} \tag{2}$$

where e = elongation; l = original length; E = Young's modulus; B and k = constants (146).

Mechanical Hysteresis

TABLE 80

Extension and sub-permanent set in a succession of cycles of extension and retraction (24). Pure gum rubber, sp. gr. 0.985, loaded at rate of 0.8 kg/cm² per 27 sec.

Cycle No.	1	2	3	4	5	6	7	8
Extension produced, %	516	568	590	604	617	627	636	643
Sub-permanent set, %	20	23	25	28	28	28	28	28

Extension, sub-permanent set, energy absorption, energy of hysteresis in succession of cycles of various amplitudes (80).

Extension in a series of cycles. Extension = $a + b \log$ (No. of cycle) where a = extension in second cycle; b = increment of extension in subsequent cycles (140).

Influence of amount of extension on amount of hysteresis. In general, the shorter the cycle, the smaller the energy of hysteresis (*cf.* Fig. 23).

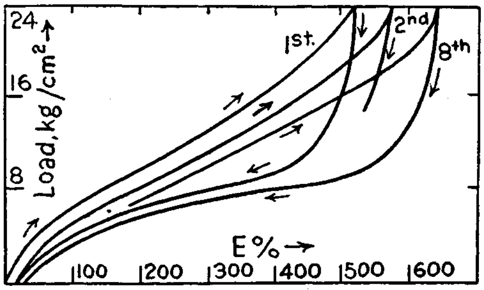

FIG. 21.—Load-strain curve for cycles Nos. 1 and 8 and part of cycle No. 2 (Table 80) (24).

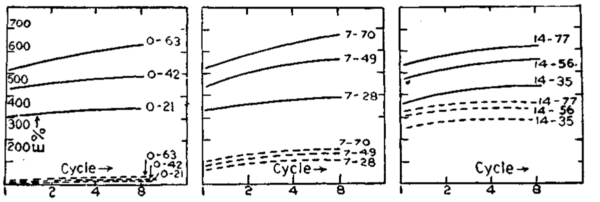

FIG. 22.—Relation between cycle number and max. (solid lines) and min. (dotted lines) extension for cycles between various loads. Stock: rubber (smoked sheet), 94 vols.; S, 3 vols.; MgO, 1 vol.; carbon black, 2 vols.; vulcanized 60 min at 149°. Load expressed in kg/cm² (80).

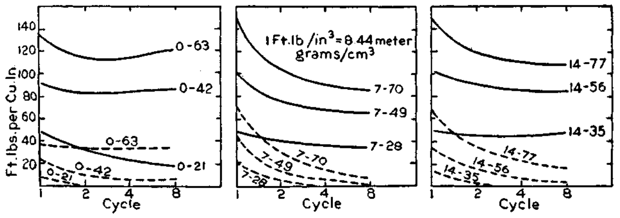

FIG. 23.—Relation between the cycle number and energy absorption (solid lines) and energy of hysteresis (dotted lines) for cycles between various loads. Load expressed in kg/cm² (80).

TABLE 81

Pure gum rubber subjected to a succession of cycles of different lengths, each cycle being repeated until the course of the load-strain curves was constant (24).

Cycle No.	Amplitude kg/cm²	Difference between elongation at same load during extension and retraction, %
1	0–4	61
2	0–8	167
3	0–12	286
4	0–16	533

Influence of rate of loading and unloading. The higher the rate of loading and of unloading, the smaller the extension and the greater the hysteresis (24).

Influence of state of cure and of the presence of a filler on energy absorption (Figs. 26 and 27) and energy of hysteresis (Figs. 28 and 29) in a succession of cycles of extension and retraction (80).

Stock A (by volume): rubber, 94; S, 3; MgO, 1; carbon black, 2.

Stock B (by volume): rubber, 63; S, 2; MgO, 1; carbon black, 2; whiting, 32.

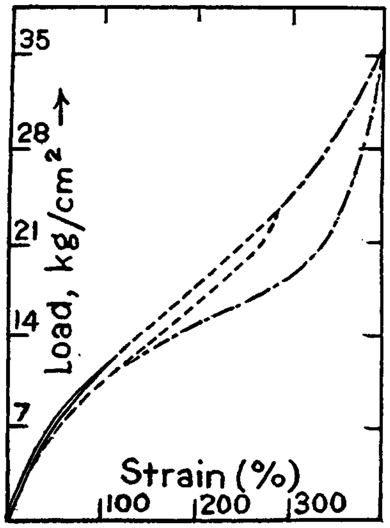

FIG. 24.—Pure gum rubber subjected to hysteresis cycles of different lengths (141).

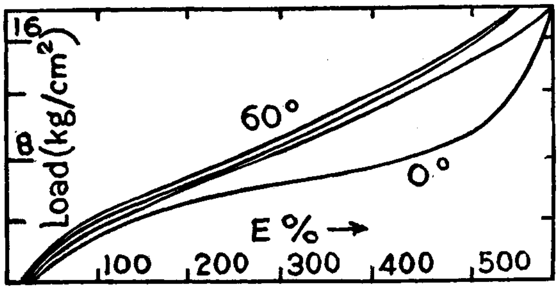

FIG. 25.—Influence of temperature on extension (24). Pure gum rubber, sp. gr. 0.985, loaded to 18.4 kg/cm² at 0° and 60°.

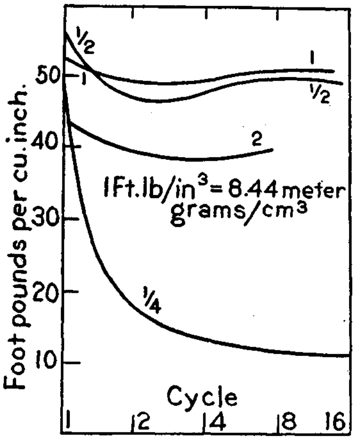

FIG. 26.—Stock A vulcanized for periods from 0.25 to 2 hr at 149° (80).

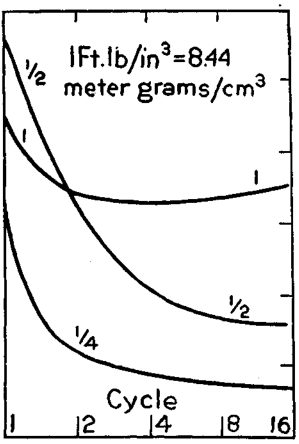

FIG. 27.—Stock B vulcanized for periods from 0.25 to 1 hr at 149° (80).

Influence of compounding ingredients on Poisson's ratio for rubber (174). (P_v, P_t, P_w: Poisson's ratio from measurements of volume, thickness, width, respectively.)

1. $P_t = P_w = P_v$ at elongations up to 200: carbon black, ZnO.
2. P_t does not equal P_w; $P_v = 0.5$.

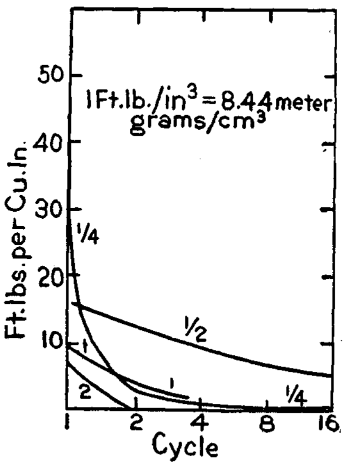

FIG. 28.—Stock A vulcanized for periods from 0.25 to 2 hr at 149° (80).

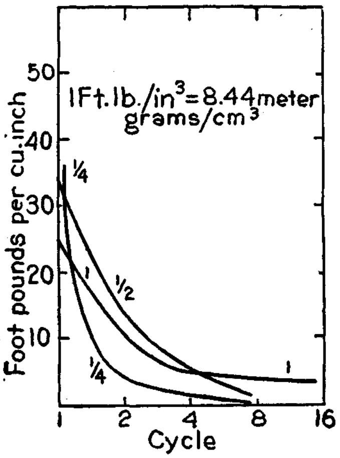

FIG. 29.—Stock B vulcanized for periods from 0.25 to 1 hr at 149° (80).

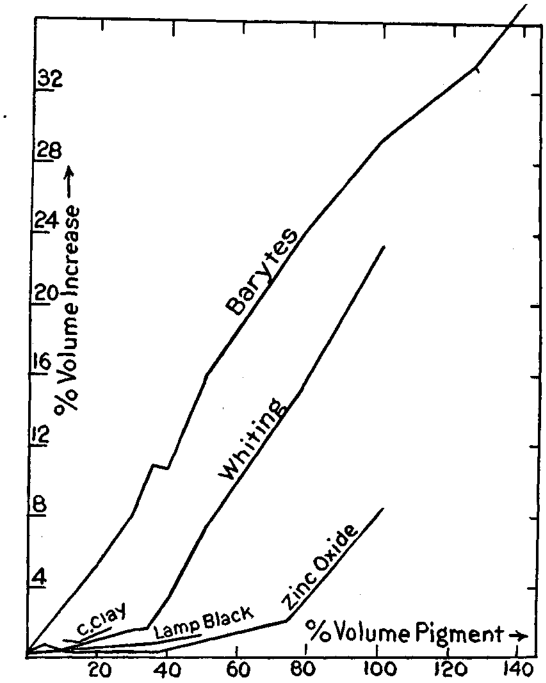

FIG. 30.—Increase in volume produced by straining to 100 % elongation stocks containing various volumes of barytes, china clay, lampblack, whiting and ZnO. Basal stock: rubber, 100; S, 5; litharge, 30 (139).

3. $P_w = P_t$; $P_v < 0.5$ at 300%: barytes, lithopone.
4. P_w does not equal P_t; $P_v < 0.5$: tripoli at high elongations (*cf.* Fig. 32).

	At 25 % elongation		
	P_t	P_w	P_v
Magnesium carbonate	0.72	0.31	0.51
Clay	0.69	0.32	0.505
Tripoli	0.61	0.39	0.50

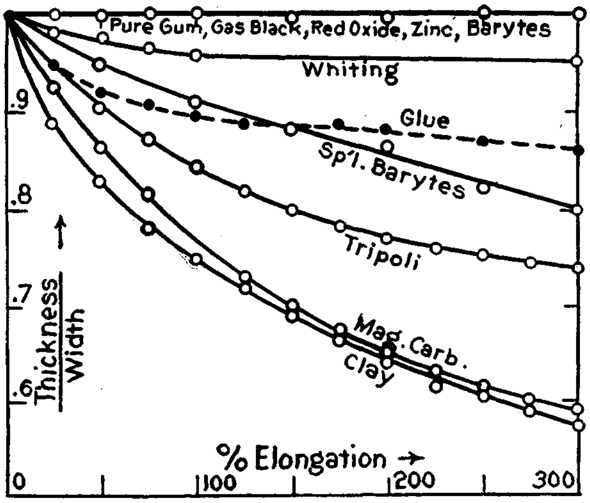

FIG. 31.—Effect of strain on the ratio thickness: width as influenced by various compounding ingredients (20 vols. per 100 vols. rubber) (174).

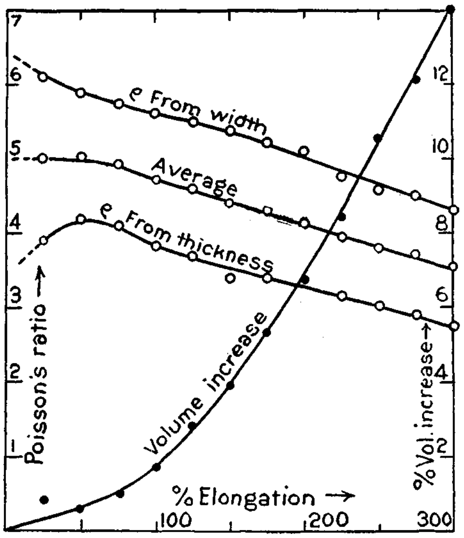

FIG. 32.—Effect of tripoli on Poisson's ratio and on increase in volume at various extensions (174). Stock contains 20 vols. tripoli per 100 vols. rubber.

Load-Compression Relations. Pure Gum Rubber

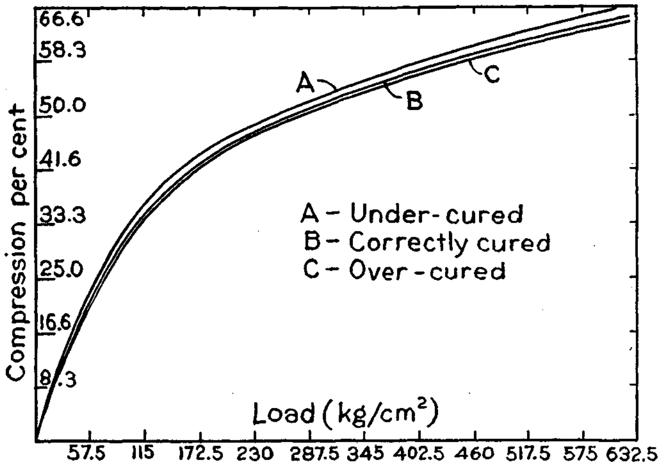

FIG. 33.—Load-compression curves for the stock: rubber, 100; S, 10; in various states of cure (17).

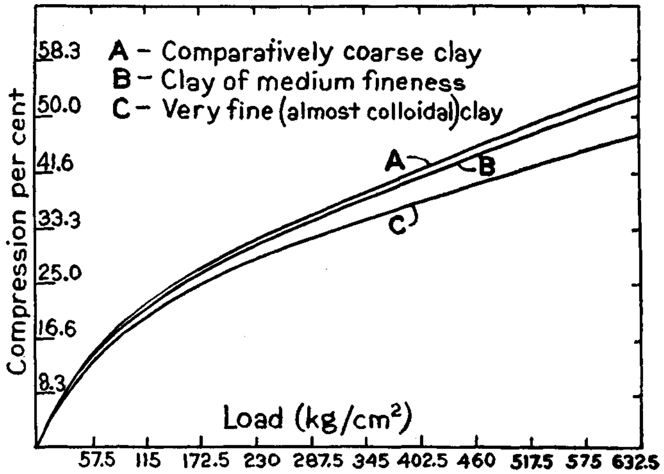

FIG. 34.—Load-compression curves for the stock: rubber, 100; china clay, 20; S, 10; ZnO, 5; diphenylguanidine, 1; using clay of different degrees of fineness (17).

Hardness

Definitions.—Plastometer number: the depression in hundredths mm produced by a steel sphere when the force against a surface of the rubber is increased from 85 to 1085 g, and then maintained for 60 sec (79).

Modulus of hardness: the force in dynes producing a depression of 1 cm^3 (79).

See p. 270 for Figs. 35–39, giving illustrative values.

Resistance to Tearing

TABLE 82.—INFLUENCE OF STATE OF CURE ON RESISTANCE TO TEAR (231)

Stock: rubber, 92.5; S, 7.5; vulcanized at 145°

Time of cure, min.	30	45	60	75	90	105	120	135	150
Resistance to tear, kg/cm^2	5.6	7.7	9.8	11.6	13.3	16.8	13.3	11.9	11.2

Compressibility

Compressibility.—92.95 × 10^{-6} of the original volume per kg/cm^2 (40). Equal to that of bronze (2), *cf.* (105).

Volume Elasticity (107).—Soft, gray rubber (sp. gr., 1.289; T_B, 58; E_B, 890): 14 000 kg/cm^2. Red rubber (sp. gr., 1.407; T_B, *ca.* 58; E_B, 630): 8000 kg/cm^2. Gray rubber (sp. gr., 2.340; T_B, 58; E_B, 340): 66 000 kg/cm^2.

Thermal Properties

Expansion.—Coefficient of cubical expansion of:

(*a*) Sample of vulcanized rubber (sp. gr., 0.996), 2.25° above to 2.25° below its maximum density: 0.000526 (88).

(*b*) Sample of black vulcanized rubber (sp. gr., 0.90166 at 17.4°; S content, 2.5 to 3 %) at 0–60.7°: 0.000763 (105).

(*c*) Gray rubber: 0.000562 (105).

Specific Heat.—Above mentioned sample (*a*): 0.415 (88).

Conductivity.—Vulcanized rubber, crepe, smoked sheet, etc. (45–100°): 0.00032 cal/sec/cm^3 (227).

Absorption

ABSORPTION OF ORGANIC VAPORS

TABLE 84.—ABSORPTION (g/g RUBBER) BY RAW RUBBER AND A RUBBER STOCK (RUBBER, 100; S, 12.5) VULCANIZED TO VARIOUS DEGREES (93)

V. C.	0.0	1.2	2.0	3.5	4.4	6.4
Carbon tetrachloride	0.99	0.975	0.99	0.98	0.99	1.05
Benzene	0.98	0.895	0.87	0.86	0.86	0.85
Carbon disulfide		0.64	0.65	0.63	0.64	0.67

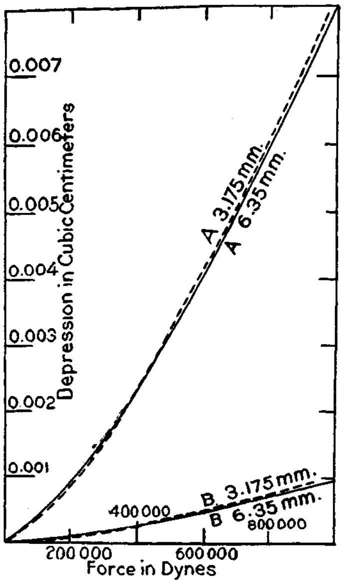

FIG. 35.—Force-volume depression curves for 2 samples of vulcanized rubber (steel balls 3.175 and 6.35 mm in diameter) (79).

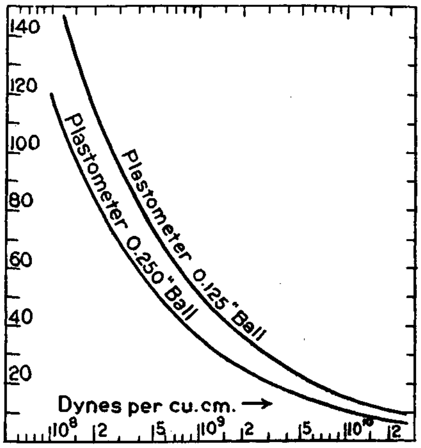

FIG. 36.—Relation between plastometer number and modulus of hardness (79).

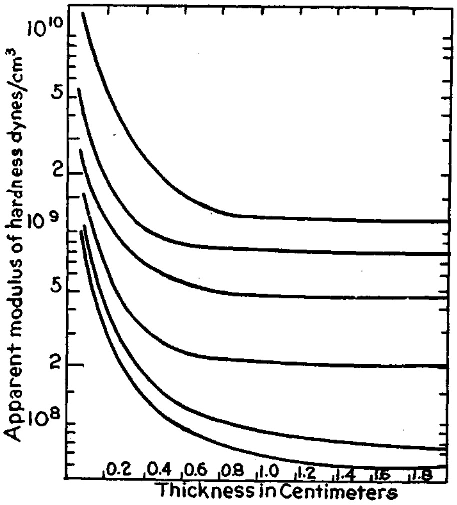

FIG. 38.—Influence of thickness of thin specimens on apparent hardness as determined by the plastometer (6 samples) (79).

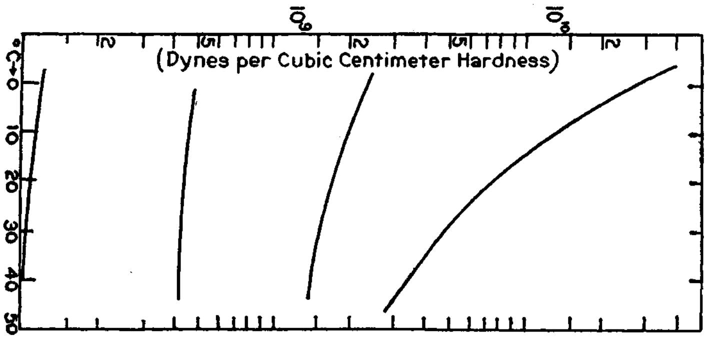

FIG. 37.—Change of modulus of hardness with temperature (4 samples) (79).

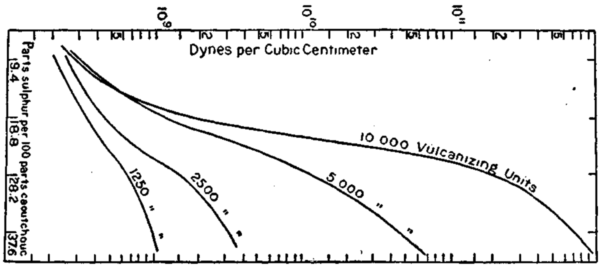

FIG. 39.—Modulus of hardness and degree of vulcanization (vulcanizing unit = (time of vulcanization at t°) × 1.1^{150-t} (79).

ABSORPTION OF WATER

TABLE 85.—ABSORPTION BY RAW RUBBER OF WATER FROM MOIST AIR (130), *cf.* (210)

Relative humidity, %		100	89	79	49	100	89	79	49
Type	Resin %	% absorption at 16°				% absorption at 30°			
Hevea sheet...	3.32	1.85	0.88	0.31	0.23	2.88	0.76	0.44	0.24
Hevea crepe...	3.43	2.80	0.89	0.39		4.54	1.06	0.37	
Castilloa......	5.2	0.62	0.28			1.57	0.23	0.16	
Congo.........	16.7	6.02	2.12	0.9		15.8	2.58	1.26	0.42

Vulcanized rubber shows the same absorption from water vapor as from liquid water (22).

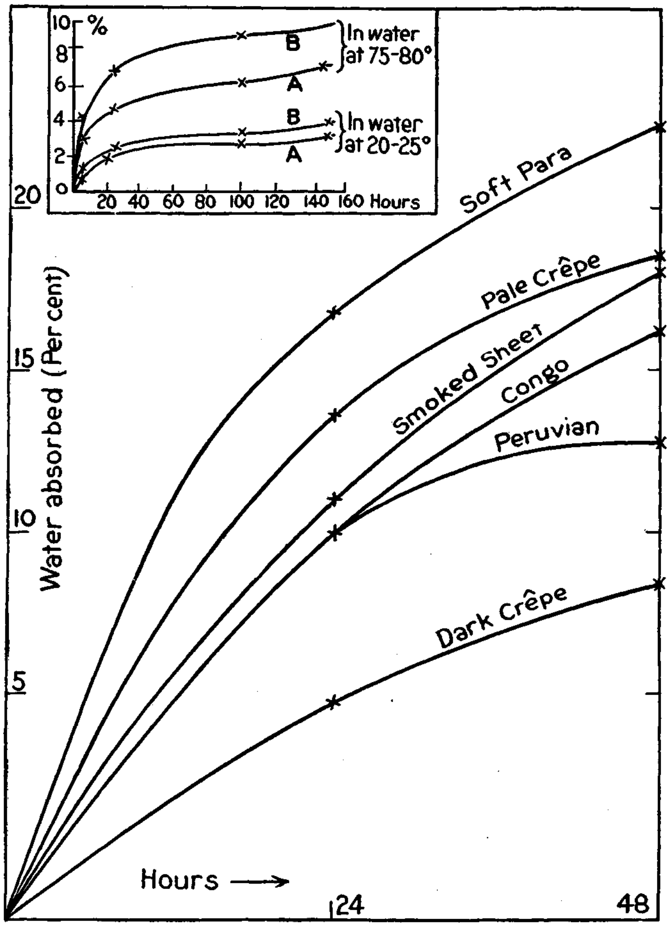

FIG. 40.—Various types of raw rubber in distilled water at 80–90° (94).

FIG. 41 (Insert).—Water absorption by cut sheet. Effect of temperature on (A) raw rubber, (B) cold vulcanized (94).

TABLE 86.—WATER ABSORPTION BY VARIOUS TYPES OF RUBBER

g/cm² surface of sheets 0.35 mm thick (22)

Type	t, °C	Immersion, hr	Absorption
Pale crepe	24	200	0.0356
	70	50	0.072
Smoked sheet	70	50	0.103
Fine Para	70	50	0.087
Latex sprayed	70	50	0.33
Vulcanized rubber*	24	50	0.0070–0.0097
	70	50	0.035–0.045
Hard rubber†	70	100	0.0137
Hard rubber‡	70	100	0.0110
Gutta-Percha	24	200	0.0122

* Stock: rubber, 24; ZnO, 18; whiting, 12; litharge, 3; S, 1.5; cured 60 min at 135°. Crepe, smoked sheet and fine Para used.

† Stock: rubber, 30; S, 17.5; *p*-nitrosodimethylaniline, 0.3; cured 120 min at 148°.

‡ Stock: rubber, 60; S, 35; cured 240 min at 148°.

TABLE 87.—ABSORPTION BY SAMPLES IMMERSED 18 WEEKS AT 15–25° (117)

Type	Medium	% absorption
Para rubber	Distilled water	31.77
Para rubber	Sea water	2.80
Gutta-Percha*	Distilled water	1.13–1.44†

* 4 samples; resin content: 20.3–46.3 %.

† Calculated on the gutta.

TABLE 88.—INFLUENCE OF DEGREE OF VULCANIZATION ON WATER ABSORPTION (94), *cf.* (22)

Stock: crepe, 100; S, 7; MgO, 5

Time of cure at 143°, min	15	30	60	120
Combined S, %	0.62	1.17	2.37	4.12
	% water absorbed			
Immersed 6 hr at 70–80°	4.45	3.6	2.8	2.3
Immersed 24 hr at 70–80°	5.32	4.74	3.9	2.9
After 48 hr more at 20°	13.2	10.5	7.8	5.9

Temperature coefficient for absorption of water by vulcanized rubber: 1.32–1.44 fold for each 10° rise in temperature (22).

Influence of pressure: water absorption is unaffected by increase of pressure from 1 to 5 atmospheres (22).

Imbibition of Liquids

TABLE 89.—IMBIBITION BY RAW RUBBER

cm³ liquid by 1 cm³ fine Para in 10 days at room temperature (151)

Carbon tetrachloride	12.05	Benzene	9.05
Chloroform	11.30	Xylene	8.89
Carbon disulfide	10.07	Ethyl ether	4.82
Toluene	9.52	Methyl alcohol	0.13

g liquid by 1 g fine Para under pressure of 1.12 kg/cm² (124)

Carbon tetrachloride	11.06	Benzene	4.41
Chloroform	9.31	Cymene	4.38
sym.-Dichloroethylene	7.35	Cumene	4.13
Thiophene	5.32	Ethylene chloride	2.71
Toluene	4.65	Ether	2.40

TABLE 90.—IMBIBITION BY VULCANIZED RUBBER

cm³ liquid by 1 cm³ rubber (sp. gr., 0.997; ash, 2; total S, 12.54; combined S, 1.28 %) in 24 hr at 17° (65)

Chloroform	9.64	Nitrobenzene	1.36
Carbon disulfide	8.11	Ethyl acetate	0.33
Toluene	7.40	Acetone	0.15
Xylene	6.35	Acetic acid	0.12
Benzene	5.86	Amyl acetate	0.085
Turpentine	5.52	Ethyl alcohol	0.025
Benzyl chloride	4.39	Methyl alcohol	0.02
Petroleum ether	4.38	Ethyl alcohol (96 %)	0.011
Kerosene	3.67	Water	0.005
Ethyl ether	3.43		

cm³ liquid by 1 cm³ "black rubber tubing," sp. gr., 1.06 (160)

Chloroform	7.37	Ethyl ether	3.09
Carbon disulfide	6.52	Ethyl acetate	0.71
Benzene	5.87	Acetone	0.21

g liquid by 1 g rubber, (stock: rubber, 90; S, 10; vulcanized 75 min at 148°) in 48 hr (214)

Benzene	3.63	Aniline	0.13
Toluene	3.84	Methylaniline	1.49
m-Xylene	3.01	Dimethylaniline	3.02
d-Pinene	2.57	*o*-Toluidine	0.69
Tetrahydronaphthalene	5.22	Diethylamine	6.24
n-Pentane	0.72	Piperidine	17.75
Carbon tetrachloride	8.50	Acetic acid	0.16
Chloroform	6.51	*n*-Butyric acid	1.57
Trichloroethylene	8.10	Dichloroacetic acid	14.20
Tetrachloroethane	8.19	Acetyl chloride	5.96
Tetrachloroethylene	6.47	Ethyl acetate	0.49
Pentachloroethane	8.02	Propyl acetate	1.27
Bromobenzene	6.17	*n*-Butyl acetate	1.43
Benzyl chloride	3.01	Isoamyl acetate	1.73
Phenyl mustard oil	3.21	Ethyl benzoate	2.26
Nitrobenzene	1.46	Cyclohexanol	0.58
Benzonitrile	2.20		

TABLE 91.—FACTORS INFLUENCING IMBIBITION

Degree of vulcanization: cm³ CCl_4 imbibed by 1 g rubber (stock: rubber, 100; S, 12.5; vulcanized to various degrees) (93)

V. C. Hours immersed	1.20	2.0	3.6	4.4	6.4
1	8.09	5.86	5.12	4.04	3.40
6	24.10	14.30	9.82	7.74	5.12
24	29.00	16.10	10.40	7.87	5.40

Temperature: cm³ C_6H_6 imbibed in 10 hr by 1 g rubber (stock: rubber, 100; S, 12.5; vulcanized to various degrees) (93)

V. C. t°C	1.2	2.0	3.6	4.4	6.4
40	8.73	6.30	5.16	4.33	3.30
50	9.00	6.55	5.37	4.60	3.60
80	10.70	7.56	5.85	5.20	4.00

Pressure: g C_6H_6 imbibed by 1 g raw fine Para (124)

kg/cm²	0.72	1.12	2.12	3.12	5.12
Imbibition	5.14	4.41	3.28	2.71	2.09

For similar data for toluene, cumene, cymene, ether, chloroform, carbon tetrachloride, ethylene chloride, *sym.*-tetrachloroethane, *sym.*-dichloroethylene and thiophene, *v.* (124).

TABLE 92.—VELOCITY OF IMBIBITION

Velocity of swelling (under a pressure of 1.12 kg/cm²)

$$k = \frac{1}{z}\log_e\frac{\omega_\infty}{\omega_\infty - \omega}$$

where k = a constant, z = time in minutes, ω_∞ = imbibition at equilibrium, ω = imbibition at time z, t = 17-18° (124).

Liquid	Benzene	Cumene	Chloroform	Thiophene
k	0.0019	0.0021	0.00057	0.00083

Solubility of Solids in Rubber

TABLE 93.—SULFUR (90)

In raw rubber: at 33°, 1.01; at 55°, 1.96 g/100 g raw rubber
In vulcanized rubber:

t, °C	Rubber: S ratio	hr cured at 141°	V. C.	Solubility g S/100 g stock
40	100:10	1	1.46	1.48
		2	2.98	1.45
		3	4.34	1.53
		4	6.54	1.61
		5	7.95	1.69
55	100:10	1	1.46	2.13
		2	2.98	2.24
		3	4.34	2.39
		4	6.54	2.56
55	100:30	3	5.47	2.36
		4	8.72	2.94
		5	13.92	3.00
75	100:30	3	5.47	3.22
		4	8.72	4.25
		5	13.92	5.42
		6	16.91	5.90

SELENIUM (228)

In raw rubber: <0.05 % at 80°C.

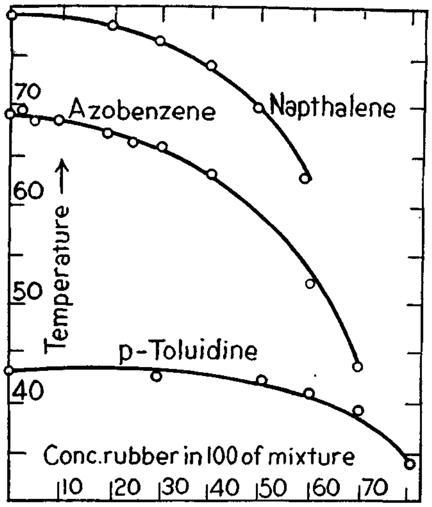

FIG. 42.—Solubility of naphthalene, azobenzene and p-toluidine in raw rubber (27).

Permeability to Gases and Vapors

Permeability is proportional to the partial pressure of the gas and to the thickness of the rubber (44, 59, 89, 229).

SPECIFIC PERMEABILITY

Unit.—cm³ gas/min/cm² area/cm thickness.

Hydrogen.—20.4 × 10^{-6} at 25° (vulcanized rubber on balloon fabric) (59). $(5.520 + 0.876t) \times 10^{-6}$, range 12.8 to 30.7° (sp. gr., 0.9455 at 18 to 20°) (89).

Carbon Dioxide.—$(-5.084 + 2.928t) \times 10^{-6}$, range 9 to 33° (sp. gr., 0.9455 at 18 to 20°) (89).

TABLE 94.—PERMEABILITY RELATIVE TO HYDROGEN AT SAME TEMPERATURE

In (59) samples are vulcanized rubber on balloon fabric. In (44) samples are vulcanized, probably by sulfur chloride

Gas	Relative permeability	t°, C	Lit.
Hydrogen	1		
Oxygen	0.445	25	(59)
	0.337	20	(44)
	0.500	25	(45)
	0.45		(72)
Nitrogen	0.160	25	(59)
	0.12	20	(45)
	0.18		(72)
Argon	0.23	25	(45)
	0.26		(125)
Helium	0.65	25	(59)
Air	0.230	25	(59)
	0.194	17	(44)
Carbon dioxide	2.91	25	(59)
	2.76	17	(44)
	2.8		(45)
	2.48		(89)
	2.47		(72)
Nitrous oxide	4.54	17	(44)
Ammonia	8	25	(59)
	11.4	17	(44)
Water vapor	55	25	(59)
Liquid water	105	25	(59)
Methyl chloride	18.5	25	(59)
Ethyl chloride	198	25	(59)

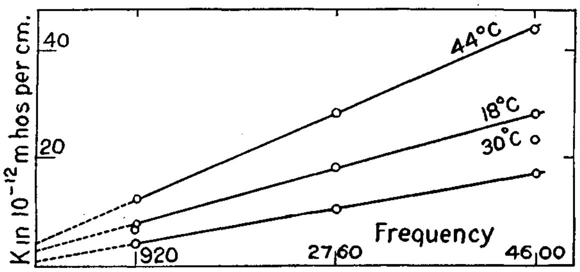

FIG. 43.—Variation of conductivity for raw india rubber with temperature and frequency (62).

Electrical Properties

RAW RUBBER, GUTTA-PERCHA AND BALATA

TABLE 95.—ELECTRICAL PROPERTIES OF RAW RUBBER (42)

Type	Age, mo	Number of samples	Dielectric constant at 1000 ∼	Power factor, %	Resistivity (10^8 megohm-cm)
Fine Para		13	2.43	0.14	35
Pale crepe		6	2.43	0.16	50
Pale crepe*		3	2.36	0.29	40
Smoked sheet	3	6	2.53	0.19	3
Smoked sheet	15	3	2.38	0.16	10
Smoked sheet*	12	3	2.35	0.29	60
Cameta		5	2.56	0.28	10
Guayule		2	2.69	0.51	60

* Thoroughly washed and dried.

TABLE 96.—ELECTRICAL PROPERTIES OF GUTTA-PERCHA AND BALATA (42)

	% composition*						
	Gutta	Resin	Mechanical impurities	H_2O, %	Dielectric constant at 1000 ~	Power factor % at 1000 ~	Resistivity (10^8 megohm-cm)
1. Gutta-Percha refined by acetone extraction.......	99.0		1.0	0	2.56	0.09	370
2. Gutta-Percha (Tjipetir plantation).............	89.2	9.3	1.5	>0	2.60	1.1	65
3. No. 2 after drying.......	89.2	9.3	1.5	0	2.61	0.23	45
4. Gutta-Percha, refined. . .	79.9	19.3	0.8		2.78	0.35	60
5. Gutta-Percha, commercial.............	57.3	39.2	3.5	2.5	4.13	3.1	
6. No. 5 after drying.......	57.3	39.2	3.5	0	3.01	1.8	25
7. Resin from Gutta-Percha	0.0	100.0			3.27		25
8. Balata, commercial sheet	44.8	39.8	15.4		3.48	2.3	

* On dry weight.

TABLE 97.—INFLUENCE OF FREQUENCY ON ELECTRICAL PROPERTIES OF RAW RUBBER AND GUTTA-PERCHA (42)

	Dielectric constant				Power factor		Resistivity (10^8 megohm-cm)
	Alternating current		Direct current 0.6 sec charge, discharge				
	1000 ~	60 ~	0.1 sec	1.0 sec	At 1000 ~, %	At 60 ~, %	
Pale crepe.........	2.38	2.40	2.65	2.70	0.3	0.5	30
Gutta-Percha*.....	2.62	2.63	2.81	2.87	0.2	0.3	50
Gutta-Percha†.....	2.82	2.84	3.01	3.07	0.4	0.5	60

* Tjipetir. † Refined commercial.

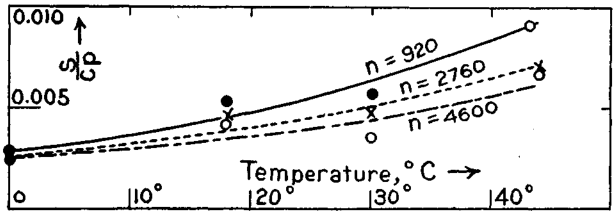

FIG. 44.—Variation of S/cp (power factor) with temperature and frequency for raw india rubber condenser (62).

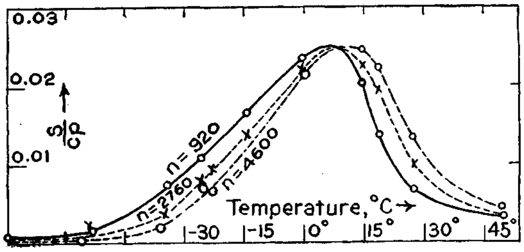

FIG. 45.—Variation of S/cp (power factor) with temperature and frequency for Gutta-Percha from −75 to 50°C (62).

TABLE 98.—INFLUENCE OF TEMPERATURE AND FREQUENCY ON ELECTRICAL PROPERTIES (62)

	Raw rubber			Gutta-Percha		
Frequency................	920	2 760	4 600	920	2 760	4 600
Temperature, °C..........	18	18	18	15	15	15
Dielectric constant for alternating current..........	2.60	2.60	2.60	2.86	2.86	2.86
Temperature coefficient per °C	−0.062	−0.062	−0.062	0.105	0.124	0.133
Temperature coefficient range	0 to 43°	0 to 44°	0 to 44°	−14 to 50°	−14 to 50°	−14 to 50°
Resistivity, alternating current, megohm-cm.......	145 000	54 500	35 400	33 700	10 200	5 600
Power factor, %..........	0.005	0.005	0.004	0.020	0.023	0.025
Specific conductance for frequency n, micromicrohm-cm............	$1.53 + 0.0058n$			$-16.9 + 0.04n$ (at 19°)		

TABLE 99.—INFLUENCE OF FREQUENCY AND TEMPERATURE ON CONDUCTANCE OF GUTTA-PERCHA (62)

Frequency		Conductance (κ) in bi-mhos (10^{12} mhos) per cm^3									
920	t, °C	−75	−53	−34	−26	−14	0	15	19	27	50
	κ	1	2	10	15	22	33	30	20	10	4
2760	t, °C	−75	−54	−35	−25	−14	0	15	19	27	50
	κ	3	9	14	35	53	91	97	87	46	14
4600	t, °C		−56	−36	−25	−14	0	15	19	27	50
	κ		3	13	49	80	146	177	163	97	32

SOFT VULCANIZED RUBBER

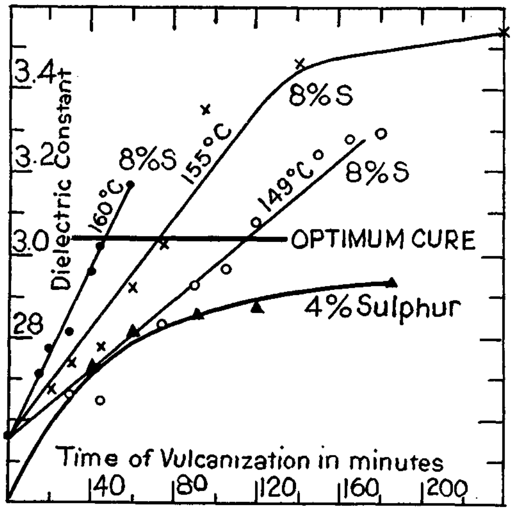

FIG. 46.—Dielectric constant at 1000 cycles; pure gum mixture (smoked sheet, 96; S, 4 and smoked sheet, 92; S, 8) vulcanized for various periods of time at various temperatures (42).

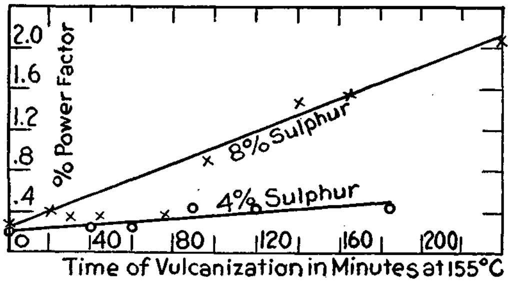

FIG. 47.—Power factor for samples described in Fig. 46 (42).

Resistivity: ranges from 10 × 10^8 to 150 × 10^8 megohm-cm irregularly (42)

TABLE 100 (42)

Composition				t, °C	Cure, min†	Dielectric constant at 1000 ~	Power factor, %	Resistivity (10^8 megohm-cm)
Rubber	Accel.*	ZnO	S					
Without free sulfur								
98	1	1	0	155	45	2.42	0.87	185
					90	2.40	0.81	195
92	3	5	0	126	15	2.49	0.42	20
					40	2.48	0.41	24
88	5	10	0	155	4	2.60	0.90	200
					12	2.59	0.80	220
85	5	10	0	126	20	2.66	0.47	20
					40	2.62	0.45	20
80	10	10	0	126	20	2.84	0.50	5

TABLE 100 (42).—(*Continued*)

Composition				t, °C	Cure, min*†	Dielectric constant at 1000 ~	Power factor, %	Resistivity (10^8 megohm-cm)
Rubber	Accel.*	ZnO	S					
With free sulfur								
91.75	3	5	0.25	126	20	2.48	0.40	27
					35	2.45	0.26	45
92.5	2	5	0.5	126	10	2.51	0.23	150
					40	2.48	0.35	80
92.75	0.75	5	1.5	126	10	2.49	0.35	150
					25	2.49	0.34	210
90.75	0.25	5	4	126	15	2.60	0.23	90
					30	2.78	0.41	10

* Tetramethylthiuram disulfide.

† Extremes of range.

TABLE 101.—INFLUENCE OF FREQUENCY (42)

Composition	Dielectric constant				Power factor		Resistivity (10^8 megohm-cm)
	Alternating current		Direct current 0.6 sec charge, discharge		At 1000 ~, %	At 60 ~, %	
	1000 ~	60 ~	0.1 sec	1.0 sec			
1. Rubber, 96; S, 4	2.89	2.90	3.25	3.32	0.35	1.2	20
2. Rubber, 90.75; S, 4; ZnO, 5; tetramethylthiuram disulfide, 0.25	2.67	2.67	2.86	2.94	0.20	0.2	80
3. (2) + ZnO, 75	9.76	10.3	11.9	13.1	1.9	4.8	0.5
4. (2) + carbon black, 20	6.12	8.61	10.3	12.4	7.5	10.5	0.4

TABLE 102.—INFLUENCE OF TEMPERATURE AND FREQUENCY (62)

Frequency	920	2 760	4 600
Temperature, °C	17	17	17
Dielectric constant for alternating current	2.73	2.71	2.71
Temperature coefficient range (−14 to 83°)	−0.150	−0.130	−0.140
Resistivity, alternating current, megohm-cm	342 300	103 000	38 100
Power factor, %	0.2	0.2	0.4
Specific conductance for frequency n, micro-microhm-cm	$2.0 + 1180 \times 10^{-12}n^2$.		

TABLE 103.—INFLUENCE OF TEMPERATURE AND FREQUENCY ON THE CONDUCTANCE OF SOFT VULCANIZED RUBBER (62)

Frequency	Conductance (κ) in bi-mhos (10^{12} mhos) per cm³											
920	t, °C	−76	−63	−42	−32	−23	−14	0	17	41	60	83
	κ	2	4	32	50	26	19	7	3	8	12	16
2760	t, °C	−76	−63	−42	−33	−23	−14	0	17	42	61	83
	κ	4	8	53	141	102	76	31	10	18	29	41
4600	t, °C	−76	−63	−42	−32	−24	−14	0	17	44	60	84
	κ	3	9	62	220	205	158	57	26	26	43	57

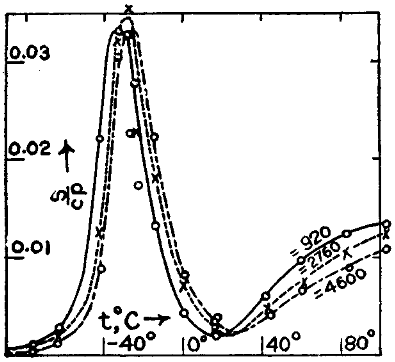

FIG. 48.—Variation of S/cp (power factor) with temperature and frequency for soft vulcanized rubber from − 90 to 100°C (62).

INFLUENCE OF COMPOUNDING INGREDIENTS

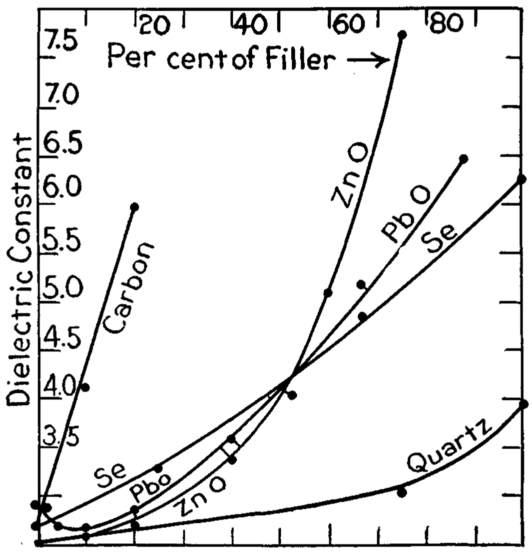

FIG. 49.—Influence of carbon black, ZnO, litharge, Se and quartz on dielectric strength (42).

In the case of ZnO, quartz, and Se, "% of filler" means the parts of filler by weight added to the following basal mixtures:

	Rubber	S	ZnO	Palm oil	Tetramethylthiuram disulfide
Zinc oxide	93.75	2		4	0.25
Quartz	92.75	2	1	4	0.25
Selenium	90.75	4	5		0.25

In the case of litharge " % filler" means the percentage present in the following series of mixtures:

Litharge	0	4	10	20	40	66	88
Rubber	96	88	82	74	52	22	9
Sulfur	4	4	4	6	8	11	1
Ozokerite		4	4				
Palm oil						1	2

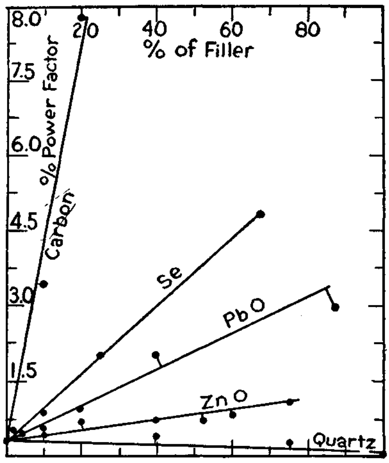

FIG. 50.—Influence of filler on the power factor at optimum cure (42); *cf.* note to Fig. 49.

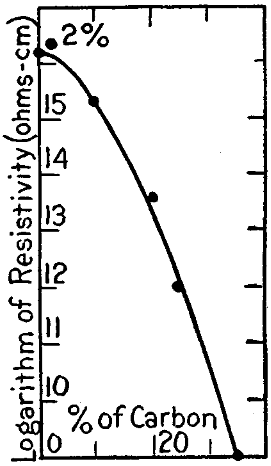

FIG. 51.—Influence of carbon black on the resistivity (42).

TABLE 104.—INFLUENCE OF BARYTES, "TITANOX," IRON OXIDE, TELLURIUM, CHINA CLAY AND ASBESTINE (42)

Stock No. 1: smoked sheet, 90.75; S, 5; ZnO, 4; tetramethylthiuram disulfide, 0.25%. Stock No. 2: smoked sheet, 90.75; S, 5; ZnO, 4; diphenylguanidine, 1%

Rubber mixture, %	Dielectric constant, 1000 ~	Power factor, %	Resistivity (10^8 megohm-cm)
No. 1	2.70	0.32	90
No. 1 + barytes, 45	3.37	1.1	20
No. 1 + titanox,* 50	3.77	1.1	13
No. 1 + iron oxide, 46	3.61	1.39	30
No. 1 + tellurium, 25	3.20	0.50	85
No. 2	2.62	0.75	190
No. 2 + china clay, 49	3.27	1.13	170
Rubber, 41; S, 2; ozokerite, 5.4; tetramethylthiuram disulfide, 0.1; asbestine, 50	4.24	2.1	14

* Approximate composition: titanium dioxide, 25; barium sulfate, 75%.

INFLUENCE OF SOFTENERS

In a stock cured by the aid of tetramethylthiuram disulfide, the following softeners have little effect on the dielectric constant: ozokerite, 10; vaseline, 10; beeswax, 10; stearic acid, 10; palm oil, 5 parts.

The following increased the dielectric constant from 2.67 to the figures noted: *p*-coumarone resin, 10, to 2.80; mineral rubber, 33, to 2.88 (42).

HARD RUBBER

TABLE 105.—ELECTRIC STRENGTH (63, 63.5)

	Thickness, mm	Electric strength, kilovolt-mm	*t*, °C
1. Rubber with 35% S*	0.5	150	10–20
2. Medium quality	0.5	36	10–20
3. Medium quality	1.0	25	10–20
		18	60
	2.0	18	10–20
		11	60
4. Medium quality	1.0	45	10–20
		32	100
5. Switch handle quality	0.5	26	10–20

* Sp. gr., 1.201.

TABLE 106.—ELECTRICAL PROPERTIES OF VARIOUS GRADES OF HARD RUBBER (3)

	Admiralty sheet (U. S.)	G. P. O. sheet* (U. S.)	Sheet†	Rods and tubes‡	Radio panels and parts*
Specific gravity	1.22	1.20	1.19	1.18	1.46
Tensile strength, kg/cm²	635	530	440	480	395
Compressive strength, (kg/cm²) ‖ to laminations, 0.5 in. cube	338	282	245	265	220
Compressive strength (kg/cm²) ⊥ to laminations	359	300	249		237
Elongation, %	6.8	4.5	4.5	5.1	3.3
Electric strength (v/mm) alternating current	367	351	325	370	322
Resistivity (megohm-cm) × 10^6	26.6	30.2	32.9	628	100
Dielectric constant at radio frequencies					4.3
Water absorption (%) (24 hr at 50°)	0.03	0.04	0.05	0.04	0.08

* Mean of 3 samples.

† Mean of 4 samples.

‡ Mean of 5 samples.

TABLE 107 (42)

	Dielectric constant, 1000 ~	Power factor, %	Resistivity, megohm-cm
Rubber, 71.4; S, 28.6	3.50	0.4	110 × 10^8

TABLE 108.—INFLUENCE OF TEMPERATURE AND FREQUENCY (62)

Frequency	920	2 760	4 600
Dielectric constant for alternating current	3.17	3.15	3.14
Temperature coefficient range (0 to 84°)	0.360	0.310	0.290
Resistivity, alternating current, megohm-cm	148 500	38 500	23 100
Power factor, %	0.5	0.5	0.5
Specific conductance for frequency *n*, micro-microhm-cm	0 + 0.01*n*		

TABLE 109.—INFLUENCE OF HEAT AND IMMERSION ON THE ELECTRICAL PROPERTIES OF A MEDIUM GRADE OF HARD RUBBER (63.5)

	Electric strength, kv/mm at 10–20°			Volume resistivity, megohm-cm			Surface resistivity, megohm		
	Immersed	Sample No. 6	Sample No. 8	Immersed	Sample No. 6	Sample No. 8	Immersed	Sample No. 6	Sample No. 8
Normal		45	29		5 × 10^8	4 × 10^8		16 × 10^6	44 × 10^3
Water	24 hr	32	29	1 wk	5 × 10^8	5 × 10^8	1 wk	1.8 × 10^6	0.8 × 10^6
Brine	24 hr	37	35	1 wk	5 × 10^8	5 × 10^8	1 wk	1.7 × 10^6	27 × 10^3
H_2SO_4*				1 wk	5 × 10^8	5 × 10^6	1 wk	15 × 10^6	1.2 × 10^6
Oil	24 hr		30	1 wk	3.5 × 10^8 at 100°	5 × 10^8 at 50°	1 wk	26 × 10^6 at 100°	5 × 10^6 at 50°
Air				6 hr	1 × 10^8 at 100°	5 × 10^8 at 50°	6 hr	4 × 10^8 at 100°	4 × 10^8 at 50°

* Specific gravity, 1.21.

TABLE 110.—INFLUENCE OF COMPOUNDING INGREDIENTS (120)

Stock: fine Para, 65; S, 35

Ingredient added	Sp. gr. of mixture	Electric strength, kv/mm
None	1.201	150
Talc	1.298	128
Soft palm pitch	1.185	118
Waste, soft grade	1.192	115
Hard palm pitch	1.224	108
Waste, hard grade	1.199	92
Caramba wax	1.171	78
Factice (vulcanized oil)	1.187	72
Zinc oxide	1.335	69

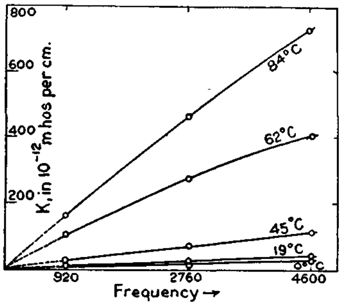

FIG. 52.—Variation of conductivity of ebonite with temperature and frequency (62).

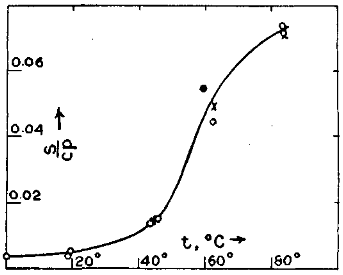

FIG. 53.—Variation of S/cp (power factor) for an ebonite condenser with temperature and frequency. Black dots denote 920, crosses 2760, and small circles 24 600 p. p. s. (62).

MILLING

TABLE 111.—INFLUENCE OF TIME OF MILLING ON PLASTICITY (78)

79 kg rubber (half sheet, half crepe) milled on a 214 cm fast mill. Extrusion time is the time in min required to extrude a length of 2 cm through the orifice of a Griffiths' plastometer at 85°.

Time, min	12.5	18	25	32.5	45	60
Extrusion time	2.77	2.05	1.72	1.47	1.23	0.97

TABLE 112.—INFLUENCE OF TIME AND TEMPERATURE OF MILLING ON PLASTICITY (172)

k = plasticity determined by a Williams' plastometer

Milling conditions		k	Milling conditions		k
Time, min	Temp., °C		Time, min	Temp., °C	
13	100	4.7	30	40	2.0
25	100	3.7	60	40	1.6
55	100	3.0	120	40	1.3

TABLE 113.—INFLUENCE OF TIME OF MILLING ON VISCOSITY OF RUBBER SOLUTIONS (25, 130)

Time of milling, min		0	10	15
Viscosity number	Fine hard Para	72.1	24.8	15.2
	Latex crepe	49.6	20.4	16.4

Time of milling, min	2.5	5	10	15	20	30	40	50	60
Relative viscosity of 2% soln	1900	540	150	110	90	70	65	60	59

TABLE 114.—TIME IN MIN REQUIRED TO PRODUCE A GIVEN DEGREE OF PLASTICITY

Influence of (*a*) distance between the rolls ("nip") and (*b*) the size of the batch of rubber on the time required to reduce rubber to a given degree of plasticity and the temperature acquired during milling in the case of a 214 cm mill, with a friction ratio of 1:1.5 and a surface speed of the front roll of 25.4 m per min (78).

	45.4 kg batch				79 kg batch			
Extrusion time, min	2.2	1.45	1.3	1.2	2.2	1.45	1.3	1.2
Nip, mm								
4.3	11	28.5	33	36.5	19	46.5	53	57.5
3.57	13	25	28	31	21.5	42.5	50	53.5
2.78	9	17.5	20.5	22.5	15.5	34.5	39.5	43
1.98	*ca.* 9	15.5	18	20	16	32.5	39	44.5
1.19	*ca.* 13	16.5	18.5	20	17	34	39	42
0.40		13.5	15.5	17	16.5	29		

	113 kg batch				147 kg batch			
Extrusion time, min	2.2	1.45	1.3	1.2	2.2	1.45	1.3	1.2
Nip, mm								
4.3	36				49			
3.57	31	60			41			
2.78	23	51	58	63	35.5	63		
1.98	30	51	57.5	62	35	59		
1.19	29	46.5	51	54	35.5	53	57.5	60

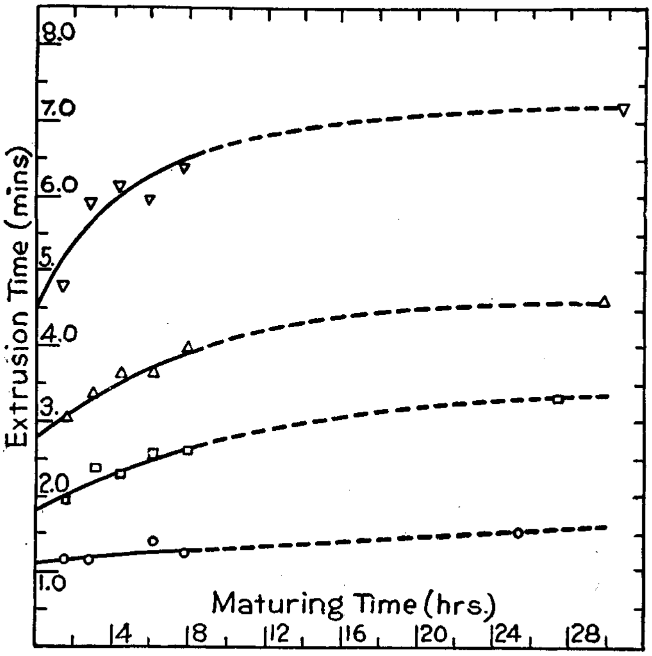

FIG. 54.

Recovery from Milling

Figure 54 shows the recovery from milling (expressed as maturing time/plasticity) of the same batch of typical pale crepe rubber milled to different degrees of plasticity and then allowed to remain at room temp. in the form of rolls 25 cm long × 7.5 cm diam. (78); the plasticity is expressed as the extrusion time in a Griffiths' plastometer (*cf.* Table 111).

Figure 55 shows the recovery of rubber (2 samples) from milling as shown by the viscosity of solutions (2 g in 97 cm³ CS_2) after storage for various periods (123).

(150) Spence and Kratz, *55*, **14**: 262; 14. (151) Spence and Kratz, *55*, **15**: 217; 14. (152) Spence and Young, *55*, **11**: 28; 12. (153) Spence and Young, *55*, **13**: 265; 14. (154) Spoon, *443*, **8**: 869; 24. (155) Spoon, *443*, **9**: 574; 25. **10**: 29; 26. (156) Stevens, *54*, **37**: 156T; 18. (157) Stevens, *54*, **40**: 186; 21. (158) Stevens, *Rubber Age* (London), **4**: 215; 23. (159) Thies, *45*, **17**: 1165; 25.

(160) Tompkins, *in Physics and Chemistry of Colloids*, p. 162. London, H. M. Stationery Office, 1921. (161) Twiss, *54*, **36**: 782; 17. (162) Twiss, *54*, **40**: 242T; 21. (163) Twiss, *441*, **65**: 607; 23. (164) Twiss, *58*, **113**: 822; 24. (165) Twiss and Brazier, *54*, **39**: 125T; 20. (166) Twiss, Brazier and Thomas, *54*, **41**: 81T; 22. (167) Twiss and Howson, *54*, **39**: 287T; 20. (168) Twiss and Murphy, *54*, **45**: 121T; 26. (169) Twiss and Thomas, *54*, **42**: 499T; 23.

(170) Twiss and Thomas, *54*, **44**: 100T; 25. (171) Van Lennap, *441*, **65**: 367; 23. (172) Vogt, *45*, **17**: 535; 25. (173) Vogt, *45*, **17**: 870; 25. (174) Vogt and Evans, *45*, **15**: 1015; 23. (175) de Vries, *Meded. van het Centraal Rubberstation*, No. **1**; 1916. (176) de Vries, *443*, **1**: 36; 17. (177) de Vries, *443*, **2**: 45; 18. (178) de Vries, *443*, **2**: 67, 112; 18. (179) de Vries, *443*, **2**: 453; 18.

(180) de Vries, *443*, **2**: 792; 18. (181) de Vries, *443*, **3**: 183; 19. (182) de Vries, *443*, **4**: 163; 20. (183) de Vries, *B79*. (184) de Vries, *B79*, p. 53. (185) de Vries, *B79*, p. 88. (186) de Vries, *B79*, p. 94. (187) de Vries, *B79*, p. 441. (188) de Vries, *64P*, **26**: 677; 23. (189) de Vries, *441*, **65**: 433; 23.

(190) de Vries, *443*, **7**: 168; 23. (191) de Vries, *443*, **7**: 409; 23. (192) de Vries, *54*, **43**: 47T; 24. (193) de Vries, *441*, **67**: 849; 24. (194) de Vries, *443*, **8**: 145, 177; 24. (195) de Vries, *443*, **8**: 587, 601; 24. (196) de Vries, *443*, **9**: 446; 25. (197) de Vries, *443*, **10**: 1; 26. (198) de Vries and Beumée-Nieuwland, *443*, **9**: 694; 25. (199) de Vries and Hellendoorn, *443*, **2**: 769; 18.

(200) de Vries and Hellendoorn, *443*, **4**: 429; 20. (201) de Vries, Riebl and Beumée-Nieuwland, *443*, **9**: 345; 25. (202) de Vries and Spoon, *443*, **4**: 163; 20. (203) de Vries and Spoon, *443*, **7**: 311, 342; 23. (204) de Vries and Spoon, *443*, **8**: 689; 24. (205) de Vries and Spoon, *443*, **9**: 849; 25. (206) Weber, *The Chemistry of India Rubber*, p. 119. London, Griffin, 1903. Philadelphia, Lippincott, 1903. (207) Whitby, *55*, **12**: 147; 13. (208) Whitby, *55*, **12**: 154; 13. (209) Whitby, *54*, **35**: 493; 16.

(210) Whitby, *54*, **37**: 278T; 18. (211) Whitby, *442*, **33**: 313; 19. (212) Whitby, *45*, **15**: 1005; 23. (213) Whitby, *450*, **1**: 12; 25. (214) Whitby, McGill University, Montreal, *O*. (215) Whitby, Dolid and Yorston, *4*, **1926**: 1448. (216) Whitby, Evans and Pasternack, McGill University, Montreal, *O*. (217) Whitby and Greenberg, *45*, **18**: 1168; 26. (218) Whitby and Jane, *Second Colloid Symposium Monograph*, p. 16. New York, Chem. Catalog Co., 1925. (219) Whitby and Jane, *69*, **20 III**: 121; 26.

(220) Whitby and Simmons, *45*, **17**: 931; 25. (221) Whitby and Walker, *45*, **13**: 816; 21. (222) Whitby and Winn, *54*, **42**: 336T; 23. (223) Wiegand) *324*, **4**: 160; 20. (224) Wiegand and Braendle, *45*, **15**: 259; 23. (225) Wightman and Trivelli, *45*, **17**: 164; 25. (226) Williams, *447*, **65**: 101; 21, (227) Williams, *45*, **15**: 154; 23. (228) Williams, *45*, **15**: 1019; 23. (229) Wroblewski, *8*, **8**: 29; 79.

(230) Zeitlin, *450*, **1**: 255; 25. (231) Zimmerman, *Rubber Age* (N. Y.), **12**: 130; 22.

FACTITIOUS PLASTICS

A. NITROCELLULOSE ("PYROXYLIN") PLASTICS[1]

Made by the application of heat and pressure to colloidal mixtures of pyroxylin with relatively non-volatile solvent (camphor or substitute for camphor) and volatile solvent (usually ethyl alcohol), followed by evaporation of the volatile solvent; ordinarily containing sufficient non-volatile solvent to insure "plasticity" at 75–90°C—*e.g.*, celluloid, fiberloid, pyralin, pyradiolin, viscoloid, xylonite.

Except as otherwise noted, the data given are for the freshly manufactured, commercial type of camphor product. Photographic film is not covered.

1. *Composition.*—Varies according to manufacturer. The following are illustrations:

PYRALIN (7)

Pyroxylin 11% N	Camphor	Stabilizer	Residual volatile solvent	Additions: dyes, pigments, etc.
68–75%	23–27%	0.5–1%	1–5%	0–14%

VARIOUS FOREIGN AND DOMESTIC SAMPLES (21)

Nitrocellulose	Camphor + solvent	Ash
58–78%	17–31%	0.7–28%

Mechanical

2. *Density.*—g cm^{-3}. 1.35 (transparent) to 1.60 (commercial pigmented material)(7). $d = 1.37 + 0.0125p$, where $p = \%$ ZnO between 1 and 15 (14). For influence of stretching *v.* (16).

3. *Permeability.*—Transparent material of thickness 0.030 in., exposed on one surface to atmosphere dried by $CaCl_2$ and on other side to summer atmosphere, transmitted moisture at rate of 0.013 g per in.^{2} per week (7).

Pyralin, from saturated air to air dried by $CaCl_2$, 0.0046 resp. 0.063 in. thick, transmitted moisture at the rate of 0.029 resp. 0.004 g in.$^{-2}$ day^{-1} in three days (7).

4. *Modulus of Elasticity* (Def. 10*a*).—Young's modulus = $(2.0 \text{ to } 3.9) \times 10^5$ lb. in.$^{-2}$ (**5, 7, 11, 12, 16, 17**). Exhibits hysteresis (13).

5. *Elastic Limit.*—Yield point = $(3.9 \text{ to } 7.4) \times 10^3$ lb. in.$^{-2}$. Varies with thickness and pigment content (**5, 7, 12, 16**).

6. *Poisson's Ratio.*—0.36 to 0.43 (**5, 11**).

7. *Tensile Strength* (Def. 4).—Varies with thickness, nature of nitrocellulose, camphor content, and pigment content. $(4.9 \text{ to } 8.5) \times 10^3$ lb. in.$^{-2}$ (**7, 11, 12**); 6 kg mm^{-2} (5). Variation with temp. °C; 20°, 7.5; 70°, 4.5; 90°, 1.0; $\times 10^3$ lb. in.$^{-2}$ (7).

8. *Ultimate Elongation at Failure.*—From 10% for 0.005 in. thick up to 40% for 0.2 in. thick; for 0.015 in. thick, from 20 to 30% for 0 pigment, to 15 to 25% for 16% pigment (7), *cf.* (**4, 5**).

9. *Resistance to Bending.*—Schopper's folding endurance tester. Sample $0.5 \times 4.0 \times 0.015$ in., double bends of 100° required to break $(B_D) = 8$ to 22. $B_D = k \times (\text{thickness})^{-1.35}$ (7).

---

[1] Acknowledgment is made to Mr. A. F. Randolph, du Pont Viscoloid Company, for a critical examination of this section.

10. *Hardness.*—Brinell, 10.7 to 11.7 ([20]). $H = \text{const.} - (0.05 \times \%\ \text{ZnO})$, approx. between 1 and 15%. Method of penetration by loaded sphere ([14]).

11. *Coefficient of Friction.*—Static, of polished material on self, glass, paper, or planed wood, 0.25 to 0.35 ([7]).

12. *Viscosity.*—Solutions in camphor-alcohol ([15]).

Thermal

13. *Thermal Expansion.*—$\frac{1}{l}\frac{dl}{dt}$ (20–50°C) = $(12 \text{ to } 16) \times 10^{-5}$ ([19, 20]).

14. *Heat Capacity (Specific Heat).*—0.34 to 0.38 cal g^{-1} °C^{-1} ([20]).

15. *Thermal Conductivity.*—Cal $\text{cm}^{-2}\ \text{sec}^{-1}\ (°\text{C}, \text{cm}^{-1})^{-1}$. 3.1×10^{-4} ([20]). 5.14×10^{-4} ([22, 27]).

16. *Working Range for Molding.*—85 to 120°C ([7]).

17. *Permanent Shrinkage on Heating.*—1.4% after two heatings to 100° in air ([18]); 0.5–1% ([7]). Variable, depends on amount of internal strain.

18. *Flash Point.*—141 to 185°C for 0.3 g of powder heated 3° per min ([15]). 160 to 200°, for material of good quality ([7, 9]). 550 to 640° for edge contact with hot porcelain rod ([21]).

19. *Loss in Weight at 110°.*—Very variable ([7, 9]), *cf.* ([21]).

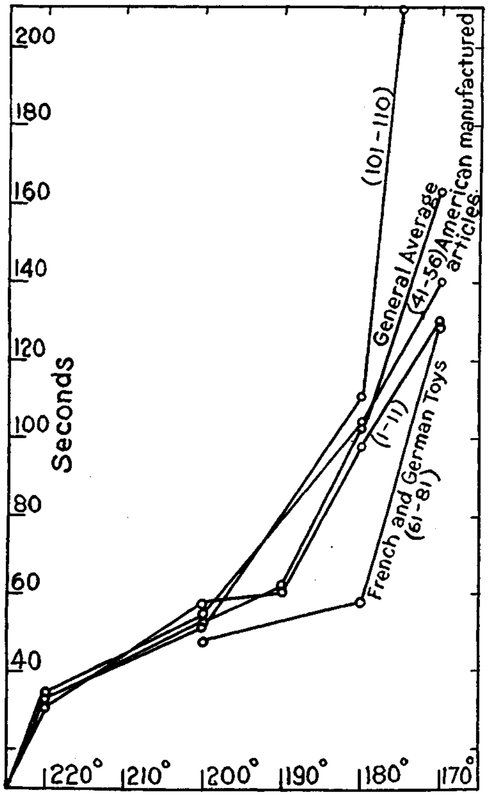

FIG. 1.—Average explosion times.

20. *Explosion Times.*—([21]). For improved method of test, *v.* ([24]).

Time in seconds	Temperature of metal, °C	Transparent pyralin		Pyradiolin	
		A	B	A	B
(A) to the start, (B) to the finish, of fuming-off or burning of 0.5 × 0.5 × 0.06 in. samples thrown on surface of molten metal ([7]).	215	63	65	300	330
	225	59	61	58	85
	235	39	42	50	65
	250	22	24	36	47
	275	10	15	12	30
	300	4	13	15	27
	350	3.5	9	8	20

21. *Rate of Combustion.*—For thin strips, 5 to 10 times that of thin paper or wood shavings of same dimensions ([21]). For composition of gases produced *see* ([21, 25]). Pyradiolin, vertically upward about ⅓ that of pyralin; horizontally or vertically downward, 0 if flame is removed after ignition ([7]).

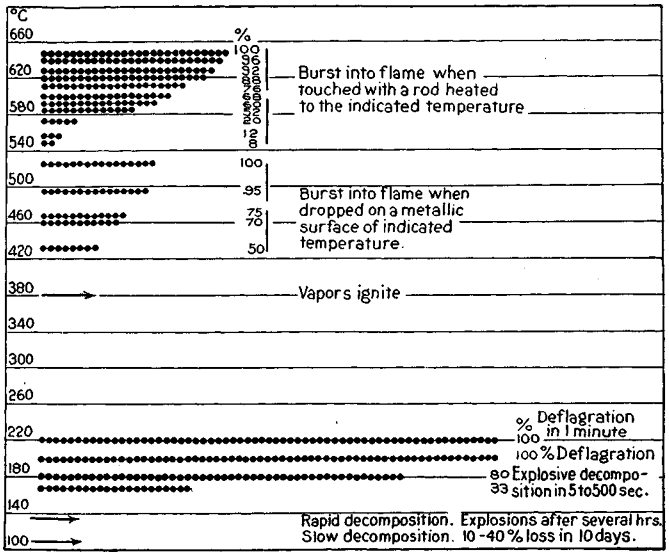

FIG. 2.—Behavior of celluloid at various temperatures.

Electrical

22. *Electrical Resistivity.*—Volume resistivity, $R_v = (2 \text{ to } 30) \times 10^{10}$ ohm-cm. Surface resistivity, R_s, at 50% humidity, *ca.* $3R_v$; at 85% humidity, *ca.* $0.2R_v$ ([3]).

([7])	R_v in 10^{10} ohm-cm			R_s in 10^{10} ohm 400 v	
Material	At 500 v 20°C	50 % humidity	Water-soaked	50 % humidity	Water-soaked
Transparent pyralin	98	7.2	6.6	$>10^4$	36
Pyradiolin	2350	2200	840	$>10^4$	600
Source	E. T. L.	Cruft Lab., Harvard			

23. *Phase Difference (Power Factor).*—In circular degrees, 3.0 to 4.6° at 6×10^5, 2.5 to 5.3° at 10^5 cycles sec^{-1} ([3]).

([7])	P. F.	Phase angle, circular degree							
Kilocycles sec^{-1} =	(2 kv.) 0.06	1	5	20	100	500	2000	1	
Transparent pyralin	2.5%	0.0301	0.026	0.0273	0.0305	0.0350	0.043	0.034*	0.034†
Pyradiolin	4.0%	0.0365	0.041	0.0402	0.0340	0.0289	0.025	0.036*	0.038†
Source	E. T. L.	Cruft Lab., Harvard							

* = at 50% humidity. † = water-soaked.

24. *Dielectric Constant.*—6.9–8.8 at 6×10^5 cycles sec^{-1}; 7.2–9.8 at 10^5 cycles sec^{-1} (3); 12 at 40 cycles (1).

(7)	(2 kv.)	* = at 50% humidity. † = water-soaked							
Kilocycles-sec^{-1} =	0.06	1	5	20	100	500	2000	1	
Transparent pyralin	6.3	7.00	6.78	6.59	6.38	6.19	5.98	7.2*	7.2†
Pyradiolin	5.6	5.65	5.42	5.23	4.97	4.79	4.58	5.7*	5.8†
Source	E. T. L.	Cruft Lab. Harvard							

25. *Dielectric Strength.*—Averages of 10 determinations using blunt needle-point electrodes under oil. Source: E. T. L. (7).

Material	Thickness, mils	Volts per mil
Pyralin:		
Black	60	780
Black	215	230
Transparent	23.4	900
Transparent	63.6	475
Transparent	91	270
White	211	210
Green transparent	200	225
Yellow transparent	64	635
Pyradiolin	59	780
Pyradiolin	60	750

Optical

26. *Refractive Index.*—$n_D = 1.46 \pm 0.03$ (7).

27. *Birefringence.*—Celluloid under tension exhibits birefringence. The *specific birefringence*, $\frac{N_E - N_O}{\%E}$, for Na light (where E is the elongation and N_E, resp. N_O, the refractive indices for the extraordinary and ordinary ray resp.), is 0.046 for 0% camphor and decreases to 0.005 for 50% camphor. For constant tension it increases with time. Data *in re* the after effects of tension on birefringence, density, and dispersion are also given in (5, 10, 11, 16).

28. *Coefficient of Absorption.*—$I = I_0 l^{-kt} = 1.81$ and 1.95, two samples (Na light) (11). Cellulose acetate transmits the ultraviolet down to 230$\mu\mu$ (13).

Chemical

29. *Chemical and Solvent Action of Various Reagents.*—A, Little or no effect at room temperature. B, Superficial attack, blistering or softening. C, Gelatinization. D, Solution with decomposition. E, Good solvent. F, Not solvent, but becomes good solvent on addition of small amounts of camphor. G, Not solvent, but becomes good solvent on addition of large amounts of camphor. H, Can be used as diluent for E. I, Causes precipitation if used as diluent. Not solvent and does not become solvent on addition of camphor (4, 7, 23, 26).

H_2SO_4. <40%, A; 45%, B; 60%, D.

HNO_3. 14%, A; 25%, B; conc. D.

HCl. 13%, A; 25%, B after several days; 35%, B and D.

Acetic acid (CH_3COOH). Dilute, B; glacial, E.

Alkaline solutions. Weak at room temp., B; with increasing strength or temp., D.

Ketones, diacetone alcohol, wood spirit, methyl, ethyl, propyl, butyl or amyl acetate, nitrobenzene, E.

The lower aliphatic alcohols, C, F.

The ethers and the lower aromatic hydrocarbons, G, H.

$CHCl_3$, $C_2H_2Cl_4$, CCl_4, gasolene, turpentine, water, I.

Oils and fats, A, except for castor oil which has slight solvent action.

$SeOCl_2$, E.

Pyridine, D.

30. *Absorption of Water.*—(7).

TESTS ON STANDARD TRANSPARENT MATERIAL

	Symbol	Thickness 0.015 in.	Thickness 0.860 in.
Net gain in weight of seasoned material, resulting from immersion in water,* %	A	1.3 to 2.1	1.6 to 2.3
Hours required to reach approximately maximum wt. and length		24	100 to 200
Net increase in length of seasoned material, resulting from immersion in water,* %	M	0.4 to 0.7	0.5 to 0.7
Loss of weight due to extraction of camphor in 2 months,† %	B	0.6 to 1.0	0.5 to 2.1
Total water absorbed by seasoned material,† %	A+B	2.3 to 2.6	2.8 to 3.2
Loss in weight of seasoned material in atmosphere dried by $CaCl_2$, ultimate, %	C	1.1 to 1.2	1.4 to 1.6
Hours required to reach approximately minimum wt. and length		100 to 200	700 to 1000
Decrease in length over $CaCl_2$, %	N	0.5	0.5 to 0.7
Maximum capacity for moisture, %	A+B+C	3.4 to 3.8	4 to 4.1
Change in length between extremes, %	M+N	1 to 1.2	1.2

* *I.e.*, net effect of absorption of water; extraction of camphor; replacement of alcohol by water (probably negligible).

† Neglecting replacement of alcohol by water.

31. *Molecular Complexity.*—"Films of celluloid have been made on water by evaporation of a dilute solution. The thinnest stable films are 10 Å thick, indicating that the molecular complex of celluloid is not over 10 Å in diameter" (2).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Addenbrooke, *121*, **66**: 629; 11. (2) Barton and Hunt, *58*, **114**: 861; 24. (3) U. S. Bureau of Standards, *O.* (4) Clement and Riviere, *La Cellulose.* Paris, 1920, p. 308–315. (5) Coker and Chakko, *62A*, **221**: 139; 20. (6) Curtis, *31A*, **11**: 359; 14. (7) du Pont Viscoloid Co., *O.* (8) Electrical Testing Laboratories, New York City, *O.* (9) The Fiberloid Corporation, *O.*

(10) Filon and Jessup, *5*, **101**: 165; 22. (11) Heymans and Allis, *285*, **2**: 217; 23. (12) Heymans and Calingaert, *45*, **16**: 939; 24. (13) Martin, *248*, **6**: 323; 22. (14) Nishida, *296*, **4**: 287; 14. (15) Nishida, *45*, **8**: 1096; 16. (16) Ramspech, *8*, **74**: 722; 24. (17) Rossi, *71*, **16**: 206; 10. (18) Souder and Hidnert, *31A*, **15**: 408; 19. (19) Souder and Hidnert, U. S. Bureau of Standards, *O.*

(20) Stifler, Columbia University, New York City, *O.* (21) Stokes and Weber, *32*, No. **98**; 17. (22) Tesche, *97*, **5**: 233; 24. (23) Ullmann, *B61*, **III**: 303; 15. (24) Weber, *31*, No. **192**; 12. (25) Will, *92*, **19**: 1382; 06. (26) Worden, *Nitrocellulose Industry*, I, Chap. IV (New York, Van Nostrand, 1911). *Technology of Cellulose Esters*, I, 2655–2759 (New York, Van Nostrand, 1921). (27) Dickinson and Van Dusen, *382*, **3**: 5; 16.

B. PHENOL RESINS AND THEIR PRODUCTS

("Bakelite," "Redmanol," "Condensite," Etc.)

L. V. REDMAN

Commercial Phenol Resins are phenol-formaldehyde condensation products, prepared under conditions that produce a resin capable of becoming hard, strong, insoluble and infusible with application of heat and pressure. Phenol Resin Products include: (1) Pure Resin; (2) Molded Products (employing as fillers wood flour, asbestos or other fibrous materials); and (3) Laminated

Products (prepared from paper or cloth which has been previously impregnated with the uncured resin).

The information given below is based upon data from (1, 2).

Type of Material

Type	Molded, and filled with			Laminated and filled with			Pure resin
	Wood flour	Asbestos	Mica	Paper	Canvas	Cloth	
Symbol	M_W	M_A	M_M	L_P	L_C	L_{Cl}	P

Tensile Strength.—One-half inch figure-8 shaped test pieces for M and P materials (A. S. T. M. [D-48-24]). For L materials, values are parallel to laminations; *v.* (3) for shape of test piece.

Tensile strength = A $\times 10^3$ lb. in.$^{-2}$ = A′ $\times 10^7$ dyne cm^{-2}.

Type	M_M, M_W and M_A	L_P	L_C	P
A......	3.5– 6.0	8.7– 25	8.5–12	5–11
A′.....	24 –40	60 –175	62 –80	35–75

Compressive Strength.—Inch-cube test-piece. (A. S. T. M. [D-48-24].) Compressive strength = A $\times 10^3$ lb. in.$^{-2}$ = A′ $\times$ 10^7 dyne cm^{-2}; at 20° unless otherwise noted; parallel or perpendicular to laminations as indicated.

Type	M_W	M_W, 100°	M_A	$L_P \parallel$	$L_C \parallel$	$L_C \perp$	P
A...	25– 36	12	18– 36	20– 45	20– 25	35– 47	26– 33
A′..	175–250	80	125–250	140–275	140–175	245–330	180–230

Modulus of Elasticity in Tension, Young's Modulus.—M = 1.5–2.5 $\times 10^6$ lb. in.$^{-2}$ = 1.1–1.75 $\times 10^{11}$ dyne cm^{-2} for the L_P material parallel to laminations; *v.* (3) for sample used.

Modulus of Elasticity in Bending.—Samples 12 in. long by 1 in. wide, with 10 in. span. M = load $\times$ span^3 ÷ 4 $\times$ width $\times$ thickness^3 $\times$ deflection at center = 1.1–2.1 $\times 10^6$ lb. in.$^{-2}$ = 75–175 $\times 10^9$ dyne cm^{-2} for the L_P material ⊥ to laminations.

Modulus of Rupture.—Samples 12 in. by 1 in. by 0.25 in.; 10 in. span. M = 3 $\times$ load $\times$ span ÷ 2 $\times$ width $\times$ thickness^2 =, for L_P material, 15 000–30 000, and for P material, 12 500–20 000 lb. in.$^{-2}$ = for L_P, 1.05–2.10 $\times 10^9$ and for P, 0.85–1.40 $\times 10^9$ dyne cm^{-2}.

Impact Behavior.—(*a*) Olsen impact machine. Test piece 2½ in. × 1 in. × ½ in. with edges and corners rounded, 2 in. span. Drop increments of ½ in. between blows, from zero up to the breaking point. The values given below are the sums of the corresponding mass-height products.

Type		M_W	M_A	L_P	$L_C \perp$	P
Σ mh	lb. in.	500–1200	200–540	400–2000	3500–5300	500–1750
	kg cm	575–1380	230–620	460–2300	4000–6000	575–2000

(*b*) Pendulum method. Energy of blow to break a ½ in. square sample. L_P, ∥ 0.3–1.5 lb. ft.; 0.04–0.20 kg m; L_C, ∥ 2–3 lb. ft.; 0.25–0.40 kg m.

Bulk Density and Hardness.—Brinell test by application of 500 kg wt. for 30 sec. Scleroscope test with hard hammer.

Type		M_W	M_A	L_P	L_C	P
d, g cm^{-3}		1.33–1.40	1.78–2.00	1.32–1.40	1.36–1.40	1.20–1.29
Hardness	Brin...	30–38	38–42	35–45	33–38	30–45
	Scler...	78–92	75–95	84–94	60–67	75–110

Water Absorption.—Per cent gain in weight of sample (5 × 10 × 1¼ cm) after 24 hr immersion in water at 20°.

Type	M_W	M_A	L_P	L_{Cl}	P
Per cent gain.....	0.05–0.20	0.05–0.10	0.20–1.0	0.20–2.0	0.05–0.07

Softening Point Under Load.—A. S. T. M. method [D-17-T-1919]. M_W, 125–130; M_A, 130–150; L_P, 125–150; P, 75–100; deg. C. Do not flow under pressure of screw heads and similar forces at ordinary temperatures.

Thermal Expansion and Specific Heat.—Mean coefficient of linear expansion = A $\times 10^{-6}$ per °C between 20 and 70°. Specific heat, c_1 in joules g^{-1} per °C, c_2 in cal g^{-1} per °C or BTU lb.$^{-1}$ per °F.

Type		M_W	M_A	L_P	L_C	P
	A	25–45	20–45	20–30	20–30	50–110
Sp. ht.	c_1, joules....	1.2–1.5	1.5–1.7	1.2–1.7		1.4–1.5
	c_2, cal or BTU.....	0.30–0.36	0.35–0.40	0.30–0.40		0.33–0.37

Electrical Resistivity.—At 20°C and 50% atmospheric humidity the total resistivity (in ohm) is of the order of 10^{10}–10^{11} for most types, that for the M_A material being somewhat lower, 10^8–10^9, and that for the pure resin sometimes higher, 10^{10}–10^{12}. The surface resistivity for L_P (in 10^9 ohm) is 10–90 000 for 24%, 0.9–660 for 50% and 0.1–15 for 84% relative humidity. Exposure to light, especially ultra-violet, decreases surface resistivity.

Dielectric Constant (ε) *and Power Factor.*—At radio frequencies. Phase difference = power factor (P. F.) × 0.57.

Type	M_W	M_M	L_P	L_{Cl}	P
ε.........	4.5–7.5	4–5	4.5–6.0	4.5–6.0	4.5–7.0
P. F., %..	1.5–7	0.5–1.5	1.5–5	2–7	0.2–3

Dielectric Strength.—A. S. T. M. low frequency test. L and P materials in 1/32 in. sheets.

Type	M_W	M_A	L_P	L_C	P
Volts mil^{-1}..........	250–700	150–500	750–1300	250–500	250–700
Kilovolts cm^{-1}......	100–280	60–200	300– 500	100–200	100–280

Flash-over Voltage.—Between two 2 cm skirted brass studs 2 cm apart. Radio frequencies, L_P, 18–28; L_C, 18–25 kilovolts.

Optical Properties.—For the pure resins, n_D^{20} = 1.62–1.70. Quite transparent in the infra-red. Darkening occurs on long exposure to sunlight.

Miscellaneous Effects.—Exposure to (1) steam, does not affect mechanical properties but increases water absorption; (2) weak acids, no effect; (3) strong acids, charring of the organic fillers; (4) strong oxidizing acids, disintegration of the resin; (5) mild alkalis, softening; (6) strong alkalis, disintegration; (7) organic solvents, no effect; (8) aging, no effect.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bakelite Corporation, Research Lab., *O.* (2) Dellinger and Preston, *31*, No. **216**; 22. (3) Dellinger and Preston, *32*, No. **471**; 23. (4) A. S. T. M., American Society for Testing Materials.

C. COMPARISON OF PROPERTIES OF HARD RUBBER, VULCANIZED FIBER, LAMINATED AND MOLDED PHENOLIC INSULATING MATERIALS[1]

Hard rubber is composed of crude rubber, sulfur, and usually some mineral filling compound. The relatively high cost of crude rubber had induced some makers of hard rubber to use reclaimed rubber or else load the new rubber with a high percentage of mineral filler. The lack of a proper understanding of this fact between the maker and the user has often resulted in unjust censure of hard rubber as an insulator. The better grades of hard rubber are made of new rubber containing no mineral filler

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[1] Dellinger and Preston, *32*, **216**: 619; 22.

and are free from excess sulfur. With these points in mind it is evident that the values assigned to a particular property or the effect of a certain test must necessarily be broad. Neither the best nor the poorest grade of hard rubber is considered in the data and opinions given in the following table.

Vulcanized fiber is made of parchmentized paper. For the better grades of fiber, rag base paper is used. The paper is run slowly through a warm concentrated solution of sulfuric acid or zinc chloride, the one solution being used in making fiber sheets one-eighth inch thick or less, the other solution being used for thicknesses greater than one-eighth inch. The purpose of the acid or zinc chloride is to soften the walls of the cellulose (cotton) fibers, so that when several sheets of treated paper are pressed together the fibers tend to mat and cohere. The treated paper is wound on a drum until the cylindrical tube of the desired thickness is obtained, the cylindrical tube being then cut so as to form a sheet whose width is equal to the width of the paper and whose length is equal to the circumference of the drum. The composite sheet of treated paper is then soaked in water to remove the acid or zinc chloride, dried, and pressed. The term "vulcanized" is somewhat misleading. Fiber does not depend upon heat and pressure to cure it as does hard rubber.

Vulcanized fiber varies much in both mechanical and electrical properties. The properties depend somewhat on the quality of rags used, the amount of residual sulfuric acid or zinc chloride, and upon the density of the finished product. Since the various processes of fiber making are difficult to control, the following statements relative to fiber must be taken as general and the recorded numerical data as average data.

The several makes and many grades of *laminated phenolic insulating material* are discussed quite fully in the paper. Any numerical value or statement given in the following summary table is an approximation.

The *molded phenolic insulating materials* are subject to as many variations as hard rubber. There is probably not as much variation in the phenolic resin binder in the molded phenolic materials as there is in the crude or reclaimed rubber binder of hard rubber. There are many other chances for variation in the press pressure and temperature, length of curing in the presses, and kind and quality of filler. Some of the fillers used are wood flour, pulverized mica, and asbestos. The kind and amount of filler will affect both the mechanical and electrical properties. All these possible variations make the data only approximate and require rather general statements in the summary table.

Most of the numerical data given in the table below are from tests made at the Bureau of Standards. The statements concerning the effects of various things on the different insulating materials are based on the experience of various members of the Bureau of Standards staff and upon the experience of the manufacturers of these materials. The manufacturers' experience on hard rubber and vulcanized fiber extends over many years, while the experience on the phenolic insulating materials is much more limited.

While it is possible to make up insulating materials which would give results different from those recorded for any particular property, yet it is believed that this table gives information in a condensed form which will serve to show some of the limitations as well as some of the possibilities of these various materials as now obtainable commercially.

Comparison of Properties of Hard Rubber, Vulcanized Fiber, Laminated and Molded Phenolic Insulating Materials

Properties	Hard rubber	Vulcanized fiber	Phenolic insulating materials	
			Laminated	Molded
Surface resistivity at 50% relative humidity, ohm	10^{12} to $>10^{15}$		10^{11}	10^{11}
Phase differences (ψ) at radio frequencies, deg	0.5*	3.0†	1.5 to 4.0	1.5 to 4.0
Dielectric constant (ϵ) at radio frequencies	3.0*	5.0†	4.5 to 6.0	5.0 to 7.5
Dielectric strength, volt/mm	10 000 to 38 000‡§	9 000 to 16 000‡§	27 000 to 45 000‡§	9 000 to 40 000‡§
Tensile strength, lb./in.^{2}	3 500 to 6 500	9 000 to 20 000	10 000 to 25 000	3 500 to 7 000
Water absorbed in 24 hr, percentage by weight	0.02	26 to 45‖	0.2 to 1.0¶	0.05 to 0.2**
Density, g/cm^3	1.12 to 1.40††	1.3 to 1.5	1.3 to 1.4	1.3 to 1.4
Thermal expansivity (at 20 to 60°C)	60 to 80 $\times 10^{-6}$	27 $\times 10^{-6}$	20 to 30 $\times 10^{-6}$	25 to 45 $\times 10^{-6}$
Effects of various agents				
Age	Deteriorates slowly, but if properly vulcanized and protected from the light it is not affected	Improves in quality by seasoning‡‡	Improves§§	No depreciation in physical or chemical properties; slight increase in hardness§§
Heat	At 65.5°C (150°F) pure hard rubber softens perceptibly; at 100°C (212°F) it is so soft it may be bent easily; at 115.5°C (240°F) it becomes leathery and may readily be cut with a knife; melts at 200°C (392°F)‡	Will not melt under any circumstances; not readily inflammable; at very high temperature chars and becomes brittle; active combustion begins at about 343°C (650°F)	Not readily inflammable; will withstand continuously a temperature of 149°C (300°F); heat tends to complete the reaction and volatile substances are driven off. Hence, when cooled it shrinks considerably and may split; shrinks and loses in weight above 60°C‖‖	See statement for laminated materials for cellulose-filled molded materials. Asbestos-filled and mica-filled materials are much more resistant to heat¶¶

Comparison of Properties of Hard Rubber, Vulcanized Fiber, Laminated and Molded Phenolic Insulating Materials.—(*Continued*)

	Hard rubber	Vulcanized fiber	Phenolic insulating materials	
			Laminated	Molded
Sunlight	Discolors and disintegrates after a few months; the sulfur of the hard rubber is oxidized, forming the equivalent of sulfuric acid; this may take up ammonia from the air or may attack the filling materials and form various sulfates upon the surface; the surface resistivity is greatly reduced***	No effect‡	No visible effect†††	After two and one-half years some materials show a slight change, such as discoloration or very fine cracks; other materials show no such change‡†††
Ultra-violet light for 20 hr	Discolors and disintegrates; the action is as pronounced for a few hours' exposure to ultra-violet light as for many months' exposure to sunlight; the surface resistivity is greatly reduced***	No data	Appreciable lowering of surface resistivity	Appreciable lowering of surface resistivity***
Moist air	Hard-rubber compounds excepting those containing organic substances other than rubber are practically moisture proof	Absorbs water freely, but without permanent injury; while saturated it becomes soft and flexible and swells; warps and twists upon drying	Absorbs slight amount of water, reducing dielectric properties‡‡‡	Absorbs slight amount of water, reducing dielectric properties
Steam	The only effect is that due to the high temperature	Same as above, except absorption is more rapid	Best grades not affected beyond slight absorption of moisture; after a few days in steam the cheaper grades will swell appreciably and split; superheated steam tends to warp and blister all grades of the material	Absorbs a slight amount of moisture; if steam is superheated, the high temperature will cause decomposition of cellulose-filled materials. The mineral-filled materials are much more resistant to heat
Solvents:				
Acetone	Attacks, dissolving oils and free sulfur‡	No permanent effect‡	No effect‡§§§	No effect‡§§§
Alcohol	Attacks to a slight degree‡	No permanent effect‡	No effect‡§§§	No effect‡§§§
Ammonia	No effect‡	No permanent effect‡	Strong solutions may cause material to swell‡	No effect other than slight absorption of moisture‡
Aniline	Softens at ordinary temperature‡	Not known	Probably no effect‡	Probably no effect‡
Benzene	Softens at ordinary temperature‡	No permanent effect‡	Probably no effect‡§§§	Probably no effect‡§§§
Carbon bisulfide	Dissolves small amount of hard rubber and any free sulfur‡	No permanent effect‡	Probably no effect‡§§§	Probably no effect‡§§§
Ether	Dissolves small amount of hard rubber and any free sulfur‡	No permanent effect‡	No effect‡	Probably no effect‡§§§
Naphtha	Softens and swells to slight extent‡	No permanent effect‡	Probably no effect‡	Probably no effect‡§§§
Oil of turpentine	Dissolves in boiling oil‡	No permanent effect‡	Probably no effect‡	Probably no effect‡§§§

Comparison of Properties of Hard Rubber, Vulcanized Fiber, Laminated and Molded Phenolic Insulating Materials.—(*Continued*)

	Hard rubber	Vulcanized fiber	Phenolic insulating materials	
			Laminated	Molded
Oil:				
Mineral	Slight softening[‡]	Slight absorption[‡]	Practically impervious[‡]	Practically impervious[‡]
Organic	Unaffected[‡]	Slight absorption[‡]	Practically impervious[‡]	Practically impervious[‡]
Weak acids	Unaffected[‡]	Swells due to absorbed water; may be attacked after some time[‡]	Practically unaffected except for absorption of water[‖‖]	Practically unaffected[¶¶¶]
Weak caustic alkalis	Unaffected[‡]	Swells due to absorbed water; may be attacked after some time[‡]	Does not successfully resist the action of alkali unless very dilute	Does not successfully resist the action of alkali unless very dilute
Stronger acids (HNO_3, HCl, H_2SO_4)	Not attacked by concentrated hydrochloric, hydrofluoric, acetic acids; not attacked by sulfuric acid of less than 1.50 specific gravity or nitric acid of less than 1.12 specific gravity[‡]	Cellulose fiber attacked; soon decomposes	Decomposes; rapidity depends on specific gravity and temperature of acid	Cellulose-filled materials decompose; rapidity depends on specific gravity and temperature of acid. Molding materials made with acid-resistant fillers, such as mica, offer much greater resistance[****]
Stronger caustic alkalis	No effect	Cellulose fiber attacked; soon decomposes	Binder and filler decompose[¶¶¶]	Completely destroyed; speed of the reaction depends on the strength of the solution
Ozone	Oxidizes and soon ruins for electrical purposes	No effect[‡]	Not known	Not known
Metallic inserts	Rapidly deteriorated by contact with iron or copper, the metals themselves being corroded; the inserts should be coated with tin, paper, unvulcanized rubber, or other mutually protecting medium	No effect[‡]	No effect	No effect
Miscellaneous				
Machining qualities	Admits of a high polish; machines less accurately than would be supposed, due to great resiliency; the better the grade the more readily it is machined; quality may be judged roughly by color and texture, toughness, color, and grain of a shaving; has tendency to warp; can be molded but not accurately to size	Admits of a fine finish; may be sawed, punched, drilled, stamped, embossed, turned, planed, bent, tapped; tough, resists shock; can not be molded[††††]	Admits of a good polish; can be sawed, punched, drilled, stamped, turned, planed, knurled, embossed, milled, tapped either with or against the grain, though not as easily as hard rubber and vulcanized fiber; tough, resists shock; cannot be molded[††††]	Admits of a fine lasting polish; can be machined, cut, filed, sawed with difficulty; can be molded accurately to size; quite brittle
Cost (1922)	About $2 per pound in sheet form	50–80 cents per pound up to 1 inch in thickness; about $5 per pound for 2 inches in thickness	About $1 per pound	Cost varies with complexity of steel molds

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[*] These values were obtained at frequencies between 750 000 and 75 000 cycles per second (400 to 4000 meters wave length), there being very little change throughout this range. The grade of the sample tested is unknown, so values differing somewhat from these might be expected on other samples using different quantities and kinds of filler.

[†] Values of ψ and K may be somewhat lower or much higher, depending on amount of moisture present in the fiber.

‡ Information obtained from sources other than the Bureau of Standards.

§ Values vary with the thickness of sample, kind of filler, shape of electrodes used, rate of increase of voltage, as well as atmospheric conditions under which tests are made.

‖ The Railway Signal Association specifications require an absorption when immersed in water at 70°F for 24 hours, not to exceed 45% by weight for one-eighth inch fiber, 30% for three-sixteenth inch fiber, and 26% for one-fourth inch fiber.

¶ Dependent upon nature of surface, surface area, and kind and amount of filler.

** Varies with polish of mold, press pressure, and temperature, length of curing, ratio of resin to filler, kind of filler, and size of sample.

†† The density depends on the amount of sulfur present and increases with the increase in amount of filler. Pure hard rubber ranges from 1.12 to 1.25. A fair commercial quality ranges from 1.25 to 1.40.

‡‡ This means seasoning or aging in a protected place, such as a storage house.

§§ These materials are of comparatively recent development, and hence no information has been gained covering very long periods. Theoretically, under certain conditions the chemical reactions would tend to continue, which would age and improve the material. One manufacturer claims a slight improvement in dielectric properties and a marked improvement in machining qualities when the aging takes place under ordinary atmospheric and temperature conditions. If the aging takes place in a moist atmosphere, the dielectric properties are subject to deterioration.

‖‖ *See* pages 580 to 583 of Technologic Paper, U. S. Bureau of Standards, No. 216.

¶¶ When subjected to temperatures above 60°C (140°F) some of the volatile matter is driven off, resulting in the shrinking and loss in weight of the material. This can be carried out many times with the same result, the material becoming more brittle. Tests made on these materials show that they are very erratic in behavior and do not expand or contract in a uniform way. It seems altogether probable that a point would be reached after all volatile matters had been driven off, when further subjection to a moderate temperature and subsequent cooling would not result in further shrinkage. This has not been proved experimentally. High temperature will produce decomposition. Further information regarding these tests will be found in Scientific Paper of the Bureau of Standards No. 352. (*See also* pages 580 to 583 of Technologic Paper, U. S. Bureau of Standards, No. 216.)

*** A further discussion of the tests at the Bureau of Standards may be found in Scientific Paper of the Bureau of Standards, No. 234.

††† *See* effect of ultra-violet light.

‡‡‡ *See* discussion on pages 599 and 600 of Technologic Paper, U. S. Bureau of Standards, No. 216.

§§§ Strong solvents affect the phenolic binder of the material to a limited extent unless the chemical reaction has been carried to the point where it is in the insoluble state. This condition would render the sheet material too brittle for general use. When water is present, the material will absorb it in various amounts.

‖‖‖ The effects vary with the materials, different molding mixtures, and acids. Nitric acid is harmful. In general weak acids will mar the surface and attack the edge of a sample soon after they come in contact with the sample, but there is little or no further change.

¶¶¶ *See* page 608 of Technologic Paper No. 216.

**** The action differs for various materials and grades. Some materials resist the action of a 30% solution of H_2SO_4 for several months and will withstand hydrochloric acid without any visible sign of attack. On other materials of this class sulfuric and nitric acids attack the surface of the sample and form a protective coating. This ruins the sample as far as further electrical use is concerned, but on removing the sample from the acid and cutting it open it is found that the acid has not penetrated more than one-sixteenth inch after several months' exposure to the acid.

†††† Thin sheets can be pressed to simple shapes when warm.

COMMERCIAL CARBONS FOR ELECTRICAL USES

N. K. Chaney

Manufactured carbon articles in the form of rods, plates, blocks, tubes, etc. in a wide variety of shapes are made by molding or extruding specially prepared mixtures of pulverized carbon "flours" with binding materials of tar or pitch, and subsequently carbonizing the binder at high temperatures. The resulting products always consist of a porous mass of carbon particles knit together by the residual carbon resulting from the decomposition of the binding materials. Because of the variations inherent in all manufacturing processes the physical properties of commercial carbons are subject to characteristic variations, the allowable range of which is determined by the service and cost requirements of the consumer. A high degree of precision in the individual determinations is therefore valueless, the typical range of variation being alone significant. Individual values where given must be regarded merely as representative.

Characteristic Range in Physical Properties of Typical Grades of Commercial Carbons (5)

	Resistance milliohm-cm	Density, g/cm³		Scleroscope hardness
		True*	Bulk	
Coke electrodes	3.5 –5.0	2.00–2.10	1.53–1.64	
Coal electrodes	3.3 –6.3	1.95–2.10	1.50–1.67	
Brushes:				
Electrographitic A	4.0 –5.0	2.03–2.07	1.50–1.60	49–61
Electrographitic B	0.8 –1.8	2.16–2.19	1.41–1.61	20–36
Artificial graphite	2.3 –3.8	2.08–2.10	1.45–1.60	30–45
Natural graphite	0.25–0.50	2.23–2.27	1.85–2.00	10–20
Arc light carbons	7.0 –8.0	1.85–1.90	1.30–1.40	70–80

* By immersion in kerosene.

Temperature Coefficient of Resistance (3)

t°C	% resistance		t°C	% resistance	
	Carbon	Graphite		Carbon	Graphite
25	100	100	2000	77.6	68.0
400		94	2200		69.0
800		81.5	2400	65.9	
1200	91.6	66.0	2800	50.9	
1600	87.0	65.0	3500	22.4	

Thermal Expansion

	Δt°C	$\frac{10^6 \Delta l}{l\,\Delta t}$	Lit.
Electrodes:			
Coal	220–1820	11.0	(5)
Coke	180–1920	7.2	(5)
Graphite	440–1720	10	(5)
Graphite		$0.55 + 0.0032t$	(2)
Arc carbon:			
Lampblack	25–1000	6.0	(5)
Coke		0.32	(4)
Coke		1.5	(4)
Coke		2.05	(4)
Coke		3.0	(4)

Mean Specific Heat, g-cal/g per °C (1)

Δt °C	Carbon	Graphite	Δt °C	Carbon	Graphite
26– 76	0.168	0.165	36– 902		0.324
26–282	.200	.195	47–1193		.350
26–538	.199	.234	48–1180	0.351	
30–752		.290	56–1450	.387	.390
40–892	.314				

‡ Information obtained from sources other than the Bureau of Standards.

§ Values vary with the thickness of sample, kind of filler, shape of electrodes used, rate of increase of voltage, as well as atmospheric conditions under which tests are made.

‖ The Railway Signal Association specifications require an absorption when immersed in water at 70°F for 24 hours, not to exceed 45% by weight for one-eighth inch fiber, 30% for three-sixteenth inch fiber, and 26% for one-fourth inch fiber.

¶ Dependent upon nature of surface, surface area, and kind and amount of filler.

** Varies with polish of mold, press pressure, and temperature, length of curing, ratio of resin to filler, kind of filler, and size of sample.

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Electrographitic A	4.0 –5.0	2.03–2.07	1.50–1.60	49–61
Electrographitic B	0.8 –1.8	2.16–2.19	1.41–1.61	20–36
Artificial graphite	2.3 –3.8	2.08–2.10	1.45–1.60	30–45
Natural graphite	0.25–0.50	2.23–2.27	1.85–2.00	10–20
Arc light carbons	7.0 –8.0	1.85–1.90	1.30–1.40	70–80

* By immersion in kerosene.

Temperature Coefficient of Resistance (3)

t°C	% resistance		t°C	% resistance	
	Carbon	Graphite		Carbon	Graphite
25	100	100	2000	77.6	68.0
400		94	2200		69.0
800		81.5	2400	65.9	
1200	91.6	66.0	2800	50.9	
1600	87.0	65.0	3500	22.4	

Thermal Expansion

	Δt°C	$\frac{10^6 \Delta l}{l\,\Delta t}$	Lit.
Electrodes:			
Coal	220–1820	11.0	(5)
Coke	180–1920	7.2	(5)
Graphite	440–1720	10	(5)
Graphite		$0.55 + 0.0032t$	(2)
Arc carbon:			
Lampblack	25–1000	6.0	(5)
Coke		0.32	(4)
Coke		1.5	(4)
Coke		2.05	(4)
Coke		3.0	(4)

Mean Specific Heat, g-cal/g per °C (1)

Δt °C	Carbon	Graphite	Δt °C	Carbon	Graphite
26– 76	0.168	0.165	36– 902		0.324
26–282	.200	.195	47–1193		.350
26–538	.199	.234	48–1180	0.351	
30–752		.290	56–1450	.387	.390
40–892	.314				

THERMAL CONDUCTIVITY

K = g-cal cm^{-2} sec^{-1} (°C, $cm^{-1})^{-1}$

10^2K	Range, °C
Electrographitic brush A (5)	
2.9	20– 43
Natural graphite brush A (5)	
3.9	20– 43
Graphite electrode (3, 5)	
5.7	20– 43
50	90– 110
39	180– 220
35	260– 340
31	350– 450
29	440– 560
27	500– 700
0.019	2800–3200
Coke electrode (3, 5)	
0.79	20– 40
1.6	37–163
1.7	105–225
1.1	160–325
1.6	170–330
1.7	200–340
1.2	240–523
1.2	263–543
1.2	283–597
0.019	3000

LITERATURE

(For a key to the periodicals see end of volume)

(1) Acheson Graphite Co., O. (2) Day and Sosman, *45*, **4**: 490; 12. (3) Hansen, *78*, **16**: 329; 09. (4) Muraoka, *8*, **13**: 307; 81. (5) National Carbon Company, O.

INDUSTRIAL ELECTRICAL INSULATORS

[1] Consult the desired property in the index of I. C. T.

[1] Consulter la propriété désirée dans l'index des I. C. T.

[1] Siehe die entsprechenden Eigenschaften im Index der I. C. T.

[1] Consultarne le proprietà nell'indice delle T. C. I.

Abbreviations

B. D.	Complete breakdown
B. T.	Burning temperature
D	Diameter
d	Specific gravity, room temperature, water = 1
E.	Engler viscometer; data given in Engler degrees
F. T.	Flash point
G	Spark gap = minimum distance between surfaces of electrodes
Max.	Maximum
P. D.	Potential difference between electrodes
P. F.	Power factor
P. Sp.	Preliminary sparking
S. T.	Solidifying temperature
S. U.	Saybolt Universal viscometer; data given are times of efflux, seconds
V	Viscometer value. For interconversion of E. and S. U. data, and for conversion of either to kinematic viscosity, *see* Vol. I, p. 33
$\% \Delta$	Per cent deviation from mean
ϵ	Dielectric constant
ρ	Volume resistivity

Abréviations

B. D.	Rupture diélectrique complète
B. T.	Température de combustion
D	Diamètre
d	Poids spécifique, à la température de la chambre, eau = 1
E.	Viscosimètre d'Engler; données en degrés Engler
F. T.	Point d'inflammabilité
G	Distance explosive = distance minimum entre les surfaces des électrodes
Max.	Maximum
P. D.	Différence de potentiel entre électrodes
P. F.	Facteur de puissance
P. Sp.	Lueur préliminaire
S. T.	Température de solidification
S. U.	Viscosimètre universel de Saybolt; les valeurs données sont les durées de l'écoulement en secondes
V	Constante du viscosimètre. Pour l'interconversion des valeurs de E. et S. U., et pour la conversion de ces deux valeurs en viscosité cinématique, voir Vol. I, p. 33
$\% \Delta$	Pourcentage d'écart de la moyenne
ϵ	Constante diélectrique
ρ	Résistivité

THERMAL CONDUCTIVITY

K = g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$

10^2K	Range, °C	10^2K	Range, °C
Electrographitic brush A (5)		39	180–220
2.9	20–43	35	260–340
Natural graphite brush A (5)		31	350–450
3.9	20–43	29	440–560
Graphite electrode (3, 5)		27	500–700
5.7	20–43	0.019	2800–3200
50	90–110		

THERMAL CONDUCTIVITY.—(*Continued*)

10^2K	Range, °C	10^2K	Range, °C
Coke electrode (3, 5)		1.7	200–340
0.79	20–40	1.2	240–523
1.6	37–163	1.2	263–543
1.7	105–225	1.2	283–597
1.1	160–325	0.019	3000
1.6	170–330		

LITERATURE

(For a key to the periodicals see end of volume)

(1) Acheson Graphite Co., *O.* (2) Day and Sosman, *45*, **4**: 490; 12. (3) Hansen, *78*, **16**: 329; 09. (4) Muraoka, *8*, **13**: 307; 81. (5) National Carbon Company, *O.*

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Abbreviations

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P. Sp.	Preliminary sparking
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S. U.	Saybolt Universal viscometer; data given are times of efflux, seconds
V	Viscometer value. For interconversion of E. and S. U. data, and for conversion of either to kinematic viscosity, *see* Vol. I, p. 33
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P. F.	Facteur de puissance
P. Sp.	Lueur préliminaire
S. T.	Température de solidification
S. U.	Viscosimètre universel de Saybolt; les valeurs données sont les durées de l'écoulement en secondes
V	Constante du viscosimètre. Pour l'interconversion des valeurs de E. et S. U., et pour la conversion de ces deux valeurs en viscosité cinématique, voir Vol. I, p. 33
% Δ	Pourcentage d'écart de la moyenne
ϵ	Constante diélectrique
ρ	Résistivité

Abkürzungen

B. D.	Dielektrische Festigkeit
B. T.	Brenntemperatur
D	Durchmesser
d	Spezifisches Gewicht, Zimmertemperatur, Wasser = 1
E.	Engler Viskosimeter, Werte in Englergraden
F. T.	Entflammungspunkt
G	Funkenstrecke = minimal Entfernung der Oberflächen der Elektroden
Max.	Maximum
P. D.	Potentialdifferenz zwischen den Elektroden
P. F.	Kraftfaktor
P. Sp.	Glimmentladung
S. T.	Erstarrungstemperatur
S. U.	Saybolt Universalviskosimeter, die angegebenen Daten sind Ausflusszeiten in Sekunden
V	Viskosimeterwert. Für die gegenseitige Abmessung von E und S. U. Werte, für die Umrechnung auf die kinematische Viskosität siehe Vol. I, p. 33
% Δ	Prozentuelle Abweichung vom Mittel
ϵ	Dielektrizitätskonstante
ρ	Widerstand im Inneren

Abbreviazioni

B. D.	Interruzione continua
B. T.	Temperatura di combustione
D	Diametro
d	Peso specifico, temperatura ordinaria, acqua = 1
E.	Viscosimetro di Engler, valori in gradi Engler
F. T.	Punto di infiammabilità
G	Lunghezza di scintilla = distanza minima tra le superficie degli elettrodi
Max.	Massimo
P. D.	Differenza di potenziale tra gli elettrodi
P. F.	Fattore di potenza
P. Sp.	Preliminare scintillamento
S. T.	Temperatura di solidificazione
S. U.	Viscosimetro universale Saybolt; i valori riportati rappresentano tempi di efflusso in secondi
V	Valore viscosimetrico. Per la conversione dei valori E. in S. U. e viceversa, e per la conversione degli uni e degli altri in viscosità cinematica, vedi Vol. I, p. 33
% Δ	Deviazione percentuale della media
ϵ	Costante dielettrica
ρ	Resistività di volume

INSULATING OILS

J. B. WHITEHEAD AND J. H. LAMPE

Only oils commonly used in industrial electrical apparatus are considered in this section. For data on other oils which might possibly meet industrial requirements, reference must be made to other sections of this volume. Among the following data are some for 7 distinct samples of domestic (U. S. A.) oil; these oils are here designated by the letters A to F, inclusive.

On n'utilise dans les appareils électriques que les huiles minérales de paraffine; on n'a considéré que de telles huiles dans cette section. Pour les données relatives á d'autres huiles qui peuvent présenter, éventuellement, une utilisation industrielle, il faut s'adresser á d'autres sections de ce volume. Parmi les données suivantes, il s'en trouve pour 7 échantillons distincts d'huiles indigènes (U. S. A.); ces huiles sont désignées par les lettres A à F, inclusivement.

Es werden nur Mineralöle paraffinischen Ursprunges in den elektrischen Apparaten benützt, nur solche sind deshalb Gegenstand des Abschnittes. Für Zahlenwerte weiterer Öle, welche vielleicht industrielle Beachtung verdienen, muss an anderer Stelle dieses Bandes nachgesehen werden. Unter den folgenden Werten sind 7 von heimischen (U. S. A.) Ölproben vorhanden. Diese Öle sind hier vom Buchstaben A bis einschliesslich F angeführt.

Solo gli olii minerali di paraffina sono adoperati negli apparecchi elettrici, e solo essi perciò sono qui presi in considerazione. Per le caratteristiche di altri olii che potrebbero eventualmente soddisfare alle richieste vedi altri capitoli di questo stesso volume. Tra i valori che seguono sono riportati quelli di 7 campioni di olii degli S. U. A. Questi olii sono indicati con le lettere da A a F inclusa.

TABLE 1.—GENERAL PROPERTIES OF VARIOUS INSULATING OILS

For dielectric strength, *see* Table 2. Bracketed numbers indicate the range of variation; *e.g.*, first entry indicates that *d* varies from 0.846 to 0.915.

Unit of $\rho = 10^{12}$ ohm-cm; of $\epsilon = 1$ cgse; of *P. F.* = 1%; of temperature = 1°C.

Oil / Prop.	U. S. A.			Germany*		France	Japan
	W. E. & M. (20)	G. E. (10)	Tobey (23)	Schendell (18)	Stern (22)	Crussard (4)	Hirobe (8)
d	0.846 0.915	0.83 0.93	0.845 0.870	0.85 0.92	0.85 0.95	0.85 0.92	0.827 0.861
V	50 100 S. U. 40°	40 120 S. U. 40°	40 110 S. U. 40°	8° 10° E. 20°	8° E. 20°	8° E. 20°	1.43° 2.96° E. 30°
ρ	13.2	20 150					
ϵ	2.5	2.15					
S. T.	− 2 −34	0 −40	−10 −15		−5	−1	
F. T.	140 170	130 190	130 190	160 170	160	160	125 152
B. T.			140 215	180 190		180	
P. F.	0.44	0.03 0.06					

* Heat conductivity of a German oil is given as 0.00031 cal/(cm deg sec) (24).

TABLE 2.—DIELECTRIC STRENGTH OF VARIOUS TRANSFORMER OILS

Average effective breakdown voltage

Unit of voltage = 1000 effective (r. m. s.) volt; of *D* and *G* = 1 in. = 2.54 cm.

Diameter (*D*) Gap (*G*)	Sphere 0.5 0.15	Disk 0.5 0.15	Needle points 0.15	Disk point 0.15	Disk 1 0.1	Lit.
Tobey			18.0	16.5		(23)
Digby & Mills	11.5		17.5	11.0		(3)
N. E. L. A.	40.0	29.0				(12)
Peek	64.0	31.0	22.0			(13, 14)
Hirobe	92.0	62.0		15.0		(8)
Schroter	92.0					(19)
Everest	20.0	20.0	22.0	18.5		(5)
W. E. & M.	61.5	48.0			36.2	(1)
Vac. Oil Co.	51.7	37.1			24.0	(1)
B. S.	61.3	49.9			28.2	(1)

TABLE 3.—DIELECTRIC STRENGTH OF INSULATING OIL E (5, 25)

Breakdown voltage: Effective (r.m.s.) kilovolt

Units of D = 1 in.; of G = 0.001 in.; 1 in. = 2.54 cm.

G	Sphere, D = 0.5			Disk, D = 0.5			Needle points			Point, disk		
	B. D.	P. Sp.	% Δ	B. D.	P. Sp.	% Δ	B. D.	P. Sp.	% Δ	B. D.	P. Sp.	% Δ
25	3.6	2.9	40							8.4	7.1	10
50	5.7	4.3	30	6.5	4.7	15	1.2	8.1	15	12.2	8.2	15
75				8.9	6.2	30						
100	13.2	7.6	40	14.5	7.4	40	17.8	13.5	10	16.0	11.8	8
150	19.5	11.1	30	19.1	11.1	40	22.1	16.3	8			
175										19.7	14.7	5
200	27.2	15.3	15	27.9	22.1	20	24.4	18.7	6			
250							26.7	20.4	8	23.3	17.4	6

TABLE 4.—DIELECTRIC STRENGTHS OF FOUR U. S. A. TRANSFORMER OILS (1)

Parallel tests by Vacuum Oil Co. (Vac.), Westinghouse Electric and Manufacturing Co. (W), and National Bureau of Standards (B. S.). Most accurate data available. Each number is average of 15 observations; individual deviation from mean = 10 %, the same in all cases.

Unit of D and G = 1 in. = 2.54 cm. V = 1 sec by S. U. at 0°C.

Electrodes	Gap G	Breakdown values, effective (r. m. s.) kilovolt, 60 cycles, 25°C							
		B. S.	Vac.	W	Mean	B. S.	Vac.	W	Mean
		A (d = 0.854, V = 55)				B (d = 0.867, V = 100)			
Disks D = 1	0.05	15.2	11.7	18.0	15.0	15.2	8.9	14.3	12.8
	0.10*	23.6	23.2	35.8	27.5	26.5	22.3	30.5	26.4
	0.15	33.6	32.9	39.3	35.3	36.3	32.2	42.8	37.1
	0.20	40.6	39.1	53.8	44.5	42.8	37.6	55.7	45.4
Disks D = 0.5	0.05	21.2	15.3	22.2	19.6	21.5	13.2	20.9	18.5
	0.10	37.9	29.4	38.9	35.4	37.1	24.8	38.7	33.5
	0.15	48.7	38.9	47.5	45.0	47.9	33.4	42.8	41.4
	0.20	49.3	45.2	51.0	48.5	49.8	46.1	54.9	50.3
Spheres D = 0.5	0.05	23.6	23.6	29.5	25.6	22.6	20.7	25.3	22.9
	0.10	44.2	45.5	51.1	46.9	38.5	35.2	48.6	40.8
	0.15	61.1		67.1	64.1	56.0	51.1	60.6	55.9
	0.20	68.9			68.9	70.5			70.5
		C (d = 0.829, V = 34)				D (d = 0.860, V = 74)			
Disks D = 1	0.05	16.5	8.8	18.5	14.6	16.8	11.0	17.8	15.2
	0.10*	33.5	25.9	40.7	33.4	29.1	24.6	37.8	30.5
	0.15	39.5	32.5	53.7	42.0	38.5	30.9	48.7	39.4
	0.20	50.8	39.8	64.8	51.8	41.2	37.9	59.8	46.3
Disks D = 0.5	0.05	27.1	20.0	24.9	24.0	25.8	14.0	19.4	19.7
	0.10	48.4	34.6	42.9	42.0	41.0	26.9	40.7	36.2
	0.15	48.8	42.3	57.9	49.7	54.3	33.7	47.0	45.0
	0.20	60.0	50.6	67.4	59.3	55.5	42.5	52.8	50.3
Spheres D = 0.5	0.05	33.4	26.3	32.9	30.8	26.2	22.5	30.0	26.2
	0.10	49.1	50.2	55.3	51.5	50.1	43.8	56.4	50.1
	0.15	67.1			67.1	61.1	52.4	56.7	56.7
	0.20					72.5			72.5

* This is the standard gap recommended by American Society for Testing Materials (1)—1 in. flat disks with square shoulders, spaced 0.1 in. apart. For this gap, the B. D. value for transformer oils should lie in the range 26.4 to 33.4 kilovolt.

TABLE 5.—RELATIVE BREAKDOWN VOLTAGES FOR THREE COMMERCIAL TEST GAPS (1)

(Voltage, gap E_1)/(voltage, gap E_2)

Unit of D and G = 1 in. = 2.54 cm.

E_1	A	B	C
A	1.00	1.80	2.05
B	0.55	1.00	1.20
C	0.50	0.85	1.00
	Disk	Disk	Sphere
D	1	0.5	0.5
G	0.1	0.2	0.15

TABLE 6.—ERROR IN THE AVERAGE OF n TESTS OF DIELECTRIC STRENGTH OF AN OIL

Based on 3000 tests (6, 7)

Unit of error = 1 %.

n	Error	Sphere long*	Sphere short*	Point, sphere
1	Av.	7.8	7.8	8.4
1	Max.	48.5	34.1	44.8
3	Av.	5.2	4.9	4.9
3	Max.	22.4	19.7	19.1
6	Av.	2.7	3.5	4.1
6	Max.	17.5	15.0	14.3

* Average: Long = 27 mm; short = 2 mm.

TABLE 7.—SPARKOVER VOLTAGE BETWEEN CONCENTRIC CYLINDERS (14)

For $\frac{R}{r} > 3.5$ corona appears in transformer oils before sparkover occurs; for $\frac{R}{r} < 3.5$, the sparkover and corona voltages are the same and obey the relation: $g = 36\left(1 + \frac{1.2}{\sqrt{r}}\right)$. g = maximum voltage gradient at surface of electrode, in kilovolt/cm; R, r = radius of outer, inner, cylinder in cm; g_o, $g_c = g_x$ observed, g computed. The * denotes where R/r becomes less than 3.5.

Unit of r = 1 cm; of P. D. = 1000 volt; of g = 1000 volt/cm (R = 3.81 cm).

r	P. D., max.	g_o	g_c
0.238	84.0	127.7	123.8
0.317	85.5	108.1	112.7
0.635	98.3	86.3	90.3
0.794	106.1	85.5	84.6
0.952	103.2	78.1	80.2
1.111*	108.5	79.4	76.9
1.270	107.5	77.0	74.3
1.587	104.3	75.1	70.4
1.905	93.7	70.7	67.2
2.540	64.3	62.4	63.1

TABLE 8.—INFLUENCE OF MOISTURE ON DIELECTRIC STRENGTH

Kilovolt (kv) for breakdown; disks, D = 0.5 in., G = 0.2 in.; temp. 25°C; U. S. A. Oil F (13, 14)

Water, volume in 10 000	0	0.5	1.0	2.0	5.0	10.0
Kv, 60 cycles, maximum	62.3	33.5	33.4	31.7	27.3	25.4
Kv, constant voltage	61.5	34.7	34.3	30.2	24.7	23.0

Ryan (17), Tobey (23), Peek (13, 14, 15), and others (11, 16, 2) show that moisture in very small quantities decreases the dielectric strength of insulating oil.

Hirobe (8), McLaughlin (9), Stern (22), Spath (21), and Schroter (19) agree experimentally that moisture has little effect on the dielectric strength of the purest oils. The potent causes of low dielectric strength are fibers and dust particles in the oil.

Their effect is increased by the presence of moisture (*cf.* Table 9). For methods and effect of cleaning electrodes, *see* (8).

TABLE 9.—DIELECTRIC STRENGTH: EFFECT OF CLEANING AND DRYING THE OIL (19)

F = effective field strength at which breakdown occurs

Unit of F = 1000 volt/cm; of $\%\Delta = 1\%$.

Condition of oil*	F	$\%\Delta$
As delivered	48.5	75
Filtered through 4 mm clay wall	115.0	50
Centrifuged	124.0	30
Filtered through ordinary filter paper	163.0	35
After prolonged drying by heat	184.0	40
Prolonged drying by heat and filtered once through celloid filter	232.0	8
As in preceding, but filtered twice	332.0	7

* Each line of the table is complete in itself; tests were not successive.

TABLE 10.—RESISTIVITY (R) AND DIELECTRIC STRENGTH (S) OF DRY OIL: VARIATION WITH TEMPERATURE (23)

R is expressed in terms of the resistance between disks, D = 4 in., G = 0.44 in.; S in terms of the effective breakdown P. D. between spheres, D = 0.5 in., G = 0.15 in. Approximately $S = S_{25} - 0.13\ (t - 25°)$ kilovolt (1); t = temperature, °C; S_{25} = value of S at 25°C.

Unit of S = 1000 volt; of $R = 10^6$ ohm; of t = 1°C.

Temperature (t)	30	40	50	60	70	80	90°C
Strength (S)	33	35	36	37	38	39	41
Resistivity (R)			1225	960	570	360	250

LITERATURE

(For a key to the periodicals see end of volume)

(1) Silsbee, *66*, **21**: 397; 21. (2) Armstrong, *107*, **62**: 1322; 13. (3) Digby and Mills, *46*, **28**: 769; 09. (4) Crussard, *106*, **13**: 443; 23. (5) Everest, *121*, **87**: 702; 21. (6) Hayden and Eddy, *129*, **41**: 102; 22. (7) Hayden and Eddy, *129*, **41**: 394; 22. (8) Hirobe, *Elect. Technical Laboratory Report*, No. **25**: Sect. 3 (Japan). (9) McLaughlin, *121*, **86**: 325; 21.

(10) Moody, W. S., General Electric Co., Schenectady, New York, *O.* (11) Moody and Faccioli, *129*, **28**: 769; 09. (12) National Electric Light Association, *Bulletin*, June, 1910. (13) Peek, *129*, **35 II**: 783; 16. (14) Peek, *120*, **18**: 821; 15. (15) Peek, *Dielectric Phenomena in High Voltage Engineering*, Chap. IV. New York, McGraw-Hill Book Company, Inc., 1915. (16) Rodman, *114*, **20**: 51; 23. (17) Ryan, *129*, **30**: 1; 11. (18) Schendell, *101*, **37**: 242; 18. (19) Schroter, *125*, **12**: 67; 23.

(20) Skinner, C. E., Westinghouse Electric and Manufacturing Co., East Pittsburgh, *O.* (21) Spath, *125*, **12**: 331; 23. (22) Stern, *101*, **43**: 140; 22. (23) Tobey, *129*, **29 II**: 1189; 10. (24) Tesche, *97*, **5**: 233; 24. (25) Wedmore, *121*, **87**: 702; 21.

INSULATING SOLIDS

F. MALCOLM FARMER

Because of inherent variations in composition and physical condition of both manufactured and natural products, no single value can be assigned to any of the various properties of solid electrical insulators. Furthermore, the value obtained in the measurement of many electrical properties depends upon the method employed and the conditions under which the test was made. For example, in determinations of either the volume or the surface resistivity, the result will depend upon the voltage employed, the duration of its application, temperature, humidity, etc. No standard procedure has yet been established for determining the various quantities. The available data have been obtained under a great variety of conditions and with many different procedures (which, in most cases, are not fully stated) so that the selection of values for these tables has been a matter of judgment, the aim being to select those values which it is believed are most typical and, consequently, the most reliable for general application. Some of the principal sources from which data have been obtained are named on p. 311. Discussions of some of these variable factors will be found in (1, 3, 9); for bibliographies, *see* (2, 18, 19).

Par suite des variations inhérentes à la composition et aux conditions physiques des produits manufacturés et naturels, il n'est possible d'assigner une valeur unique à aucune des propriétés variées des isolants électriques solides. De plus, les valeurs obtenues par les mesures de plusieurs propriétés électriques dépendent de la méthode employée et des conditions dans lesquelles l'essai a été effectué. Par exemple, dans les déterminations de la résistivité du volume et de la résistivité superficielle, le résultat dépend du voltage employé, de la durée de l'application, de la température, de l'humidité, etc. Aucune procédure type n'a encore été établie pour déterminer les quantités variées. Les données disponibles ont été obtenues suivant une grande variété de conditions et avec des procédures différentes (qui, dans la plupart des cas, ne sont pas complètement spécifiées); de sorte que la sélection des valeurs pour ces tables a été une question de jugement, l'objectif étant de choisir celles des valeurs qui étaient présumées les plus typiques et par conséquent les plus dignes de confiance pour l'application générale. Quelques unes des sources principales dont ont été tirées les valeurs sont indiquées à la page 311. On trouvera les discussions relatives à quelques uns des facteurs variables à (1, 3, 9); en ce qui concerne la bibliographie, *voir* (2, 18, 19).

Entsprechend der eigenartigen Änderung in der Zusammensetzung und des physikalischen Zustandes der festen Isolatoren, kann man sowohl den künstlichen als auch den natürlichen Produkten keinen einzelnen Wert ihrgend welcher der verschiedenen Eigenschaften zu ordnen. Es hängt ferner der gemessene Wert vieler elektrischer Eigenschaften von der angewandten Methode und den Bedingungen unter welchen die Probe ausgeführt worden ist, ab. Z. B. bei der Bestimmung des Oberflächen Widerstandes wird das Ergebnis von der angewandten Volt-Zahl, der Dauer der Einwirkung, der Temperatur, der Feuchtigkeit u. s. w. abhängen. Bis jetzt ist keine diesbezügliche Standardmethode zur Messung der verschiedenen Grössen aufgestellt. Die erreichbaren Daten sind unter den verschiedenen Bedingungen und sehr verschiedenen Prüfungsvorgängen (die in vielen Fällen auch nicht ganz angegeben sind) erhalten. Es ist deshalb diese Auswahl nach besonderem Urteil gemacht worden, mit dem Ziel im Auge, diejenigen Werte herauszugreifen, die man als die typischesten ansieht und demzufolge allgemein am zuverlässlichsten sein werden. Einige der hauptsächlichsten Quellen aus denen die Werte geschöpft wurden sind Seite 311 angegeben. Zur Diskussion einiger der veränderlichen Faktoren, (1, 3, 9), Literatur dazu, *siehe* (2, 18, 19).

A causa di alterazioni nella composizione e nello stato fisico sia dei prodotti artificiali che naturali, non si può assegnare un valore determinato alle varie proprietà degli isolanti elettrici solidi. Inoltre, il valore ottenuto nella misura di molte proprietà elettriche dipende dal metodo impiegato e dalle condizioni nelle quali la prova è stata fatta. Per espempio, quando si determina la resistività di volume o di superficie, il risultato dipende dal voltaggio adoperato, dalla durata di applicazione, dalla temperatura, dalla umidità, ecc. Non è stata ancora stabilita una procedura uniforme per determinare le varie grandezze.

I dati disponibili sono stati ottenuti in condizioni molto diverse e con metodi differenti (il più delle volte neppure completamente indicati); per modo che la scelta dei valori per queste tabelle è stata fatta con un certo arbitrio e con lo scopo di raccogliere i valori ritenuti più tipici e quindi suscettibili di una più generale applicazione.

Alcune delle fonti principali dalle quali i dati sono stati tratti sono indicate a pag. 311. Per la discussione di alcuni dei fattori variabili si veda (1, 3, 9) e per le indicazioni bibliografiche si veda (2, 18, 19).

Manufacturers Mentioned in this Section

M1	Alberene Stone Company, New York, N. Y.
M2	Chicago Mica Company, Chicago, Ill.
M3	Continental Fibre Company, Newark, Del.
M4	Electrose Manufacturing Co., Brooklyn, N. Y.
M5	Garfield Manufacturing Co., Garfield, N. J.
M6	General Electric Co., Schenectady, N. Y.
M7	General Insulate Co., Brooklyn, N. Y.
M8	Hemming Manufacturing Co., Garfield, N. J.
M9	Irvington Varnish and Insulator Co., Irvington, N. J.
M10	Mica Insulator Co., Schenectady, N. Y.
M11	Minerallac Electric Co., Chicago, Ill.
M12	Mitchell-Rand Mfg. Co., New York, N. Y.
M13	National Vulcanized Fibre Co., Wilmington, Del.
M14	Spaulding Fibre Co., Inc., Tonawanda, N. Y.
M15	D. M. Stewart Manufacturing Co., Chattanooga, Tenn.
M16	Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

TABLE 1.—INDEX AND DESCRIPTION OF MATERIALS

Glass, *v.* p. 87, porcelain, *v.* p. 66, rubber and rubber products, *v.* p. 254, phenol condensation products, *v.* p. 296

I. Bituminous, Wax and Molded Materials

INDEX No.

1. Ambrion.—A molded product (German). Asbestos, impregnated with a pitch or rosin binder. Several grades—some fireproof, some limited to 80 to 100°C.

2. Asphalt.—Various grades known as bitumen, byerlite, elaterite, gilsonite, manjak, and mineral pitch. A black, natural product found in various parts of the world. Used extensively as base for insulating varnishes, for impregnating insulating materials, and (in Europe) for insulating wires and cables (instead of rubber). Hard at ordinary temperatures, plastic at 40–60°C, melts at 100–200°C, depending upon purity.

3. Beeswax.—The secreted substances of which the bee's honeycomb is constructed; yellow; agreeable odor and taste. Solid at ordinary temperatures, plastic when warm, melts at 62–64°C.

4. Ceresin.—A yellow or white wax made by purifying and bleaching ozokerite (*see* 10). Used extensively in manufacture of insulating compounds.

5. Electrose.—Trade name for a product manufactured and molded by M4; working temperature limit, about 90°C.

6. Gummon.—Trade name for a coal tar and asbestos product manufactured and molded in desired shape by M5. Black, hard, dense, not easily drilled or sawed, can be highly polished, and will withstand 200°C indefinitely.

7. Hemit.—Trade name for a coal tar and asbestos product manufactured and molded in desired shape by M5. Hard, dense, not easily drilled or sawed; withstands temperature of 600 to 800°C. Grade "B" is gray and hygroscopic; grade "A" is impregnated, making it black and more nearly waterproof.

8. Insulate.—Trade name for a mineral product manufactured and molded in desired shape by M7. Non-hygroscopic; maximum working temperature, 70°C.

9. Minerallac.—Trade name for asphaltic base insulating material manufactured by M11 in various grades for different applications (principally cable joints, cable terminals, etc.). Some grades semi-liquid, others semi-solid at 25°C. Moisture-proof.

10. Ozokerite (*See* Ceresin).—A natural, mineral wax material, usually associated with rock salt or gypsum; found throughout the world, but principally in Galicia. Is probably paraffin resulting from natural decomposition of petroleum. Natural color brown or black, but white when purified; melts at 110°C.

11. Paraffin.—Translucent, more or less colorless wax material obtained in the distillation of petroleum. Various commercial grades; melts at 45 to 80°C, depending upon grade; unaffected by ordinary acids and alkalies.

11(*a*). Petrolatum.—A neutral and purified residue derived by distillation of petroleum. Three forms—liquid, soft, and hard. The soft form is a grease similar to vaseline and is used extensively as an impregnating material for paper insulated cables; melts about 50–55°C; electrical properties vary greatly with the purity.

12. Rosin.—A variety of resin. Product of distillation of oil of turpentine from crude turpentine.

13. Tegit.—Trade name for a coal tar and asbestos product manufactured and molded in desired shape by M8. Uses limited to 200°C.

II. Fibrous Materials and Fiber Products

14. Cellulak.—Trade name for laminated paper insulation manufactured by M9. Processed under heat and pressure. Hard, tough, readily machined.

15. Cellulose.—A carbohydrate similar in chemical composition to starch. When pure, is amorphous and white; is basis of practically all fibrous insulating materials. Unsized, well bleached linen paper is practically pure cellulose.

16. Conite.—(*See* 18.) Trade name for a thin, hard, vulcanized fiber prepared by M3 with special care to insure its freedom from acid.

17. Empire Cloth.—Trade name of M10 for various varnished cloths having coatings of linseed-oil base (*see* 29).

18. Fiber, Vulcanized.—Also known as fiber, horn fiber, hard fiber, indurated fiber, leatheroid, etc. Made by treating layers of paper stock made from pure cotton cellulose (old cotton rags free from dirt, oil, and grease) with concentrated acids or zinc chloride. Compressed under great pressure to desired thickness; soaked and washed in water for long periods to remove acid or chloride; air dried, pressed in steam-heated presses and calendered to final thickness. Hard, tough, bone-like, hygroscopic, absorbs water readily, disintegrates with strong acids, unaffected by organic solvents and oils, becomes brittle at 80 to 100°C sustained temperature, readily machined, various colors. Manufactured by M3, M13, M14, and others.

19. Fish Paper.—Also known as tarpon paper, leather paper, leatheroid, and fiberoid. Prepared in similar manner to vulcanized fiber using cotton rag stock. Flexible; dark gray; thickness about 0.1 to 1.2 mm.

20. Kobak Cloth.—Trade name (M10) for black varnished cambric (*see* 28).

21. Kraft Paper (For cables).—Unsized paper made from wood pulp stock by sulfate process (21*a*). Hygroscopic. Used extensively in Europe in high tension power cables where it is impregnated with an insulating material (21*b*) after application to conductors.

22. Manila Paper (For cables) (*See* 26).—Unsized paper made from old manila rope (22*a*). Used extensively in America on high tension power cables where it is impregnated with an insulating material (22*b*) after application to conductors.

23. Paraffined Paper.—Bond paper coated or saturated with hot paraffin. Used extensively in low voltage electric condensers.

24. Pressboard.—Also known as fullerboard and presspan (in Europe). A high grade cardboard paper made from cotton rag and paper clipping stock. Hygroscopic.

25. Pressboard, Treated.—Pressboard dried (sometimes in vacuum) and varnished (25*a*) or boiled in mineral oil (25*b*) to make it moisture-proof and to increase dielectric strength.

26. Rope Paper (*See* 22).—Paper made from old rope stock (hemp and jute). Compressed but unsized. Hygroscopic.

27. Varnished Cloth (*See* 17, 20, 28, 29, 30, 31 and 33).—Also known as treated cloth. Thin cotton, linen, or silk cloth dried and coated with various thicknesses of various kinds of liquid insulating materials so applied and treated as to produce a smooth, sheet insulating material which is flexible, tough, and uniform in thickness. Great variety manufactured (some under trade names) by M6, M9, M10, M12, M16, and others.

28. Varnished Cambric, Black (*See* 27).—Coated with an asphaltic material and an oxidizing oil. Black, oil-proof, but not moisture-proof; is more flexible, and remains flexible longer, than the yellow cambric; is, also, more resistant to action of corona discharge (*i.e.*, ozone and nitric acid). Thickness, 0.1 to 0.4 mm.

29. Varnished Cambric, Yellow (*See* 27).—Also known as varnished muslin, oiled cambric and oiled muslin. Coated with linseed oil and a resin; filler is yellow and translucent; absorbs moisture, but is oil-proof. Thickness, 0.1 to 0.4 mm.

30. Varnished Duck or Canvas, Black.—Same as black varnished cambric except that the base is duck or canvas. Thickness, 0.4 to 0.8 mm.

31. Varnished Duck or Canvas, Yellow.—Same as yellow varnished cambric except that the base is duck or canvas. Thickness, 0.4 to 0.8 mm.

32. Varnished Paper.—Paper [cotton (bond), linen, and hemp (manila) stock papers, also fish paper] treated like varnished cloth. Treatment greatly increases resistance to moisture absorption and increases dielectric strength (*ca.* 25%).

33. Varnished Silk.—Same as yellow varnished cambric except that base is silk. Thickness, 0.05 to 0.2 mm.

34. Woods, Hard.—Maple, hickory, cherry, ash, and yellow pine principally used. Dried (34*a*) and impregnated with oil (34*b*), paraffin (34*c*) or rosin, either by boiling until evolution of gas ceases or by impregnation under pressure after drying *in vacuo*.

III. Mineral Materials

35. Alberene (*See* soapstone, 47).—A fine grade of natural soapstone uniformly gray in color, free from metallic veins. Marketed by M1. Does not split or shale under intense local heating, such as electric arc. Stated to be capable of withstanding 1300 to 1600°C. Soft, easily machined, sawed, and drilled.

36. Asbestos Paper.—Soft, flexible sheet material made from fibrous asbestos with 15 to 20% cotton. Very hygroscopic.

37. "Lava."—A form of talc (hydrated magnesium silicate), similar to pumice, which, while in its natural state, is formed or machined to desired shape and then baked at 1100°C, making it very hard. It is then not affected by any lower temperature; very porous, but dimensions not affected by absorption of water; slightly affected by HCl, but not by other ordinary acids and alkalis; very light yellow.

38. Lavite.—Trade name for patented product manufactured by M15. Similar to "lava." Compares with glass in hardness; unaffected by temperatures up to 1000°C, or by ordinary acids or alkalis; porous; very light yellow.

39. Marble.—Crystalline limestone which takes a high polish. Pure marble is white; colored marbles contain impurities, such as iron oxide. Much used for electrical switchboards where, because of porosity, it is frequently impregnated with insulating material to increase dielectric strength; often stained black (called marine finish) to prevent discoloration due to oil staining, etc.

40. Mica.—A laminated mineral composed of crystallized anhydrous silicate of aluminum and potash, or soda. Pure mica is transparent, but frequently colored by salts deposited between laminations. Laminations easily separated so that mica can be split down to 0.005 mm. In natural state it is not uniform in quality, is not flexible, and largest pieces are relatively small; hence it is reconstructed, by splitting into thin laminations and cementing together the small pieces, with suitable binders, to form continuous sheets of various thicknesses, which are marketed under trade names (*see* 41 to 45 inc.). Powdered and flaked mica is used in conjunction with suitable binders to make molded insulations (a substitute for hard rubber, etc.). Properties vary considerably with impurity content, and with sources from which obtained, the principal of which are India, Africa, Canada, and United States. The clear variety has highest dielectric strength.

41. Mica Cloth.—Reconstructed mica (*see* 40) with special binder and backed with cloth. Flexible (to various degrees); thickness, 0.1 to 3 mm.

42. Mica Bond.—Trade name for mica cloth, mica paper, and mica plate products manufactured by M2 (*see* 41, 43 and 44).

43. Mica Paper.—Reconstructed mica (*see* 40) with special binder and backed with Japanese paper. Flexible; thickness, 0.25 to 0.5 mm.

44. Mica Plate.—Reconstructed mica (*see* 40) with shellac binder. Not flexible; thickness, 0.25 to 3 mm.

45. Micanite.—Trade name for mica cloth, mica paper, and mica plate products manufactured by M10 (*see* 41, 43, 44).

46. Slate.—Natural rock of clay or mica composition with natural cleavage. Formed by geological processes involving high temperature and pressure. Principal components are silica and alumina with some iron oxides, lime, magnesia, potash, and soda. Slate for electrical purposes is principally the mica variety from Vermont (purple to green), Maine, and Pennsylvania; the last two are dark gray (called black slate). Is hygroscopic and contains relatively large amount of water of composition, hence thorough drying followed by oil treatment or coating with insulating varnish or enamel greatly improves insulating value. Easily machined; takes good polish.

47. Soapstone (*See* Alberene, 35).—A natural, soft stone; a variety of talc. (Also called steatite.) Slightly soapy or oily to touch. Easily machined, drilled, and sawed. Hygroscopic. Withstands temperatures of the order of 1500°C.

IV. Gum Materials

48. Amberite.—(Ambroid.) Compressed scrap amber (fossilized vegetable resin). Equal to native amber in volume resistivity, but surface must be kept clean for high surface resistivity.

49. Copal.—A resinous substance which, when dissolved in alcohol, oil of turpentine, or linseed oil, makes a colorless varnish. Very inflammable; brittle when cold.

50. Shellac.—A crude form of lac, a resinous gum exuded by an East Indian insect, also obtained from sap of certain trees. Shellac dissolved in alcohol is extensively used as an insulating varnish which on drying forms hard, protective coating. Brittle, brown, hygroscopic.

V. Miscellaneous Materials

51. Enamel.—A hard, smooth, and flexible coating baked on magnet wire as substitute for cotton and silk, or in addition thereto. Composition more or less a manufacturing secret, but stated in some cases to be stearin pitch, cellulose acetate, or cellulose nitrate. Applied by running wire through thin bath and rapidly drying each coat by passing through hot oven. Occupies less space than cotton and silk, has greater thermal conductivity; moisture-proof and mineral oil-proof, but more or less soluble in vegetable oil, animal oil, alcohol, turpentine, and coal tar solvents; withstands 100°C indefinitely; breaks down electrically at 300°C.

52. Galalith.—German product manufactured from skim-milk heated with caustic soda and precipitated with acid. The precipitate, in sheet and plate form, is dried, saturated with formaldehyde, and again dried and pressed. Used as substitute for ivory. Translucent and yellowish white; readily shaped, after softening in hot water; rather hygroscopic.

53. Ivory.—Tusks of the elephant, walrus, etc. Hard and white.

TABLE 2.—ELECTRICAL PROPERTIES

Volume resistivity (*see* Vol. I, p. 41) = $R_v \times 10^n$. Surface resistivity (*see* Vol. I, p. 41) = $R_s \times 10^n$. Power factor = cos φ. Temperature = 18 to 25°C except as indicated. Unit of: R_v = 1 ohm-cm; R_s = 1 ohm; frequency = 1 cycle/sec; dielectric constant = 1 cgse (essentially, air = 1); thickness = 1 mm.

Index No.	Material	Resistivity				Dielectric constant		Dielectric strength		Power factor	
		R_v	n	R_s	n	Frequency	Constant	Thickness	Kv/mm	Frequency	cos φ
35	Alberene	(*See* Soapstone)									
48	Amberite (ambroid)	5	16	2	15		2.8*				
1	Ambrion	2	13					0.8	6		
36	Asbestos paper	2	5					1.0	4		
2	Asphalt						2.7	2.0 to 3.0	1 to 2		
3	Beeswax	5 to 20†	14	8	14§		1.85		10		
14	Cellulak							3.0	16		
15	Cellulose	1	9				3.9 to 7.5				
4	Ceresin	5	18	8	16						
16	Conite							0.12	15		
49	Copal							3.0	3		
5	Electrose	1 to 15	14	1 to 1000	12			3.0	25		
51	Enamel	1	14					0.02	20 to 25		
18	Fiber, vulcanized	5 to 20	9	1	10	90 to 650‡	5.0 to 7.5	1.0	8 to 18	90 to 650‡	0.045
								3.0	5 to 12		
								6.0	4 to 9		
								12.0	3 to 6		
19	Fish paper							0.1 to 1.2	10 to 15		
52	Galalith	1	10	6	10				6 to 8.5		
6	Gummon	3	12	3	12				3		
7	Hemit	1	10	1	10				2		
8	Insulate (No. 2)	8	15	4	14			10	1.5 to 2		
53	Ivory	2	8	6	9						
21*a*	Kraft paper							0.15 to 0.2	4 to 6		
21*b*	Kraft paper					60	3.5	0.15 to 0.2	30 to 40	60	0.005
37	"Lava"								3 to 10		
38	Lavite	5 to 25	8	1	11				8 to 10		
22*a*	Manila paper					920 to 4600	2.0	0.15 to 0.2	3 to 5	920 to 4600	0.007 to 0.008
22*b*	Manila paper	2	9			60	3.5	0.15 to 0.2	20 to 30	60	0.005
34*b*	Maple, oiled							25	3.0		
34*c*	Maple, paraffined	3	10	8	11		4.1	15	4.5		
39	Marble	1 to 100	9	6	9	60	8.3	25	2 to 4	90 to 650	0.003 to 0.05
						90 to 650‡	9.5 to 11.5				
40	Mica	1 to 200	15	1 to 3000	10		4.5 to 7.5	0.05	80 to 200	800	0.001 to 0.07
								0.3	40 to 120		
								0.6	25 to 75		
41, 43	Mica, cloth and paper							0.1 to 3	40 to 15		
44	Mica plate							0.1 to 3	50 to 25		
9	Minerallac					60	2.7	0.5	40		
10	Ozokerite	5	14				2.2	0.6	45		
11	Paraffin	1 to 500	16	1†	16		1.9 to 2.3		15 to 50		
23	Paraffined paper								40 to 60		
11*a*	Petrolatum	2 to 10	12			60	2.2	2.5	20	60	0.005
24	Pressboard	1	9					0.2 to 3.0	12 to 5		
25*a*	Pressboard						2.9	0.5 to 3.0	15 to 10		
25*b*	Pressboard						4.5	0.5 to 3.0	30 to 20		
12	Rosin	5	16	7	14		2.5				
50	Shellac	1	16	7	13		2.7 to 3.7				
46	Slate	1	8	1	8		6.0 to 7.5	25	0.2 to 0.4	950	0.086
47	Soapstone	6	8					25	1.0		
13	Tegit	2	12	7	11				2		
28	Varnished cambric b							0.1 to 0.4	70 to 50		
29	Varnished cambric y						3.5 to 5.5	0.1 to 0.4	60 to 45		
30	Varnished canvas b							0.4 to 0.8	12 to 30		
31	Varnished canvas y							0.4 to 0.8	25 to 10		
32	Varnished paper								10 to 25		
33	Varnished silk							0.05 to 0.2	70 to 45		
34*a*	Woods, hard, dried	1 to 4000	10			90 to 650‡	3.0	25	0.4 to 0.6	90 to 650‡	0.025

* Amber.

† Has very large negative temperature coefficient, R_v at 30° being about 1⁄16 of that at 90°C.

‡ Kilocycles.

§ Fresh surface. Deteriorates rapidly.

TABLE 3.—MECHANICAL AND THERMAL PROPERTIES 18 TO 25°C

Unit of: density = 1 g/cm^3; strength = 1 kg/cm^2 (for Nos. 21, 22, 28 to 33 = 1 kg per cm width); expansivity = 10^{-4} per °C; thermal conductivity = 1 milliwatt per (cm °C).

Index No.	Material	Density	Strength		Cubic expansivity	Thermal conductivity
			Tensile*	Compressive		
1	Ambrion	1.4 to 1.8	150	190		
36	Asbestos paper	3.2				2.5
2	Asphalt	1.04 to 1.40			5 to 7	
3	Beeswax	0.96				0.35
4	Ceresin	0.75				
16	Conite		550 to 1100			
18	Fiber, vulcanized	1.2 to 1.5	625 to 1050	1800 to 3200	0.27	
52	Galalith	1.3				
6	Gummon		40	40		
7	Hemit		140	110		
53	Ivory	1.9				
21*a*	Kraft paper	0.8	500 to 700†			
21*b*	Kraft paper		400 to 500†			
37	"Lava"	2.5 to 2.7		1400 to 2100	Negligible	8
38	Lavite	2.5 to 2.7	400 to 800‡	1400 to 2100		
22*a*	Manila paper	0.8	700†			1.2
22*b*	Manila paper		500†			1.7
39	Marble	2.5 to 2.8	100 to 200‡	600 to 1500	0.3 to 0.6	30
40	Mica	2.7 to 3.1				3.6
41, 43	Mica, cloth and paper					1.0 to 1.6
9	Minerallac	1.0			7	
11	Paraffin	0.87 to 0.94			3 to 6	2.6
25*a*	Pressboard					1.4
50	Shellac					2.5
46	Slate	2.7 to 2.9	550 to 700‡	700 to 1000	0.15 to 0.3	20.0
47	Soapstone	2.6 to 2.8		550		
13	Tegit		85	80		
28, 29	Varnished cambric		8 to 10§			2.5
30, 31	Varnished canvas		10 to 20§			
33	Varnished silk		2 to 3§			
34	Woods, hard, dried	0.6 to 0.9	500 to 1000	250 to 550	0.1 to 2.0	1.5 to 2.5

* For Nos. 38, 39, 46 data are for transverse strength, as noted.

† In machine direction (*i.e.*, lengthwise of majority of fibers). Strength crosswise about half as great.

‡ Modulus of rupture (transverse strength)—probably somewhat higher than tensile strength.

§ Kg per cm of width. Stress in direction of warp. About half as strong when stress is in direction of filler.

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(For a key to the periodicals see end of volume)

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THERMAL INSULATING MATERIALS FOR MODERATE AND LOW TEMPERATURES

F. H. Schofield and J. A. Hall

This section covers the various types of commercial insulating materials, associated structural materials and some miscellaneous materials. For the second group of materials reference should also be made to the sections of I. C. T. dealing with these classes of materials.

In the tables below the various materials are assembled in groups which are arranged approximately in the ascending order of the lowest thermal conductivity of any material of the group.

The thermal conductivity, k, is given in 10^{-3} joule cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$, one unit of which = 0.239×10^{-3} g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$, = 0.192×10^{-3} BTU ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$. *See also* vol. I, p. 25 for other conversion factors.

Cette section comprend les types variés des matières isolantes du commerce, les matériaux de construction associés, et quelques matières diverses. En ce qui concerne le deuxième groupe de matières, il faut aussi consulter les sections des I. C. T. qui traitent de ces classes de matières.

Dans les tables ci dessous, les matières variées sont arrangés en groupes approximativement dans l'ordre ascendant de la conductibilité thermiqué la plus basse du groupe.

La conductibilité thermique, k, est donnée en 10^{-3} joule cm^{-2} sec^{-1}(°C, cm^{-1})$^{-1}$, une unité de celle-ci = $0{,}239 \times 10^{-3}$ g-cal cm^{-2} sec^{-1}(°C, cm^{-1})$^{-1}$, = $0{,}192 \times 10^{-3}$ BTU ft.$^{-2}$ sec^{-1}(°F, in.$^{-1}$)$^{-1}$. Voir vol. I, p. 25 pour d'autres facteurs de conversion.

Dieser Abschnitt behandelt die verschiedenen Typen von handelsüblichen Isoliermaterial, damit zusammenhängendem Material und einigem verschiedenen anderen. Für die zweite Gruppe der Materialien soll auch in dem Teil der I. C. T. nachgeschlagen werden, die diese Klasse von Materialien behandeln.

In der unteren Tafel sind die verschiedenen Materialien in Gruppen angeordnet und zwar ansteigend von dem kleinsten Wert der Gruppe für die thermische Leitfähigkeit.

Die thermische Leitfähigkeit, k, ist gegeben in 10^{-3} Joule cm^{-2} sec^{-1}(°C cm^{-1})$^{-1}$, deren Einheit = $0{,}239 \times 10^{-3}$ g-cal cm^{-2} sec^{-1}(°C, cm^{-1})$^{-1}$, = $0{,}192 \times 10^{-3}$ BTU ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$. Umrechnungsfaktoren, Bd. I, p. 25.

Questa sezione comprende i diversi tipi di materiali isolanti che si trovano in commercio, i prodotti analoghi per costruzioni e materiali varii. Per il secondo gruppo di materiali, si consultino anche le sezioni della I. C. T., che trattano di queste classe di materiali.

Nelle tabelle seguenti, i diversi materiali sono disposti in gruppi approssimativamente secondo l'ordine della conduttività termica, crescente dalla più bassa del gruppo in su.

La conduttività termica, k, e data in 10^{-3} joule cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$, di cui una unità = $0{,}239 \times 10^{-3}$ g-cal cm^{-2} sec^{-1} (°C, cm^{-1})$^{-1}$, = $0{,}192 \times 10^{-3}$ BTU ft.$^{-2}$ sec^{-1} (°F, in.$^{-1}$)$^{-1}$. Vedi inoltre tomo I, p. 25, per altri fattori di conversione.

Thermal Conductivity

Material	Bulk density, g/cm³	t°C	k	Lit.
Air	0.00129	0	0.23	(19, 22)
Silk			0.40	(30)
Scrap from spinning mill	0.10_1	0	0.44_2	(36)
		50	0.52_4	
		100	0.59_5	
Braided	0.14_7	0	0.45_5	(36)
		50	0.54_7	
		100	0.60_5	
Scrap from spinning mill	0.10_0	−200	0.23_2	(15)
		−150	0.31_4	
		−100	0.37_2	
		− 50	0.43_7	
		0	0.49_5	
		50	0.55_9	
Fabric		40	0.46	(59)
"Calorox" (fluffy mineral matter)	0.064	30	0.31_8	(52)
Slag wool (mineral wool)	0.15	30	0.42	(14, 52)
	0.20	30	0.45	
	0.25	30	0.48	
	0.30	30	0.52	
With binder, waterprf. Rock cork	0.25	30	0.50	(52)
Cork	*v. infra* p. 315.			
Ashes (soft wood)		20	0.32	(32)
Rubber, hard sponge, rigid	0.087	25	0.34	(14)
	0.090	25	0.40	
	0.16	35	0.42	(55)
Cellular (expanded after vulcanizing under very high gas pressure, cells unbroken)	0.09	20	0.36	(14)
Sponge (vulcanizing rubber mixed with ammonium carbonate, cells broken)	0.22	20	0.54	(14)
Ebonite	1.19	−190	1.3_8	(29, 50, 13, 20, 10, 11, 59)
		− 78	1.5_7	
		0	1.6_0	
Soft, vulcanized	1.1	30	1.7_6	(52, 20)
Commercial, 40 % pure rubber		25	2.8_4	(59)
50 % pure rubber			2.2_1	(59)
67 % pure rubber			1.7_5	(59)
92 % pure rubber			1.6_8	(59)
100 % pure rubber (Plantation crepe)			1.3_4	(59)
Kapok, loosely packed	0.015	20	0.35	(52, 4, 28)
Tightly packed			0.50	
Wool	0.09	0	0.37_2	(26)
		60	0.49_7	
Pure	0.09	30	0.36_4	(9)
Pure, very loose packing	0.04	30	0.42_3	
Slightly greasy	0.14	0	0.38_4	(36)
		50	0.48_8	
		100	0.58_2	
	0.08	75	0.77	(8)
Blankets	0.08	30	0.43	(42)
Cotton, tightly packed	0.08	−150	0.37_8	(36, 15)
		0	0.55_8	
		150	0.75_5	
Fabric		40	0.80	(59)
Cotton wool, tightly packed	0.08	30	0.42	(52, 23)
Glass wool	0.22	50	0.41_8	(41)
		100	0.50_0	
		200	0.65_1	
		300	0.81_3	
Wood fiber, shredded, soft, flexible	0.09	35	0.42	(55)
Rice paper		40	0.46	(59)
Blotting paper		20	0.63	(30)
Corrugated cardboard 5 layers per in.		20	0.63	(4)

THERMAL CONDUCTIVITY.—(*Continued*)

Material	Bulk density, g/cm³	t°C	k	Lit.
Pasteboard	0.69	30	0.71	(52)
Cardboard, various		50	1.7–3.4	(59)
Skeleton cardboard bricks (Ewing's)		20	0.99	(14)
Felted flax fibers	0.18	30	0.47	(52)
Flax and paper lining for steel railway cars		30	0.45 to 0.65	(52)
Felt, asphalt-impregnated	0.88	30	1.01	(52)
Wood felt, flexible paper stock	0.33	30	0.52	(52)
Felted vegetable fibers	0.18	30	0.47	(52)
Wool felt	0.15	40	0.63	(50)
	0.33	30	0.52	(52)
Hair felt	0.27	30	0.36	(52)
Balsa wood, across grain	0.11_8	30	0.45	(52, 59)
Balsa wood, waterproofed	0.12_8	30	0.52	
Balsa wood, medium	0.14_3	30	0.55_3	(52)
Balsa wood, heavy	0.33	0	0.83_9	(52)
Pseudo balsa wood (⊥ grain)	0.25		0.67	(59)
Pseudo balsa wood (‖ grain)			1.21	(59)
Cottonseed hull fiber, loose pack	0.071	30	0.45	(52)
Eucalyptus bark fiber		0	0.45	(14)
Saragossa grass	0.15	30	0.45	(14)
	0.22	30	0.49	
Straw fibers, pressed	0.14	0	0.45_4	(25)
		20	0.46_6	
Eelgrass	0.25	30	0.46	(52)
Ceiba wood, ⊥ grain, untreated	0.11	30	0.47	(52)
Curled cattle hair, loose, soft, flex	0.088	35	0.48	(55)
Sugar cane fiber (bagasse) board	0.25	35	0.54	(55)
Pressed wood pulp board	0.19	30	0.43	(52)
Waterproof lith board (slag wool, veg. fiber, waterprf. binder)	0.20	30	0.55	(52)
Bulrush in cloth	0.14	30	0.49	(52)
Kingia australis (shredded fiber from outside layer of trunk)	0.13	30	0.49	(14)
Solid from outside		30	0.76	
Solid from inside		30	1.0_6	
Horsehair, compressed	0.17_2	20	0.50_9	(26)
		65	0.54_7	
Diatomite	*v.*, p. 315.			
Peat, dry	0.19	30	0.52	(36)
Peat boards	0.23	20	0.58_1	(18)
	0.37	20	0.87_3	
	0.73	20	1.1_6	
Peat blocks	0.84	20	1.7_4	(18)
Charcoal	0.18	20	0.55	(4, 14, 25, 36, 38)
Sawdust, various	0.20	30	0.60	(12, 52, 36, 8)
Shavings, various	0.14	30	0.60	(52)
Leather, chamois		85	0.63	(30)
Leather, cowhide		85	1.7_6	(30)
Leather, sole	1.0	30	1.5_9	(52)
Jongdala wood (⊥ grain)		30	0.67	(14)
Jongdala wood (‖ grain)		30	1.2_0	
Asbestos, cork, straw and diatomite steam-pipe covering, dry, loose	0.41	0	0.69_8	(36)
		50	0.81_3	
		100	0.88_4	
		150	0.91_8	
		200	0.94_3	
Idem., molded with water to solid	0.69	150	1.1_6	(36)
		220	1.4_0	
Asbestos-diatomite, loose	0.55_0	50	0.94_1	(41)
	0.60_9	50	0.91_8	
	0.62_5	50	0.86_0	
	0.66_3	50	1.0_6	
	0.60_9	50	0.91_8	
	0.60_9	100	0.93_0	
	0.60_9	200	0.95_3	
	0.60_9	300	0.96_5	

THERMAL CONDUCTIVITY.—(*Continued*)

Material	Bulk density, g/cm³	t°C	k	Lit.
Asbestos, wool	0.40	0	0.90	(15, 36, 4)
	0.50	0	1.3_6	
	0.60	0	1.7_5	
	0.70	0	1.9_7	
	0.40	−100	0.68	
	0.40	0	0.90	
	0.40	100	1.0_1	
Asbestos, slate	1.8	50	2.2	(15)
Wood (asbestos and cement compressed)	2.0	50	3.9	(52)
Pipe coverings of asbestos felt corrugated asbestos paper, etc	0.3 to 0.5	50	0.8 to 1.0	(52, 54, 31)
Paper, thin layers with organic binder	0.50	30	0.71	(52)
Paper		20	1.6	(30, 50)
Corrugated	0.14	30	0.66	(52)
Asbestos car lining	0.43	30	0.68	(52)
Asbestos-and-plaster blocks	0.29	30	0.81_5	(52)
	0.47	30	1.3_0	
Fire felt, flexible (asbestos sheet)	0.42	30	0.86	(52)
Fire felt, rigid (asbestos sheet, cement coated)	0.68	30	0.92	(52)
Asbestos-diatomite-cork (loose)	0.33	50	0.81_3	(41)
	0.33	100	0.84_8	
	0.33	200	0.89_0	
Magnesia-asbestos (85 % MgO)	0.3	30	0.75	(31, 52)
Cork linoleum	0.54	20	0.80	(15)
Linoleum (dry)	1.18	0	1.7_5	(15)
		20	1.8_6	
Steel wool	0.15_2	55	0.80_3	(40)
	0.10_1	55	0.87_5	
	0.07_6	55	0.90_4	
Linen		20	0.86	(32)
Kiri wood (⊥ grain)			0.88	(59)
Pumice gravel	0.3	20	0.92	(15)
	0.6	0	1.7_5	(18)
		20	1.8_6	
Cypress wood (⊥ grain)	0.46	30	0.96	(52)
Coffee husks		30	0.98	(14)
Fuller's earth	0.53	30	1.0_1	(52)
Blast furnace slag	0.79	20	1.8_6	(18)
2 to 5 mm grain size No. 1	0.36	20	1.0_5	
3 cm grain size No. 2	0.36	20	1.5_1	
Nos. 1 and 2 mixed	0.30	20	1.2_8	
Spruce (⊥ grain)	0.41		1.1	(59)
Spruce (‖ grain)			2.2	(59)
Coal dust	0.73	30	1.1_1	(50)
		90	1.2_5	
White pine (⊥ grain)	0.50	30	1.1_3	(52)
	0.45	60	1.0_7	(50)
(‖ grain)		60	2.5_7	
Cedar (⊥ grain)	0.48		1.1_3	(59)
Virginia pine (⊥ grain)	0.55	30	1.3_8	(52, 59)
Pitch pine (⊥ grain)		30	1.4_9	(14)
Cement paper, plain (14 layers each 0.38 mm)	0.62	20	1.2_7	(50)
		50	1.3_5	
Cement paper, treated (12 layers, each 0.46 mm)	1.0_2	20	1.5_6	
		50	1.6_5	
Cement wood (sawdust and Portland cement)	0.71	0	1.2_8	(36)
		20	1.3_9	
	0.82	20	1.7_4	
Snow	0.50	0	$1._3$	(22)
	0.11	0	1.0_7	(24)
	0.45	0	0.49	
	0.24	0	1.67	(37)
	0.25	0	1.8_8	
	0.27	0	1.34	
Mahogany (⊥ grain)	0.55	30	1.3_0	(52)
			1.7	(35)
	0.70	20	1.6	(59)
(‖ grain)			3.1	(59)
Oak (⊥ grain)	0.61	30	1.3_7	(52, 59)
	0.82	0	1.9_8	(38)
		15	2.1_0	

THERMAL CONDUCTIVITY.—(*Continued*)

Material	Bulk density, g/cm³	t°C	k	Lit.
Oak (∥ grain)	0.82	12	3.49	(38)
		20	3.61	
		50	4.31	
Soil, dry		20	1.38	(30)
wet		20	6.70	
normal, including stones 2 to 7 cm	2.04	0	5.00	(15)
		20	5.28	
		70	5.82	
Garden mold, dry			2.01	(35)
Teak (⊥ grain)	0.64	0	1.63	(38)
		15	1.75	
		50	1.98	
	0.72	20	1.4	(59)
(∥ grain)	0.60	12	3.72	(38)
		18	3.84	
		50	3.94	
Fir (⊥ grain)	0.54	20	1.4	(38, 54, 59)
(∥ grain)	0.55	20	3.5	(38)
Walnut (⊥ grain)	0.65	20	1.4	(59)
(∥ grain)			3.3	
Baobab wood (∥ grain)		30	1.41	(14)
Fuller board, treated				
11 layers each 0.51 mm	1.39	20	1.61	(50)
		50	1.75	
16 layers each 0.76 mm	1.15	20	6.1*	
		50	6.9*	
4 layers each 1.42 mm	1.09	20	1.49	
		60	1.66	
2 layers each 3.1 mm	0.95	20	1.42	
		50	1.46	
Fuller board soaked in transformer oil				
3 layers each 3.18 mm	1.01	20	2.12	
		50	2.27	
		50	5.15*	
Fuller board, untreated				
15 layers each 0.38 mm	1.38	20	2.68	
		50	2.68	
7 layers each 7.6 mm	1.26	20	2.55	
		50	2.63	
16 layers each 7.6 mm	1.28	20	6.28*	
		50	6.62*	
21 layers each 0.25 mm	1.39	20	2.60	
		50	2.89	
4 layers each 1.42 mm	1.15	20	1.95	
		50	2.15	
9 layers each 1.42 mm	1.15	20	6.37*	
		50	6.90*	
3 layers each 3.18 mm	1.01	20	1.45	
		50	1.62	
Facing cement (Mg oxychloride)		0	1.46	(14)
Boxwood	0.90	20	1.51	(3)
		100	1.72	
Coke dust	1.00	20	1.51	(18)
Concrete, pumice gravel and cement	0.60	20	1.51	(15)
		30	1.63	
Pumice pebbles 9, fine sand 2, Portland cement 1	1.17	85	2.3	(8)
1: 12, air-dried 2 weeks	2.05	0	7.66	(38)
		20	8.15	
		30	8.36	
Granulated cork 3, fine sand 2, Portland cement 1	1.27	85	2.58	(8)
Slag 9, fine sand 2, Portland cement 1	1.52	85	2.96	(8)
Lime mortar, "Beffes No. 3"	1.75	90	3.51	(8)
Cement mortar, Portland No. 1	1.72	90	3.36	(8)
Portland No. 2	1.89	90	5.35	(8)
Concrete, blast furnace slag 9 pts vol., cement 1 pt. vol	0.55	50	2.21	(36)
Concrete	1.6	0	8.36	(26)
Concrete plus moisture 10 % by volume	2.3	0	12.1	
Cement mortar 10.5 mm thick, including 4 mm reinforcing metal	2.12	90	5.77	(8)
12.0 mm thick, including 3 mm reinforcing metal	1.97	90	5.97	(8)
Concrete, gravel 9, fine sand 2, cement 1	1.99	90	6.40	(8)
Concrete, gravel 9, fine sand 2, cement 1, air-dried six months	2.18	20	7.65	(15)
Portland cement	2.0	60	3.0	(36, 30)
Ash (⊥ grain)	0.74	20	1.7	(59)
(∥ grain)			3.1	(59)
Bricks, very porous, dry	0.71	20	1.74	(18)
	0.81	20	1.98	
Bricks, very porous, moisture 1.2 % volume	0.74	20	1.69	(7)
Moisture 5.8 % volume	0.79	20	2.44	
Moisture 21.5 % volume	0.94	20	3.96	
Bricks, hand-made, dry	1.54	0	3.83	(38)
Bricks, machine-made, dry	1.67	0	5.12	(38)
		40	5.35	
		80	5.46	
	1.62	50	4.81	(25)
Bricks, machine-made				
Moisture 0.8 % volume		50	4.99	(25)
Moisture 1.2 % volume		50	9.56	
Old brick masonry	1.85	0	3.82	(15)
		20	4.07	
		47	4.42	
Maple (⊥ grain)	0.72	30	1.70	(52, 50)
(∥ grain)	0.72	30	4.35	(50)
Fish paper				
21 layers each 0.25 mm	1.06	20	1.72	(50)
		50	1.81	
75 layers each 0.25 mm	1.06	20	4.80*	
		50	5.08*	
10 layers each 0.58 mm	1.03	20	2.01	
		50	2.16	
6 layers each 1.4 mm	1.01	20	2.37	
Paraffined fish paper				
30 layers each 0.18 mm	1.06	20	1.92	(50)
		50	2.02	
15 layers each 0.38 mm	1.13	20	2.17	
		50	2.19	
8 layers each 0.97 mm	1.15	20	2.07	
Powdered graphite				
100 mesh	0.48	40	1.83	(50)
40 mesh	0.42	40	3.85	
20 mesh on 40 mesh	0.70	40	11.9	
Cement paper and mica				
No. 226, 5.7 mm thick		20	1.85	(50)
		50	1.93	
No. 227, 5.05 mm thick		20	1.95	
		50	2.08	
No. 247, 5.7 mm thick		20	2.10	
		50	2.18	
No. 227, 13 mm thick		20	9.32*	
		50	9.88*	
Fish paper and mica		60	2.0	(50)
Celluloid, white	1.4	30	2.10	(52)
Fiber, vulcanized		50	2.1–3.3	(59)
Fiber, white	1.2	20	2.76	(50)
		50	2.91	(50)
Micanite		30	2.1–4.2	(59)
Varnished cambric, tacky				
30 layers each 0.23 mm	1.17	20	2.17	(50)
		50	2.28	
75 layers each 0.23 mm	1.17	20	4.30*	
		50	4.38*	
Varnished cambric, dry 30 layers each 0.23 mm	1.24	20	2.16	
		50	2.23	
Kraft paper and mica, No. 312, 13.2 mm thick		20	11.2*	(50)
		50	11.8*	
Idem., 5.6 mm thick		50	2.28	
Paraffin wax	0.89	30	2.30	(52)
Micarta folium, No. 249, 5.9 mm thick		50	2.31	(50)
14.5 mm thick		50	11.3*	
Cellulose, compressed	1.42	15	2.44	(4)

* Longitudinally.

THERMAL CONDUCTIVITY.—(*Continued*)

Material	Bulk density, g/cm³	t°C	k	Lit.
Presspan		54	2.49	(49)
Black bias cloth, 22 layers each 0.23 mm	1.26	50	2.51	(50)
80 layers each 0.23 mm	1.26	20	3.82*	
		50	4.26*	
Lignum-vitae	1.16	20	2.52	(3)
		100	3.02	
Mica tape, 30 layers each 0.15 mm	1.06	50	2.68	(50)
30 layers each 0.20 mm	1.12	50	2.63	
120 layers each 0.15 mm	1.06	50	14.5*	
Plaster of paris, powder		20	10.9	(30)
Plaster of paris, cast		20	3.0	
Fine river sand, dried	1.52	0	3.02	(15)
		20	3.26	
		160	3.84	
Fine river sand with normal moisture content (*ca.*6.9 % by weight)	1.64	20	11.3	(15)
		50	11.5	
Gypsum plaster	0.74	30	3.35	(52)
Plaster	1.69	20	7.9	(15)
Mica		41	3.6	(49)
Mica, various		50	4.2–5.9	(59)
Gravel	1.85	20	3.7	(15)
Bitumen		30	4.2 to 6.3	(14)
Flooring composition		30	8.5	(14)
Greenhart	1.08	20	4.69	(3)
		100	4.61	
Water	1.0	20	5.9	(22)
Glass, lead		15	6.0	(33)
Glass, soda	2.59	20	7.2	(3, 33, 50)
		100	7.6	
Limestone, Villers-Adam, soft	1.81	90	6.01	(8)
Lerouville, hard	2.55	90	12.9	(8)
Fine-grained, dry	1.66	0	6.29	(38)
		25	6.86	
		40	7.21	
Coarse-grained, dry	1.99	0	8.38	(38)
		25	9.30	
		40	9.90	
Caen stone			18.0	(20)
Limestone		0	19 to 24	(39)
		100	16 to 21	
		350	13 to 15	
Asphalt composition	2.12	0	6.05	(38)
		10	6.52	
		20	6.98	
		30	7.44	
Alumina (compressed powder)	1.84	47	6.77	(27)
Chalk			9.2	(20)
Porcelain		90	10.4	(30)
Slate, ⊥ cleavage		95	15.0	(30)
Slate, ∥ cleavage			13.2 to 15.1 23.0 to 27.2	(20)
Sandstone, grey, natural, freshly cut	2.26	10	15.5	(38)
		20	16.7	
		40	18.4	
Sandstone, air-dried six months	2.25	0	12.2	
		20	12.9	
		30	13.2	
Basalt		20	20	(53, 46, 17, 39)
Ice	0.92	0	22	(22, 34, 48)
Granite	2.8		22	(20)

Hollow Tile Ceiling (4). k at 10°C.—*Sample* A: Top tile 1, air 2.5, tile 1, air 11, tile 1, air 2.5, tile 1 cm, $k = 6.86$. *Sample* B: Top tile 0.85, air 0.8, tile 0.85, air 13, tile 0.85, air 0.8, tile 0.85, concrete 3 cm, $k = 6.76$. *Sample* C: Same as B but with the 13 cm air space filled with concrete, $k = 11.9$. Heat flow up.

THERMAL CONDUCTIVITY OF DIATOMITE

d \ t	0°C	100°	200°	300°	400°	Remarks
0.20	0.52	0.62	0.73	0.83	0.94	Average values. The use of binding materials will increase the conductivity by amounts varying up to 100% (5, 14, 18, 36, 38, 44, 52)
0.30	0.61	0.74	0.86	0.98	1.11	
0.40	0.73	0.88	1.03	1.18	1.34	
0.50	0.86	1.03	1.21	1.39	1.57	

THERMAL CONDUCTIVITY OF CORK

d \ t	0°C	20°	40°	60°	80°	100°	Remarks
0.05	0.32	0.34	0.36	0.37	0.39	0.41	Average values. Use of binding materials gives increases up to 30 % (4, 8, 14, 15, 26, 36, 38, 44, 52, 57, 58)
0.10	0.37	0.39	0.41	0.43	0.45	0.47	
0.20	0.46	0.49	0.52	0.54	0.57	0.60	
0.30	0.56	0.60	0.63	0.66	0.69	0.73	
0.35	0.61	0.65	0.68	0.72	0.75	0.79	

THERMAL CONDUCTIVITY OF POWDERS UNDER REDUCED AIR PRESSURES

For granular powders, Smoluchowski gives the following formula connecting the thermal conductivity k with the pressure p of the gas in the interstices:

$$k = A \log (1 + ep)$$

where, for a given gas A is a constant depending on the arrangement of the grains and e on the material of which they are composed. For spongy powders this law does not hold. In the following table the conductivity of various powders (having the indicated average grain diameters in mm) is given in hectoerg ($=10^{-5}$ joule) per cm² per sec per (deg. C per cm). Smoluchowski, *Acad. Sci. Crac. Bull.* **5b**: 129; 10 and **8a**: 548; 11.

Pressure mm Hg	Quartz 0.26 mm	Emery 0.11 mm	Quartz 0.09 mm	Lycopodium 0.03 mm	Zinc 0.028 mm	Iron 0.025 mm	Rice 0.003 mm	Diatomite	Lampblack
0.05	1.4		0.6						
0.10	2.8		1.1					1.3	
0.20	5.6	2.0	2.1	1.0	1.1	0.9	0.6	2.1	1.0
0.50	11.7	5.0	4.8	2.2	2.4	1.9	1.3	3.9	2.0
1.0	20.1	8.8	8.8	4.1	4.4	3.4	2.3	5.9	3.0
2.0	33.5	15.1	15.1	6.9	7.5	5.9	3.7	8.8	4.2
5.0	61	28.5	29.7	13.1	15.1	12.2	7.1	13.4	6.6
10	88	43.9	48.1	20.5	25.1	20.5	10.9	17.6	8.4
20		66	71	28.9	40.1	33.5	16.3	21.3	10.5
50		88		38.9	67	59	24.7	26.8	13.8
100		105		43.9	88	77	31.8	30.1	16.3
200		113		46.0	109	100	38.5	33.1	18.8
400		121		48.1	126	121	43.9	34.8	21.8
700		128		50	136	132	48.1	35.6	23.4
Solid					111000	60100			

THERMAL DIFFUSIVITY

Thermal diffusivity, $\Delta t = k/dc$, where k = thermal conductivity, d = bulk density, c = specific heat. $\Delta t = 10^{-3} \times A$ cm² sec⁻¹

Material	A	Lit.
Gutta-Percha, 43°	0.486	(45)
Ebonite	0.928	(47)
Coal	1.13	(17, 34)
Rubber, 26°	1.42	(45)
Water, 20°	1.43	(22)
Snow (d = 0.19), 0°	2.50	(1)
(d = 0.33), 0°	4.60	(1)
(densely packed), 0°	4.1	(21)
Gypsum	3.0	(17)
Soil, very dry	3.1	(22)
Garden sand	3.6	(6)
Sandy clay	5.1	(6)
Coarse sand	7.6	(6)
Garden sand	8.7	(6)

THERMAL DIFFUSIVITY.—(*Continued*)

Material	A	Lit.
Frozen mold	9.2	(56)
Gravel	12.5	(56)
Sandy loam	13.6	(6)
Porphyritic trachyte	5.9	(2)
Trap rock	7.86	(51)
Sandstone	10.7	(51)
Marble	11.1	(17, 46)
Ice, 0°	11.4	(34)
Basalt	11.5	(46)
Granite	13.1	(34, 46)

ADSORBED MOISTURE IN EQUILIBRIUM WITH AIR OF VARIOUS HUMIDITIES (60)

	Moisture content (per cent of dry weight)				
Rel. humidity, %	15	30	50	70	90
Absorbent cotton (cottonwool)	8.9	10.1	20.6	22.2	25.8
Cotton cloth	2.99	4.56	6.7	9.6	13.5
Raw silk	5.0	7.1	9.0	13.3	19.0
Paper pulp (pine)	4.55	6.3	7.9	9.5	12.0
Kraft paper	2.50	3.85	5.4	7.0	9.2
Sole leather	7.0	11.1	16.0	20.6	29.2
Feathers	5.0	6.4	8.1	10.4	12.7
Rubber (solid tire)	0.17	0.28	0.60	0.74	0.99
Fuller's earth	4.54		7.5		15.6
Asbestos fiber	0.22	0.26	0.40	0.62	0.84
Diatomite	0.50	0.88	1.40	2.00	3.19
Kaolin	0.30	0.60	0.92	1.06	1.27
Glass wool	0.09	0.09	0.17	0.23	0.40
Lampblack	2.48	3.42	3.85	4.31	6.0

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THERMAL INSULATING MATERIALS FOR HIGH TEMPERATURE

GORDON B. WILKES

	Bulk density, g/cm^{-3}	Max. safe temperature for continuous use, °C	Mean coefficient of thermal conductivity* 600 to 25°C
Insulating blocks composed chiefly of			
1. Diatomaceous earth and asbestos	0.32–0.40	700– 900	0.00072–0.00096
2. Rock and slag wool mixtures	0.26–0.40	700– 900	0.00090–0.00120
Insulating bricks			
1. Diatomaceous earth (natural)	0.48	850–1000	0.00066–0.00108
2. Clay, diatomaceous earth and cork (fired)	0.43	850–1000	0.00096–0.00120
3. Diatomaceous earth and clay (fired)	0.64–0.96	1100–1300	0.00150–0.00360

* Joule, cm^{-2} sec^{-1} (°C, cm^{-1}).

Values taken from U. S. Bur. Stand., trade catalogs of The Celite Products Co., Armstrong Cork and Insulation Co., and mainly from determinations in Heat Measurement Laboratory, Mass. Inst. Tech.

THERMAL DIFFUSIVITY.—(*Continued*)

Material	A	Lit.
Frozen mold	9.2	(56)
Gravel	12.5	(56)
Sandy loam	13.6	(6)
Porphyritic trachyte	5.9	(2)
Trap rock	7.86	(51)
Sandstone	10.7	(51)
Marble	11.1	(17, 46)
Ice, 0°	11.4	(34)
Basalt	11.5	(46)
Granite	13.1	(34, 46)

ADSORBED MOISTURE IN EQUILIBRIUM WITH AIR OF VARIOUS HUMIDITIES (60)

	Moisture content (per cent of dry weight)				
Rel. humidity, %	15	30	50	70	90
Absorbent cotton (cottonwool)	8.9	10.1	20.6	22.2	25.8
Cotton cloth	2.99	4.56	6.7	9.6	13.5
Raw silk	5.0	7.1	9.0	13.3	19.0
Paper pulp (pine)	4.55	6.3	7.9	9.5	12.0
Kraft paper	2.50	3.85	5.4	7.0	9.2
Sole leather	7.0	11.1	16.0	20.6	29.2
Feathers	5.0	6.4	8.1	10.4	12.7
Rubber (solid tire)	0.17	0.28	0.60	0.74	0.99
Fuller's earth	4.54		7.5		15.6
Asbestos fiber	0.22	0.26	0.40	0.62	0.84
Diatomite	0.50	0.88	1.40	2.00	3.19
Kaolin	0.30	0.60	0.92	1.06	1.27
Glass wool	0.09	0.09	0.17	0.23	0.40
Lampblack	2.48	3.42	3.85	4.31	6.0

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THERMAL INSULATING MATERIALS FOR HIGH TEMPERATURE

GORDON B. WILKES

	Bulk density, g/cm^{-3}	Max. safe temperature for continuous use, °C	Mean coefficient of thermal conductivity* 600 to 25°C
Insulating blocks composed chiefly of			
1. Diatomaceous earth and asbestos	0.32–0.40	700– 900	0.00072–0.00096
2. Rock and slag wool mixtures	0.26–0.40	700– 900	0.00090–0.00120
Insulating bricks			
1. Diatomaceous earth (natural)	0.48	850–1000	0.00066–0.00108
2. Clay, diatomaceous earth and cork (fired)	0.43	850–1000	0.00096–0.00120
3. Diatomaceous earth and clay (fired)	0.64–0.96	1100–1300	0.00150–0.00360

* Joule, cm^{-2} sec^{-1} (°C, cm^{-1}).

Values taken from U. S. Bur. Stand., trade catalogs of The Celite Products Co., Armstrong Cork and Insulation Co., and mainly from determinations in Heat Measurement Laboratory, Mass. Inst. Tech.

RAW MATERIALS OF THE PAINT AND VARNISH INDUSTRIES

AVERAGE BULKING VALUES AND SPECIFIC GRAVITIES OF THE MORE COMMON DRY PIGMENTS USED IN THE PAINT INDUSTRY

HENRY A. GARDNER AND H. C. PARKS

	Specific gravity	Wt. per solid gal., lb.	1 lb. bulks, gal.
Basic carbonate white lead	6.81	56.73	0.01763
Basic sulfate white lead	6.41	53.40	0.01873
Zinc oxide	5.66	47.15	0.02121
Zinc oxide, leaded (contains 35% basic lead sulfate)	5.95	49.56	0.02018
Lithopone (*ca.* 28% ZnS, 72% $BaSO_4$)	4.30	35.82	0.02792
Titanox (25% TiO_2, 75% $BaSO_4$)	4.30	35.82	0.02792
Talc (contains *ca.* 5% $CaCO_3$)	2.85	23.74	0.04212
Barytes	4.45	37.07	0.02698
China clay	2.62	21.82	0.04583
Silica	2.65	22.07	0.04531
Whiting ($CaCO_3$)	2.71	22.57	0.04431
Venetian red (20% Fe_2O_3)*	3.05	25.41	0.03935
Red oxide (40% Fe_2O_3)	3.45	28.74	0.03479
Red oxide (95% Fe_2O_3)	4.95	41.23	0.02425
Indian red (90% Fe_2O_3)	4.92	40.98	0.02440
Ferric oxide (98% Fe_2O_3)	5.15	42.90	0.02331
Tuscan red	3.95	32.90	0.03040
Ochre	2.80	23.32	0.04288
Sienna, raw	3.27	27.24	0.03671
Sienna, burnt	3.95	32.90	0.03040
Umber, raw	2.68	22.32	0.04480
Umber, burnt	3.80	31.65	0.03160
Brown oxide (50% Fe_2O_3)	3.35	27.91	0.03583
Mineral brown (45% Fe_2O_3)	3.34	27.82	0.03595

	Specific gravity	Wt. per solid gal., lb.	1 lb. bulks, gal.
Chromium oxide	4.95	41.23	0.02425
Litharge	9.40	78.30	0.01277
Orange mineral	8.80	73.30	0.01364
Red lead	8.80	73.30	0.01364
Pure paranitraniline toner	1.50	12.50	0.08000
Para red 10% (on lime and barium base)	2.65	22.07	0.04531
Pure toluidine red toner	1.49	12.41	0.08058
Chrome green, C. P.	3.90* 5.08*		
American blue (iron cyanide blue)	1.85	15.41	0.06489
Ultramarine blue	2.35	19.58	0.05107
Chrome yellow, C. P*	6.00*		
Lampblack	1.78	14.83	0.05743
Carbon black	1.81	15.08	0.06631
Drop black	2.64	21.99	0.04548
Graphite	2.36	19.66	0.05086
Mineral black filler (clay base with from 15 to 30% carbon)	2.71	22.57	0.04431
Zinc dust	7.06	58.81	0.01700
Aluminum dust	2.64	21.99	0.04548
Lead dust	11.09	92.38	0.01082

* These will vary widely according to composition required for shade or tone and character of base.

Red and brown oxides of variable composition. Matter other than iron oxide may be clay, silica, etc.

AVERAGE CONSTANTS OF OILS USED IN PAINT AND VARNISH INDUSTRY

HENRY A. GARDNER AND L. L. STEELE

Oil	Species	Specific gravity $\frac{15.5°C}{15.5°C}$	Iodine (Hanus) No.	Saponification No.	Acid No.	Refractive index 25°C
	Vegetable and seed oils					
Chia	*Salvia hispanica*	0.934	196	192	0.6	1.486
Corn	*Zea mays*	0.921	125	190	4.0	1.480
Cottonseed	*Gossypium herbaceum*	0.924	112	194	0.9	1.472
Hempseed	*Cannabis sativa*	0.927	149	191	4.0	1.482
Kapok seed	*Eriodendron anfractuosum*	0.924	119	196		
Linseed (boiled)	*Linum usitatissimum*	0.941	172	187	2.7	1.490
Linseed (heavy bodied)	*Linum usitatissimum*	0.968	133	189	2.8	1.497
Linseed (lithographic)	*Linum usitatissimum*	0.970	102	199	2.7	1.498
Linseed (raw)	*Linum usitatissimum*	0.934	186	191	2.0	1.480
Oticia	*Conepia grandifolia*	0.969	180	189	8.0	
Palo maria	*Calophyllum inophyllum*	0.934	97	193	46.0	1.474
Perilla	*Perilla ocimoides*	0.934	200	188	2.0	1.487
Poppyseed	*Papaver somniferum*	0.926	134	192		
Raisinseed (grapeseed)	*Vites*, spp.	0.926	133	193	4.5	1.471
Rosin oil	*Pinus palustris*	0.964	69	36	32	
Rubberseed	*Hevea brasiliensis*	0.924	137	193	57	
Sesame	*Sesamum orientale & indicum*	0.924	110	190	1.5	
Soya bean	*Soja hispida*	0.924	129	189	2.3	1.481
Sunflower	*Helianthus annuus*	0.924	125	189	7.5	1.480

Oil	Species	Specific gravity $\frac{15.5°C}{15.5°C}$	Iodine (Hanus) No.	Saponification No.	Acid No.	Refractive index 25°C
		Nut oils				
Lumbang (candlenut)	*Aleurites moluccana*	0.927	152	192	1.0	1.477
Lumbang (soft)	*Aleurites trisperma*	0.938	164	194	4.4	1.493
Peanut	*Arachis hypogaea*		102	193	2.2	1.479
Tung (American)	*Aleurites fordii*	0.941	166	195	0.2	1.517
Tung (Chinese)	*Aleurites fordii*	0.944	165	192	4.8	1.517
Walnut	*Juglans regia*	0.926	143	193		1.477
Wood (Japanese)	*Aleurites cordata*	0.934	154	193	0.9	1.508
		Marine animal oils				
Channel catfish		0.923	123	192	11	1.474
Fur seal	*Phoca vitulina*, etc.	0.925	132	182	9	1.477
Grayfish		0.916	135	180	2	1.470
Menhaden	*Alosa menhaden (Brevoortia tyrannis)*	0.932	158	187	4	1.485
Salmon	*Salmo salar*	0.927	159	183	10	1.479
Sardine	*Clupea sardinus*	0.919	135	177	10	1.480
Shark		0.910	133	160	5	1.482
Shark liver	*Borealis scymnus*	0.922	136	62	1.5	1.471
Skate liver	*Squatina vulgaris*	0.932	152	180	2	1.471
Tuna fish		0.933	184	190	0.5	
Whale	*Balæna*	0.924	148		9	1.482
Yellow tail fish	*Seriola dorsalis*	0.932	180	190	0.6	

TOXICOLOGY OF GASES AND VAPORS

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In the following paragraphs the numbers in bold face have the following significance:

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2. Percentage fatal in 30 minutes or less.
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5. Maximum safe concentration.
6. Properties (1).
7. Portal of entry (1).
8. Symptoms (1).
9. Occupations (1).

Acrolein, $CH_2{:}CHCHO$.—**1.** 52°. **2.** 0.001 (2). **5.** 0.00033 (2). **6.** Colorless, pungent fluid, of fiery taste. **7.** As vapor, through organs of respiration and mucous membranes. **8.** Itching in the throat; irritation of eyes, exciting lachrymation; conjunctivitis, irritation of the air passages, bronchial catarrh. **9.** Manufacture of lard, linoleum, stearic acid; bone and fat rendering, galvanizing, tallow refining, tinsmithing, varnish boiling.

Ammonia, NH_3.—**1.** −35.5°. **3.** 0.25–0.45 (3). **4.** 0.03 (3). **6.** Colorless gas of sharply penetrating odor. **7.** As gas, through organs of respiration. Seldom pure, mostly in combination with other gases. Immediate effects on the conjunctiva and the cornea. **8.** Acute inflammation of the respiratory organs, cough, edema of the lungs, chronic bronchial catarrh, redness of the eyes, increased secretion of saliva, retention of urine. **9.** Manufacture of acetylene, ammonium salts, artificial ice, artificial silk, bone-black, dyes, shellac, soda, varnish; work around coke-ovens, refrigerating plants, sewers; bronzing, dyeing, galvanizing, gas purifying, mercerizing, shoe finishing, sugar refining, tinsmithing; work with glue, illuminating gas.

Aniline, $C_6H_5NH_2$.—**1.** 184.4°. **4.** 0.00004–0.00006 (3). **6.** Colorless oil acquiring tint on exposure to air and light. **7.** Absorption through skin, directly or by saturation of clothing; absorption through respiratory organs as volatile particles and impalpable dust; through digestive organs. **8.** Pallor of skin, vertigo, unsteady gait, loss of appetite, increased frequency of respiration, anemia, slowing of the pulse, eczematous eruptions, bloody urine, spasmodic muscular pains, cyanosis. **9.** Manufacture of aniline, artificial leather, calico, explosives, coal-tar products, dyes, paint, colored pencils; vulcanizing, tanning, printing, typesetting, photography, painting, lithography; work with feathers; compounding, mixing, reclaiming rubber, and work in press rooms.

Arsine, AsH_3.—**1.** −54.8°. **2.** 0.05 (2). **5.** 0.001 (2). **6.** Colorless, extremely offensive gas, with the odor of garlic. **7.** As gas, through respiratory organs, generally mixed with hydrogen. **8.** General malaise, difficult breathing, fainting fits, gastric disturbances, jaundice, bluish discoloration of the mucous membrane, pain in the region of spleen and kidney, darkened urine, fetor of the mouth resembling garlic. **9.** Manufacture of dry batteries, dimethyl sulfate, dyes, fertilizer, nitroglycerin, shoddy, zinc chloride; acid dipping, filling toy balloons, bronzing, enamelling, galvanizing, lead and lime burning, pickling, metal refining, tinsmithing; work with aniline, sulfuric acid, submarine storage batteries; ferro-silicon work.

Benzene, C_6H_6.—**1.** 80.2°. **4.** 0.001–0.0015 (3). **5.** 0.0005 (3). **6.** Unstable, extremely volatile, colorless fluid, burning with a bright sooty flame. A coal tar product. **7.** As vapor, through the respiratory organs; re-absorption through the skin. **8.** Headache, vertigo, anemia, muscular tremor, scarlet lips, spots of extravasated blood in the skin, irritant cough, fatty degeneration of liver, kidneys and heart. **9.** Manufacture of aniline, artificial leather, dry batteries, carbolic acid, colors, dyes, explosives, fertilizer, lacquer, paint, rubber tires, shellac, shoes,

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Bromine, Br_2.—**1.** 58.6°. **2.** 0.1 (3). **3.** 0.004–0.006 (3). **4.** 0.0004 (3). **5.** 0.0001 (3). **6.** Fuming liquid with an extremely disagreeable odor. **7.** As gas, through the respiratory organs. **8.** Pallid countenance, emaciation, decayed teeth, bronchial irritation and asthma, gastric disturbances, irritation of the skin. **9.** Manufacture of dyes; chemical and pharmaceutical industries.

Carbon Disulfide, CS_2.—**1.** 46.2°. **3.** 0.001 (3). **4.** 0.0002–0.0003 (3). **5.** 0.0001 (3). **6.** When pure, a limpid, highly refractive, volatile fluid, having an odor like chloroform; imperfectly refined, it is pale yellow, with an offensive odor. **7.** As vapor, through respiration; as fluid, through the skin. **8.** Headache, pain in the extremities, trembling, deafness, reduction of the reflexes, accelerated heart action, nausea, digestive trouble, emaciation, disturbance of sense of vision, excitement and violent temper followed by depression, hyperstimulation of the sexual instinct, later its abnormal decline, chronic dementia. **9.** Manufacture of ammonium salt, artificial silk, carbon disulfide, celluloid, insecticide, matches, paint, putty, smokeless powder; asphalt testing, cementing rubber shoes, rubber cement mixing, dry cleaning, enamelling, oil extracting, tallow refining, sulfur extracting, vulcanizing, rubber drying and reclaiming, work with paraffin and glue.

Carbon Dioxide, CO_2.—**1.** −78.2°. **2.** 30.0 (3). **3.** 6.0–8.0 (3). **4.** 4.0–6.0 (3). **5.** 2.0–3.0 (3). **6.** Specifically dense, odorless, colorless gas, collecting near the ground or floor. **7.** As gas, by inhalation. **8.** Anemia, cyanosis, headache, drowsiness, vertigo, tinnitus, and general nervousness. **9.** Manufacture of alkali salts, carbon dioxide, fertilizer, pottery, soda, starch, wine, white lead, yeast; blacksmithing, brass founding, brewing, brick, charcoal and lime burning, lime kiln charging, mining, sugar refining; work in boiler rooms, caissons, drying rooms, silos; work around furnaces, sewers.

Carbon Monoxide, CO.—**1.** −190°. **2.** 0.5–1.0 (7). **3.** 0.2–0.3 (3). **4.** 0.05–0.10 (3). **5.** 0.04 (7). **6.** Colorless, tasteless gas, odorless in diffused state, burning with a blue flame in air. **7.** As gas, through the respiratory organs. **8.** Stage 1 (7): Tightness across forehead, dilatation of cutaneous vessels, headache (frontal and basal), throbbing in temples, weariness, weakness, dizziness, nausea and vomiting, loss of strength and muscular control, increased pulse and respiration rates, collapse. Stage 2: Increased pulse and respiration, fall of blood pressure, loss of muscular control, especially sphincters, loss of reflexes, coma usually with intermittent convulsions, Cheyne-Stokes' respiration, slowing of pulse, respiration slow and shallow, cessation of respiration, death. **9.** Manufacture of acetylene, carbide, celluloid, cores (founding), felt hats, incandescent lamp filaments; baking, blacksmithing, brass founding, cable splicing, calico printing, charcoal burning, charging (zinc smelting), chimney sweeping, copper smelting, enamelling, incandescent lamp finishing; work with bisque kilns, coke ovens, coal tar; work in drying and boiler rooms.

Carbon Tetrachloride, CCl_4.—**1.** 76.74°. **2.** 0.03–0.04 (3). **3.** 0.015–0.02 (3). **4.** 0.0025–0.004 (3). **5.** 0.001 (3). **6.** Colorless liquid with pleasant odor, having a narcotic action somewhat similar to chloroform (11). **7.** As vapor, through the respiratory organs. **8.** Nausea, vomiting, abdominal pain, stupor deepening into coma, absence of reflexes, clonic convulsions, weak pulse, increased temperature and death (11). **9.** Used in industry as a rubber solvent, an ingredient of certain types of paint, a fire extinguisher, and a shampooing agent.

Chlorine, Cl_2.—**1.** −33.6°. **2.** 0.10 (3). **3.** 0.004–0.006 (3). **4.** 0.0004 (3). **5.** 0.0001 (3). **6.** Yellowish-green, suffocating gas of penetrating odor, whose water solution is a greenish-yellow. **7.** As gas, through the respiratory organs. **8.** Pallid countenance, emaciation, decayed teeth, bronchial irritation and asthma, gastric disturbances, irritation of the skin, chloracne. **9.** Manufacture of alkali salts, brooms, chloride of lime, chlorine, disinfectants, dyes, phosgene, sulfur and zinc chloride; pulp beating, bleaching, calico printing, laundry work, photography.

Chloroform, $CHCl_3$.—**1.** 61.2°. **2.** 0.03–0.04 (3). **3.** 0.007 (3). **4.** 0.0025–0.003 (3). **5.** 0.001 (3). **6.** Heavy colorless liquid, with characteristic odor and sweet taste; used as an anesthetic (11). **7.** As vapor, through the respiratory organs. **8.** In anesthesia the untoward symptoms are shallow or irregular respiration, sudden cessation of respiration, pulse either very slow or very rapid, dilatation of the pupils, cyanosis, asphyxia leading to dilatation of the heart, vagus stimulation, and finally failure of heart due to asphyxial condition. In delayed poisoning there is great prostration, delirium, coma, death (11). **9.** Chloroform manufacture, but the principal hazard is in its use as an anesthetic.

Chloropicrin, CCl_3NO_2.—**1.** 112°. **2.** 0.05 (2). **3.** 0.002 (2). **4.** 0.0001 (2). **6.** Colorless oil, insoluble in water. Sufficiently volatile to keep the strata of air above it thoroughly poisonous, and persistent enough to be dangerous after 5 or 6 hours. **7.** As gas, through the respiratory organs. **8.** Lachrymatory and respiratory irritant, with specific action on the vomiting center. Causes coughing, nausea, vomiting, and in large quantities unconsciousness. Secondary effects are bronchitis, shortness of breath. **9.** Warfare.

Dichlorodiethyl Sulfide, $(CH_2ClCH_2)_2S$.—**1.** 215–217°. **5.** 0.002 (2). **6.** Oily fluid with sharp odor. Its peculiar property of blistering the skin, combined with its high persistency, makes it the most valuable war gas known. **7.** As vapor, through the respiratory passages, and through the skin. **8.** Conjunctivitis and superficial necrosis of the cornea; hyperemia, edema and, later, necrosis of the skin, leading to skin lesion of great chronicity; congestion and necrosis of the epithelial lining of the trachea and bronchi. Systemic effects due to the absorption of the substance into the blood stream and its distribution to the various tissues of the body (4). **9.** Warfare.

Hydrogen Chloride, HCl.—**1.** −82.9°. **2.** 0.5 (2). **3.** 0.15–0.2 (3). **4.** 0.005–0.01 (3). **5.** 0.005 (2). **6.** Pure HCl is a colorless gas that fumes when open to the air, forming a dense, acid, white mist. The crude commercial acid is, for the most part, impure, containing arsenic among other mixtures. **7.** Action on skin and nasal mucous membrane; seldom as vapor affecting the respiratory organs. **8.** Irritation of mucous membranes, conjunctivitis, coryza; pharyngeal, laryngeal, and bronchial catarrh; dental caries. **9.** Manufacture of alkali salts, ammonium salts, aniline, dry batteries, camphor, carbolic acid, dyes; dipping, mixing, recovering, transporting acid; cartridge dipping, shoddy carbonizing, calico printing, acid finishing (glass).

Hydrogen Cyanide, HCN.—**1.** 26.5°. **2.** 0.048 (9). **3.** 0.012–0.024 (9). **4.** 0.005–0.006 (3). **5.** 0.002–0.004 (3) **6.** Colorless, highly volatile fluid, of penetrating, pungent, and irritating odor. **7.** As gas, through the respiratory organs; also through the epidermis. **8.** Headache, vertigo, unsteadiness of gait, nausea, loss of appetite, disturbance of gastric and intestinal functions, slowing of the pulse, albuminuria. **9.** Manufacture of ammonium salts, celluloid, dyes; acid dipping, blacksmithing, browning (gun barrels), calico printing, case hardening, electroplating, fulminate mixing, gas purifying, gold refining, photography, pickling, silver refining, tanning, tempering; work around blast furnaces, and with illuminating gas.

Hydrogen Sulfide, H_2S (10).—**1.** −60.2°. **2.** 0.06–0.1 (10). **3.** 0.05–0.07 (3). **4.** 0.02–0.03 (3). **5.** 0.01–0.02 (10). **6.** Colorless gas with odor of rotten eggs in low concentration; burns with bluish flame forming SO_2 and water; mixed with 7 parts air, explodes with violence when ignited. **7.** As gas, through the respiratory organs. **8.** Poisoning is of two types—acute and subacute—causing asphyxiation and irritation (conjunctivitis, bronchitis, pharyngitis, and depression of the central nervous system), respectively. In low concentration the symptoms are headache, sleeplessness, dullness, dizziness, and weariness; pain in the eyes, followed by conjunctivitis, is fairly constant; bronchitis and pains in the chest are frequent. Further poisoning produces depression, stupor, unconsciousness and death. Spasms—clonic and tonic—are present. Death from asphyxia is caused by paralysis of respiratory center, while death from subacute poisoning is associated with edema of the lungs. **9.** Manufacture of alkali salts, celluloid, dyes, fertilizer, matches, soda, sodium sulfide, starch, artificial silk; bronzing, cable splicing, flax retting, gas purifying, petroleum refining, pyrites burning, sugar refining, tanning; work around blast furnaces; work with glue, illuminating gas, sewers.

Iodine, I_2 (11).—**1.** 184.35°. **4.** 0.0003 (3). **5.** 0.00005–0.0001 (3). **6.** At ordinary temperatures gives off invisible vapor very irritating to the nose and eyes (1). **7.** As vapor. **8.** Inflammation of the lungs and pulmonary edema. **9.** Manufacture of iodine.

Mercury, Hg.—**1.** 357.33°. **5.** Less than 0.000125 causes symptoms of poisoning after daily exposure for 2 or 3 months (5). **6.** Silver-white, shining metal, unchangeable in air, but evaporating at house temperature (6). **7.** Through the uninjured skin, and the respiratory organs in the form of vapor and dust (amalgam dust, dust of the compounds of mercury) (6). **8.** Industrial mercurial poisoning is a chronic poisoning occasioned by work in this metal for a long period. The first symptom is generally increased ptyalism, with swelling and inflammation of the gums and of the buccal mucous membrane, often with the formation of rodent ulcers; frequently disturbances of digestion, lassitude and pallor. With further absorption of the metal, "erethism" supervenes—a peculiar psychic excitability (timorousness, bewilderment, irritability), tremor. Death may result in the worst cases in consequence of the violent tremor and spasms affecting the entire body; in other cases increasing weakness (6). **9.** Mining and smelting of quicksilver; mirror plating, amalgam gilding and silvering; manufacture of thermometers, barometers, manometers, incandescent electric lamps, Roentgen and Hittorf tubes, mercurial vapor lamps, salts of mercury, amalgams, colors, pharmaceutic products, antiseptic dyes, inflammable materials, explosives; use of mercury salts, especially in the hare's fur business and felt hat manufacture; photography, steel engraving (6).

Nitrogen Oxides (Expressed in Percentages as Nitric Acid) NO.—**1.** −153°. **2.** 0.07 (12). **3.** 0.01 (12). **4.** 0.007 (12). **5.** 0.0033 (12). **6.** NO is colorless gas readily transformed into brown NO_2 by atmospheric oxygen. **7.** As gas, through respiratory organs. **8.** Local cauterization of the respiratory tract, leading to laryngitis, bronchitis, hyperemia, hemorrhages and severe edema in addition to vicarious emphysema of the lungs. In men the real illness generally appears only 4 to 6 hours or more after inhalation of the gas; in animals lung edema and a condition threatening to be dangerous ensue promptly (12). **9.** Manufacture of aniline, artificial leather, celluloid, dimethyl sulfate, explosives, felt hats, fertilizer, imitation pearls, incandescent lamps, picric acid, soda; dipping, mixing, recovering, transporting acid; bleaching, cartridge dipping, dipping and wringing gun-cotton, enamelling, etching, fur preparing, galvanizing, lithography, mining, nitrating, photo-engraving, pickling, metal refining, steel engraving; work with glue, jewelry, mordants, nitric acid, nitroglycerin, sulfuric acid.

Nitrobenzene, $C_6H_5NO_2$.—**1.** 210.9°. **4.** 0.0001 (3). **5.** 0.00002 (3). **6.** Colorless, highly refractive fluid having an odor like that of bitter almonds. (All nitro-compounds of benzene have similar properties). **7.** As gas, through the respiratory organs. **8.** Methemoglobin formation, general debility, anemia, presence of free hematoporphyrin, albumin, and sometimes free poison in the urine; jaundice, gradually becoming cyanosis; skin eruptions, visual disturbances, dyspnea, odor of bitter almonds in breath. **9.** Manufacture of aniline, dyes, explosives, perfumes, smokeless powder, soap.

Phosgene, $COCl_2$.—**1.** 8.2°. **2.** 0.02–0.05 (2). **3.** 0.0025 (2). **5.** 0.0001 (2). **6.** Colorless gas of suffocating odor. **7.** As vapor, through the respiratory organs. **8.** Destruction of lung tissue, emphysema and edema, myocardial insufficiency due to the emphysema, pleural thickening and adhesions, chronic bronchitis, mild diffuse bronchiectasis, nocturnal dyspnea, polycythemia. **9.** Manufacture of dyes, phosgene.

Phosphorus Trichloride, PCl_3.—**1.** 76°. **2.** 0.00035 (3). **3.** 0.00003–0.00005 (3). **4.** 0.000001–0.000002 (3). **5.** 0.0000004 (3). **6.** Liquid with sharp smell, fuming in air, and decomposing into phosphorous acid and hydrochloric acid (13). **7.** As vapor, through the respiratory organs. **8.** Sensation of suffocation, difficulty of breathing, lachrymation, bronchitis, edema and inflammation of the lungs, with frothy, blood-stained expectoration. **9.** Manufacture of phosphorus trichloride and organic compounds; use of phosphorus trichloride as chlorinating agent and as solvent of phosphorus.

Phosphine, PH_3.—**1.** −85°. **2.** 0.2 (14). **3.** 0.04–0.06 (3). **4.** 0.01–0.02 (3). **6.** Colorless gas of nauseating odor. **7.** As gas, through the respiratory organs. **8.** Oppressed feeling in the chest, headache, vertigo, tinnitus aurium, general debility, loss of appetite, great thirst. **9.** Manufacture of acetylene, red phosphorus; phosphorus extracting, work with ferro-silicon.

Sulfur Dioxide, SO_2.—**1.** −10°. **2.** 0.2 (2). **5.** 0.01 (2) **6.** Gas with pungent odor and suffocating effect. **7.** As gas, through the respiratory organs. **8.** Irritation of the mucous membrane of the respiratory organs and eyes, spasmodic cough, bronchial catarrh, digestive disturbances, blood-tinged mucus. **9.** Manufacture of alkali salts, bricks, brooms, carbolic acid; work around blast furnaces, brass foundries, sulfuric acid towers; bleaching, zinc charging.

Sulfur Trioxide, SO_3.—**2.** 0.001 (2). **5.** 0.0002 (2). **6.** White solid, which evolves dense white fumes on exposure to the air. **7.** As gas, through the respiratory organs. **8.** Irritation of the respiratory organs, bronchitis. **9.** Manufacture of sulfuric acid.

Toluidine, $CH_3C_6H_4NH_2$.—**1.** 200°. **4.** 0.00025 (3). **5.** 0.0001–0.00025 (3). **6.** Reddish brown liquid. **7.** As vapor, through the respiratory organs. **8.** Headache, weakness, difficulty in breathing, cyanosis, convulsions, psychical disturbances, air hunger, marked irritation of the renal organs (13). **9.** Manufacture of aniline, coal-tar dyes; tank and still work (13).

LITERATURE

(For a key to the periodicals see end of volume)

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(10) Sayers, Mitchell and Yant, *313*, No. **2491**; 23. Also *29*, **231**: 59; 25- (11) F. P. Underhill, *Toxicology, or the Effects of Poisons*, 1924. (12) Lehmann and Hasegawa, *Arch. Hyg.*, **77**: 323; 12. (13) J. Rambousek, *Industrial Poisoning*. London, 1913. (14) Sollmann, *Manual of Pharmacology and Its Application to Therapeutics and Toxicology*. Philadelphia, Saunders, 1924.

PREVENTION AND EMERGENCY TREATMENT OF GAS POISONING

I. Prevention of poisoning

A. For all gases

1. Prevention of escape of vapor or fumes into the air of working places.
2. Good ventilation.
3. Testing before entering air suspected of containing poisonous gases.
4. Never entering or working alone in places where the air is known to be contaminated by poisonous gases.
5. Wearing of respirators, gas masks, hose masks, or oxygen breathing apparatus—the latter especially if the air is low in oxygen.
6. Education of workmen regarding the danger of poisoning and methods of prevention.

B. For special gases

1. Protection of the skin by suitable clothing and by the application of oils, etc.

   In the case of dichlorodiethyl sulfide (mustard gas), ordinary clothing affords no protection, but cloth painted with linseed oil is adequate. Oiling the skin gives some protection from short exposure to low concentrations of this gas and in high concentrations increases the efficiency of removal-treatment; for long exposure, oils give practically no protection.
2. Abstinence from alcohol, at least during and immediately after labor, especially when exposed to such gases as aniline, toluidine, and nitrobenzene.
3. Scrupulous cleanliness of working places and personally on the part of the workmen.
4. Physical examination of prospective employees to see that they are not suffering from any disease that would make them more susceptible to certain poisonous gases; reexamination of employees at stated intervals (every 30 days for workers in aniline) to detect beginning of poisoning, especially where exposed to fumes of aniline, mercury, and other gases, the action of which is cumulative and danger of acute poisoning is not so great.

II. Emergency treatment

A. For all gases

1. Immediate removal from poisonous atmosphere to fresh air.
2. Immediate administration of artificial respiration (preferably by the Schaefer prone pressure method) if breathing has ceased.
3. Calling a physician.
4. Keeping the patient at rest, lying down (very important).
5. Keeping the patient warm and stimulating circulation by rubbing limbs of patient.

B. For special gases

1. Administration of pure oxygen, especially in case of carbon monoxide poisoning.[1]
2. Administration of stimulants: Black coffee, caffein, camphor, or ether in case of poisoning by aniline, hydrogen cyanide, hydrogen sulfide, phosphine, and toluidine; subcutaneous administration of atropine in poisoning by hydrogen chloride, hydrogen sulfide, and phosphine; hypodermic administration of morphine in poisoning by hydrogen cyanide; inhalation of chloroform in poisoning by phosgene; inhalation of ammonia vapor or soda spray in poisoning by hydrogen chloride, phosgene, phosphorus trichloride, and chloropicrin; infusion of alkaline solution in poisoning by arsine, bromine, iodine, and sulfur dioxide.
3. Venesection is recommended in treatment of poisoning by bromine, chlorine, iodine, nitrogen oxides, phosgene, and chloropicrin, but must not be used after collapse has started.
4. In the case of dichlorodiethyl sulfide (mustard gas) prevention is especially important as palliative measures are not very successful. The respiratory lesions may be treated by frequent spraying or instillation of a few drops of 1 % sodium bicarbonate, followed by liquid petrolatum and gargling of the throat with a weak Dakin's solution. The eyes should be kept clean by frequent irrigation with a saturated solution of boric acid or with 1 % sodium bicarbonate, followed by a few drops of oil. All clothing should be removed to the skin. Burns of the skin from the vapor should be treated with antiseptics and protected from any irritation. Irritant drugs, such as picric acid or mercuric chloride solutions, should not be applied.

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[1] Five per cent carbon dioxide in oxygen, if available, may be administered in carbon monoxide poisoning.

AIR CONDITIONING

A. HYGROSCOPIC PROPERTIES OF INDUSTRIAL MATERIALS

D. C. Lindsay

Hygroscopic Moisture.—The moisture contained in a hygroscopic material in equilibrium with the relative humidity of the surrounding atmosphere. The moisture content of a hygroscopic material when in equilibrium depends upon the relative humidity of the surrounding atmosphere but varies widely with different materials. The moisture content also varies to a slight extent with different temperatures at the same humidity. Hygroscopic moisture in materials is in most industries termed "*regain*," and is expressed in parts of water per 100 parts of dry material.

Hygroscopic Properties of Materials.—The hygroscopic properties of materials vary widely from one another and even in the same material a wide variation is frequently observed, and is dependent upon the prior history of the material. The curves given below are based upon a critical study of available data. Qualitatively, they are correct and can be used where extreme accuracy is not required. Consistency in form will be noted in all cases. For the accurate determination of hygroscopic characteristics of materials, the use of insulated cabinets provided with air circulation and automatic instruments (10) for controlling temperature and humidity are recommended as being superior to the taking of such data, within a stagnant atmosphere, the moisture equilibrium of which is maintained by hygroscopic solutions such as sulfuric acid.

Electrostatic Condition of the Atmosphere—Electrical charges are dissipated at normal temperatures (18 to 30°C) at a relative humidity of 50 % or above.

(10) Sayers, Mitchell and Yant, *313*, No. **2491**; 23. Also *29*, **231**: 59; 25- (11) F. P. Underhill, *Toxicology, or the Effects of Poisons*, 1924. (12) Lehmann and Hasegawa, *Arch. Hyg.*, **77**: 323; 12. (13) J. Rambousek, *Industrial Poisoning*. London, 1913. (14) Sollmann, *Manual of Pharmacology and Its Application to Therapeutics and Toxicology*. Philadelphia, Saunders, 1924.

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Electrostatic Condition of the Atmosphere—Electrical charges are dissipated at normal temperatures (18 to 30°C) at a relative humidity of 50 % or above.

This is of extreme importance in textile mills and printing plants where the charged atmosphere prevalent during the winter causes bristling of the fibers and hampers operations.

The elimination of static by humidification has been successfully applied to reduce explosion hazards in munition plants and other explosive atmospheres.

Mildew Fungi.—These will thrive in relatively still atmosphere only at relative humidities above 75%.

FAVORABLE CONDITIONS OF TEMPERATURE AND HUMIDITY ARTIFICIALLY CREATED AND MAINTAINED IN MANUFACTURING PROCESSES

Industry and product	Process	Temp., °C	Relative humidity, %
Cotton.......	Carding................	20 to 23	50
	Combing...............	20 to 23	60–65
	Roving.................	20 to 23	50–60
	Spinning...............	20 to 23	60–65
	Spooling, twisting........	20 to 23	65
	Warping................	20 to 23	65
	Weaving................	20 to 23	75–80
Wool.........	Carding................	23 to 25	65–70
	Spinning...............	23 to 25	55–60
	Weaving................	20 to 23	50–55
	Storage for shipping......	20 to 23	55–60
Silk..........	Dressing...............	21 to 25	60–65
	Spinning...............	21 to 25	65–70
	Throwing..............	21 to 25	65–70
	Weaving...............	21 to 25	60–70
Confectionery	Chocolate enrobing.......	18	≯55
	Hard candy making......	21	≯50
	Storage..............	− 1 +15*	≯70 ≯55
Tobacco......	Softening...............	29	85
	Cigar and cigarette making	21 to 23	55–70
Printing.......	Lithographing...........	21	45
	Relief and offset.........	25	45
	Folding................	25	65
	Binding................	21	45
Baking........	Dough fermentation......	27	65
	Proofing................	32 to 35	80–90
	Loaf cooling............	21	65
Electrical cable	Winding insulation.......	≯40	≯ 5
Cellulose lacquers.......	Application.............	24	≯20
Munitions......	Fuse loading............	21	55
Cereals........	Seal packing prepared, crisp cereals............	23	45–50

* Divergence in practice.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bailey, *45*, **12**: 1102; 20. (2) Campbell, *45*, **9**: 658; 17. (3) Carrier Engineering Corporation Laboratory, *O.* (4) Forest Products Laboratory, *O.* (5) Hartshorne, *122*, **39**: 905; 17. (6) Houston, Carson and Kirkwood, *Paper Trade J.*, **76**, No. **15**: 237; 23. (7) Kress and McNaughton, *Paper*, **22**, No. **24**: 11; 18. (8) Kujirai and Akahira, *210*, **1**: 95; 23. (9) Kujirai, Kobayashi and Toriyama, *210*, **1**: 79; 23. (10) Lindsay and Wadleigh, *38*, **8**: 677; 25. (11) Müller and Haussner, *Herstellung und Prüfung des Papiers*, p. 1642. (12) Schloesing, *34*, **116**: 808; 93. (13) Selvig and Kaplan, *45*, **12**: 783; 20. (14) Wilson and Fuwa, *45*, **14**: 913; 22.

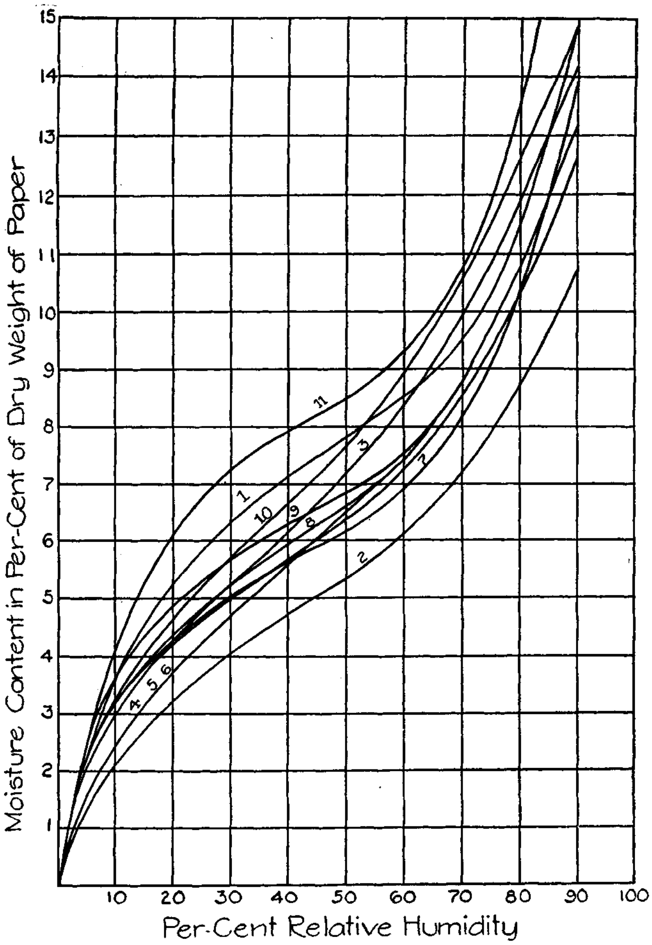


FIG. 1.—Hygroscopic moisture of various papers (*cf.* (2, 3, 6, 7, 11)).

Curve No.	Description	Ash, %	Rosin, %	Rag, %	Chemical wood bleached, %	Coniferous, %	Manila and jute, %	Lit.
1	Sulfite cellulose pulp...........							(3, 11)
2	News print..................	24.4	1.0		100			(6)
3	Writing......................	2.9	2.2		100			(6)
4	Fine white writing............	0.8	1.2	100				(6, 7)
5	White bond..................	1.0	1.0	100				(6)
6	Fine white bond..............	0.2	1.0	100				(6)
7	Commercial ledger............	0.6	1.7	75	25			(6)
8	White ledger.................	0.9	1.2	100				(6)
9	Index bristol.................	1.0	1.7	50	50			(6)
10	Kraft wrapping...............	0.3	1.3			100		(6)
11	Rope manila..................	1.6	1.5			25	75	(6)

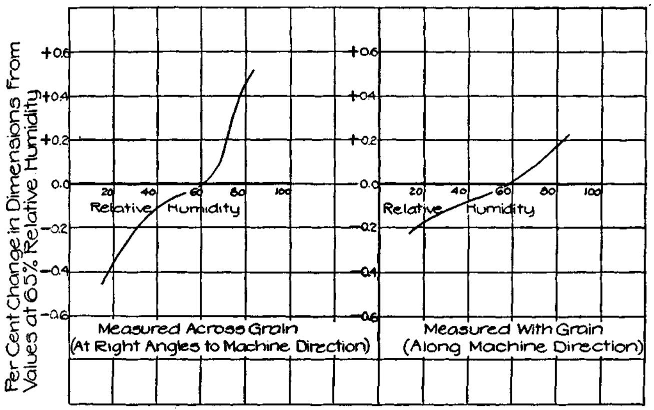


FIG. 2.—Composite curves for all papers in Fig. 1. Variation in dimensions with variation in relative humidity.

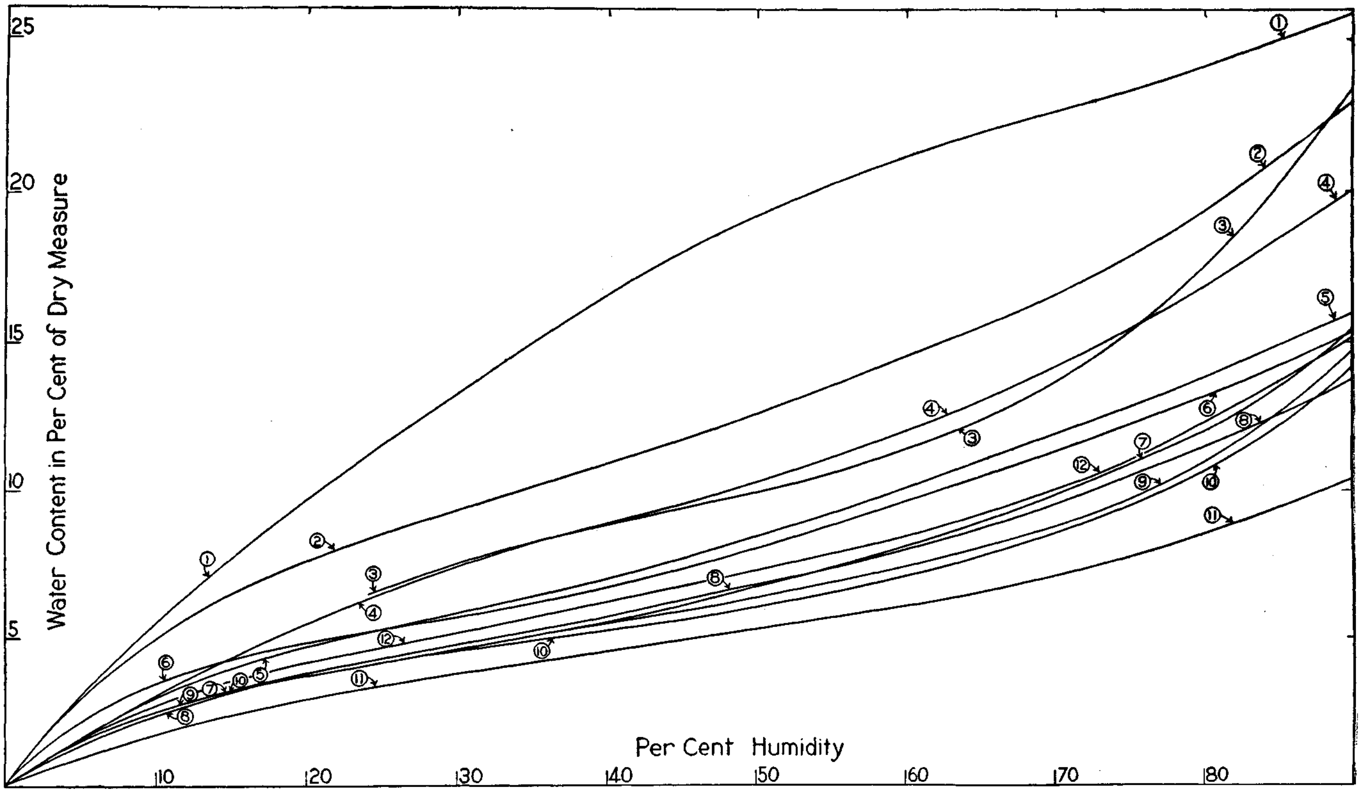


Fig. 3.—Hygroscopic moisture of natural fiber textile materials [3, 5, 12, 14]).

Curve No.	Material	Curve No.	Material	Curve No.	Material	Curve No.	Material
1	Absorbent cotton	7	Indian cotton	4	Jute	10	American cotton
2	Wool, worsted	8	Cotton cloth	5	Manila hemp	11	Linen
3	Silk, new yellow	9	Egyptian cotton	6	Sisal hemp	12	Flax

All observations at approx. 25°C.

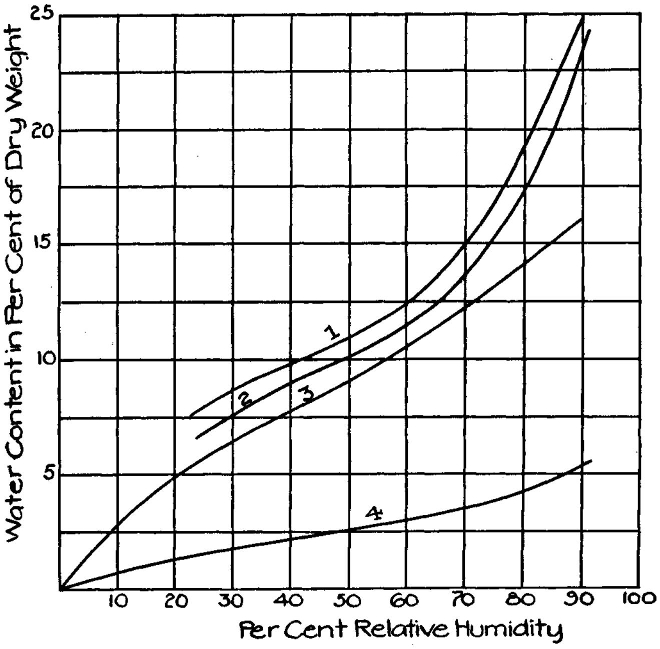


Fig. 4.—Hygroscopic moisture of artificial textile fibers compared with crude constituents and natural silk (3, 14).

Curve No.	Material
1	Viscose rayon (artificial silk)
2	Natural silk, new yellow
3	Nitrocellulose
4	Cellulose acetate

All observations at approx. 25°C.

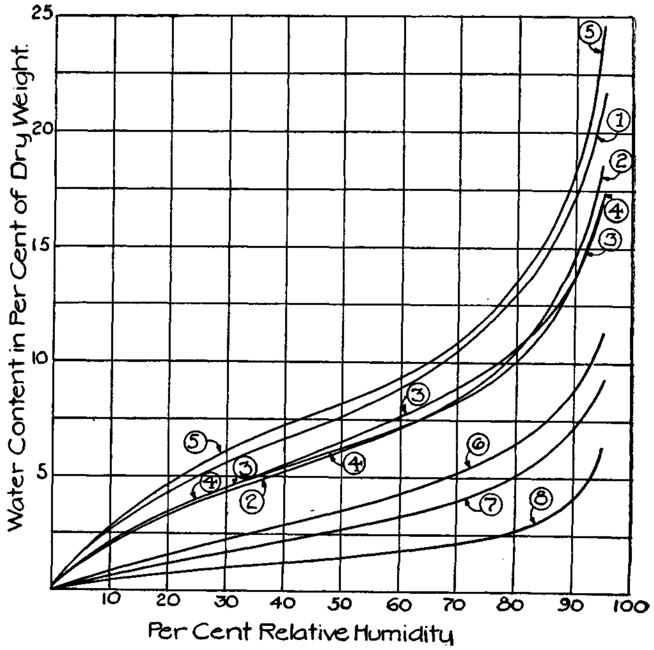


Fig. 6.—Hygroscopic moisture of various fibrous materials prepared for electrical insulation (8, 9).

Curve No.	Material
1	Manila paper
2	Red rope paper
3	Press board
4	Leatheroid paper
5	Silk
6	Red rope paper (varnished)
7	Empire cloth
8	Asbestos paper

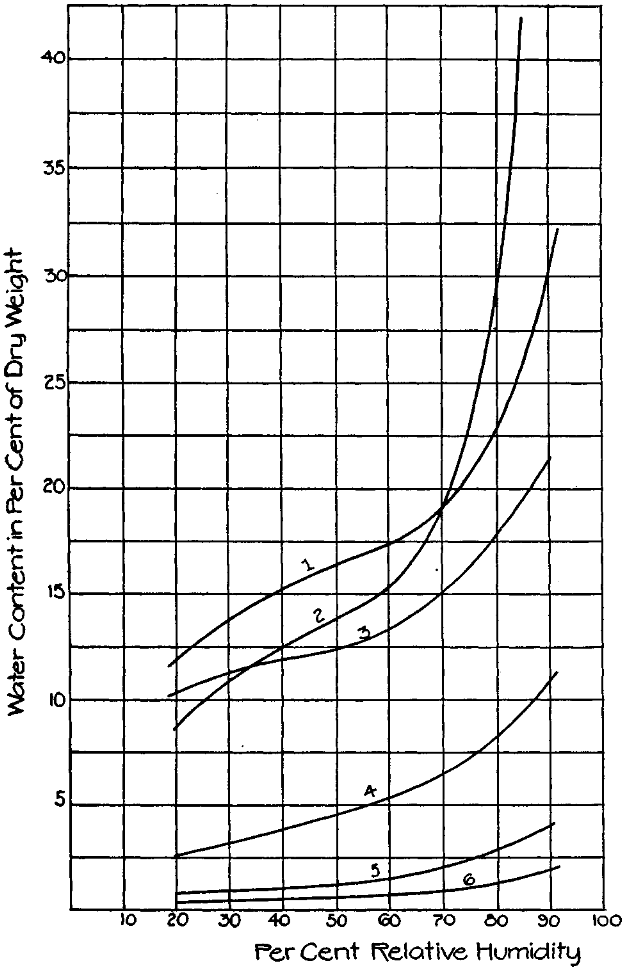


FIG. 5.—Hygroscopic moisture of leather and rubber (³).

Curve No.	Material
1	Leather (sole oak tanned)
2	Sheepskin
3	Gold beater skin
4	Latex, dipped cord
5	Reclaimed rubber
6	Smoked, crepe sheet

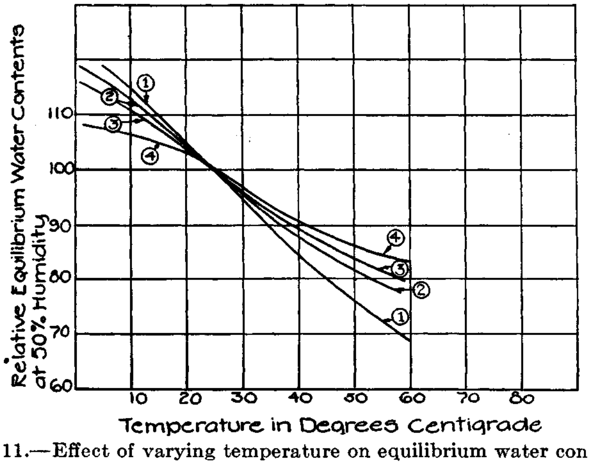


FIG. 11.—Effect of varying temperature on equilibrium water content at constant relative humidity of 50 % (¹⁴).

Curve No.	Material
1	Wood
2	Silk
3	Wool
4	Cotton

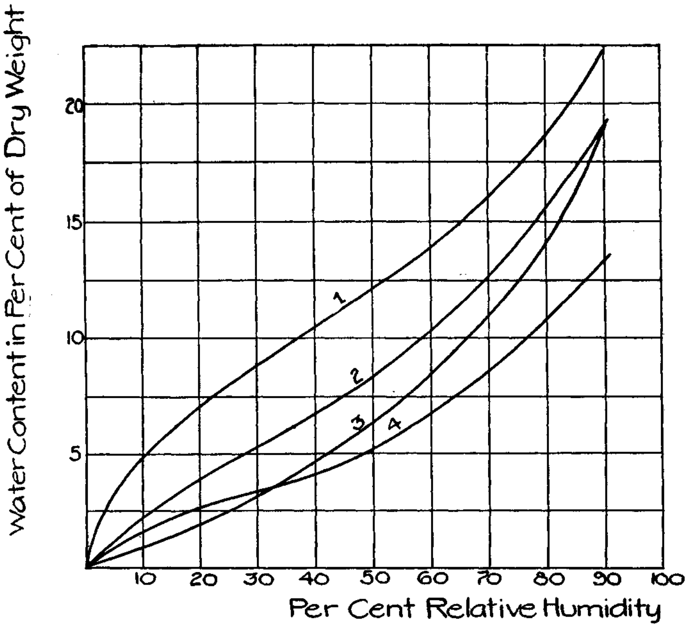


FIG. 7.—Hygroscopic moisture of cereal foods (¹, ³, ¹⁴).

Curve No.	Material
1	Macaroni
2	Flour (patent)
3	Bread
4	Crackers

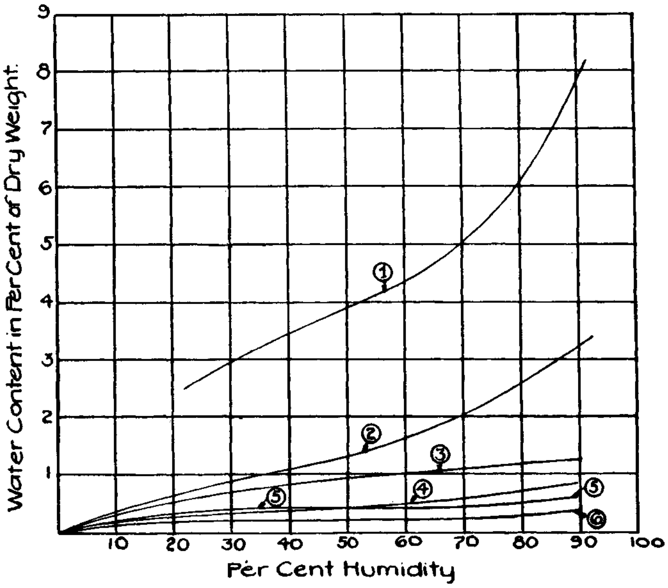


FIG. 8.—Hygroscopic moisture of some inorganic substances (¹⁰, ¹⁴).

Curve No.	Material
1	English ball clay
2	Kieselguhr
3	Kaolin
4	Asbestos fiber
5	Zinc oxide
6	Glass wool

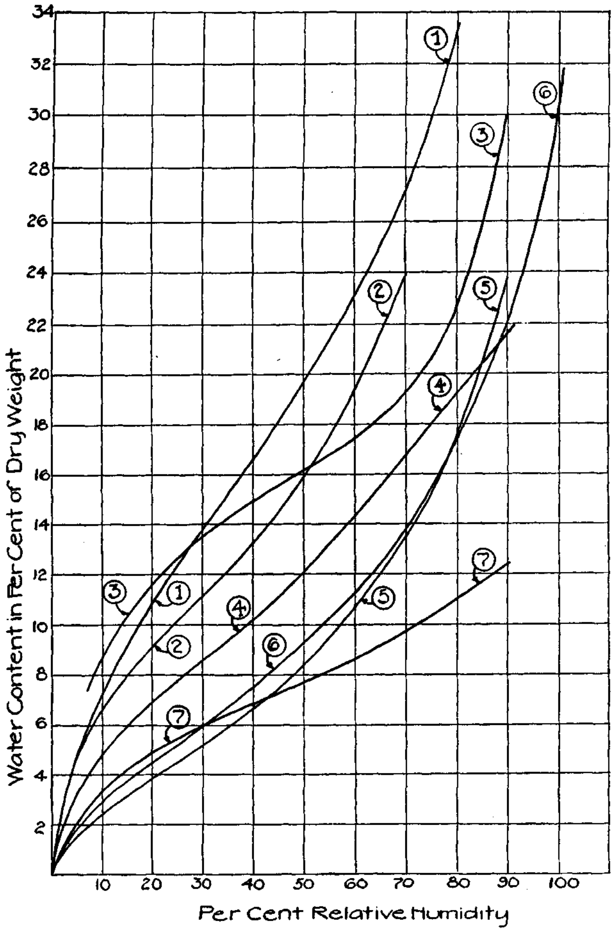


FIG. 9.—Hygroscopic moisture of some organic substances.

Curve No.	Material	Lit.
1	North Carolina leaf tobacco	(3)
2	Cigarette tobacco (Fatima)	(14)
3	Sole leather (oak tanned)	(3)
4	Catgut	(14)
5	Soap (Ivory)	(14)
6	Lumber*	(4)
7	Glue (hide, first grade)	(14)

* All species of timber have been found to have approximately the same values at given relative humidities. Rate of absorption or evaporation from timbers varies according to the density of the species.

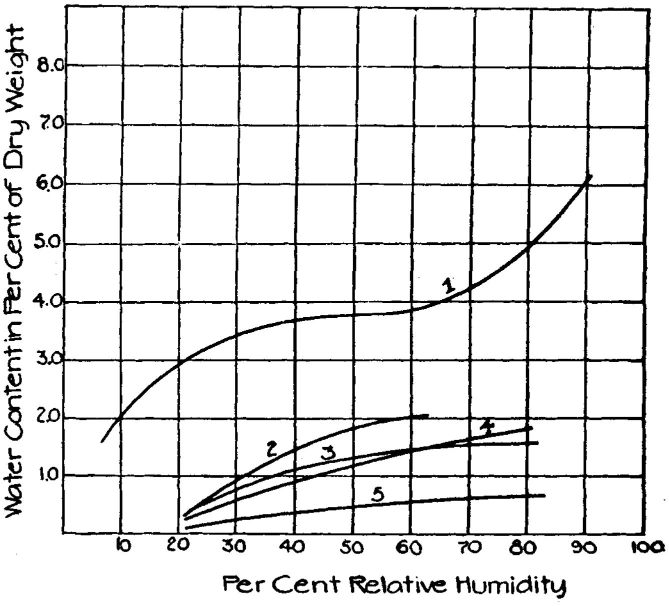


FIG. 10.—Hygroscopic moisture of carbon products (13, 14).

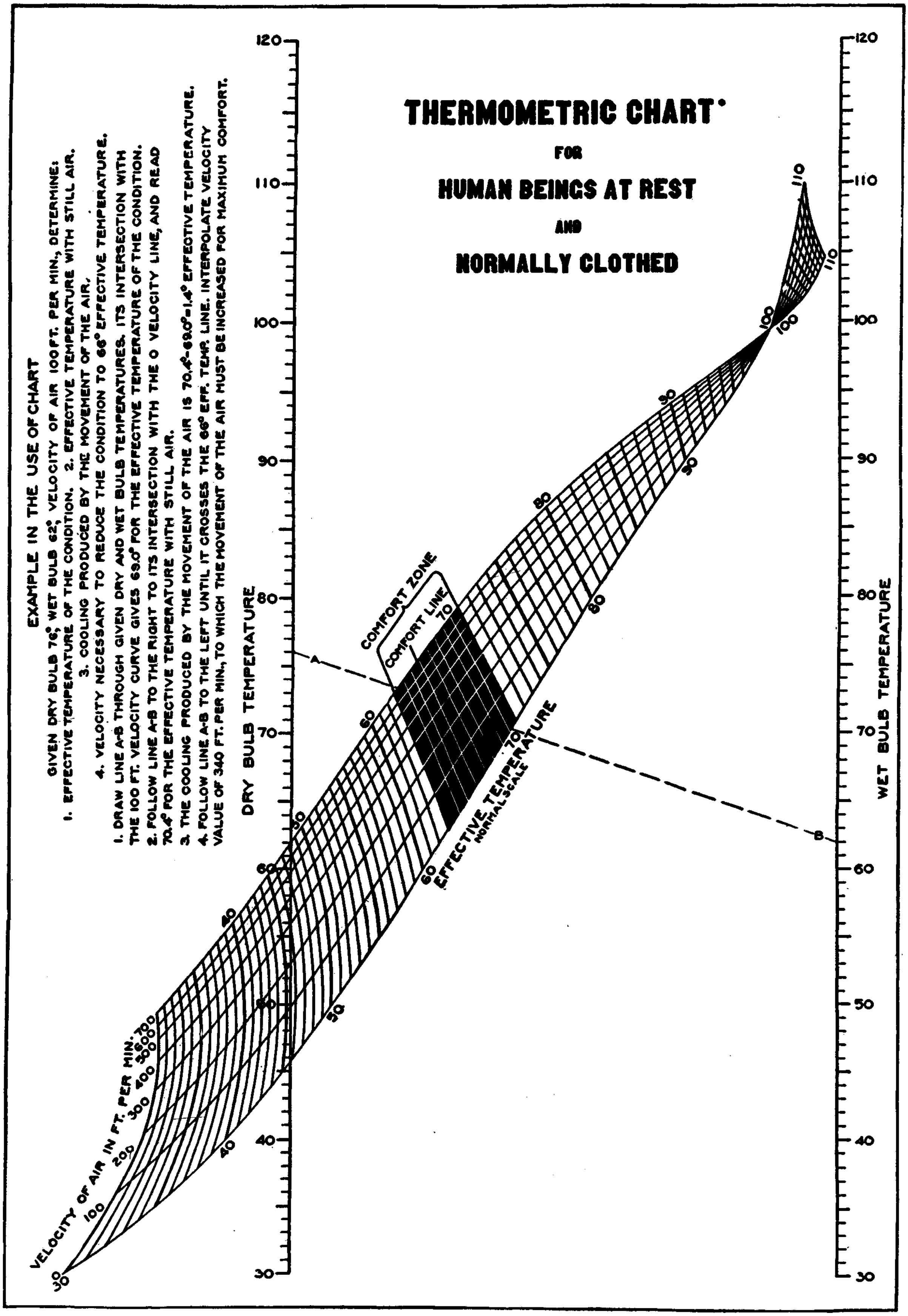
Curve No.	Material
1	Carbon black for rubber trade
2	By-product furnace coke (Franklin Co., Ill., coal)
3	By-product coke, domestic size (Pittsburgh bed coal)
4	By-product coke (domestic size)
5	Connellsville, 72 hour bee-hive foundry coke

B. SPACES OCCUPIED BY HUMAN BEINGS

R. R. SAYERS

EFFECTS OF TEMPERATURE AND HUMIDITY ON HUMAN BEINGS IN STILL AIR

Temperature of air, relative humidity 100 %	Effects when at rest				Effects when at moderate work		
	Pulse rate	Body temperature	Metabolism	Remarks	Pulse rate	Body temperature	Remarks
°F 98	Greatly increased	Marked increase	Marked increase	Very hot, even with little clothing	Very rapid	Marked increase	Very hot
95	Marked increase	Increased	Increased	Hot, even when little clothing worn	Very rapid	Marked increase	Very hot
90	Increased	Increased	Increased	Very warm	Rapid	Increased	Hot
85	No change	No change	Slight increase	Warm	Increased	Slight increase	Very warm
75–80	Slight decrease	Slight decrease	Minimum metabolism	Comfortable	Slight increase	Slight increase	Comfortable or warm
65–70	Decrease	Slight decrease	Slight increase	Slightly cool to comfortable	Slight increase	Slight increase	Comfortable
55–60	Decrease	Slight decrease	Slight increase	Cool, clothing needed for comfort	Slight increase	Slight increase	Comfortable to cool
45–50	Decrease	Slight decrease	Increased	Cool, clothing needed for comfort	Slight increase	Slight increase	Cool



THERMOMETRIC CHART*
FOR
HUMAN BEINGS AT REST
AND
NORMALLY CLOTHED

EXAMPLE IN THE USE OF CHART

GIVEN DRY BULB 76°, WET BULB 62°, VELOCITY OF AIR 100 FT. PER MIN., DETERMINE:

1. EFFECTIVE TEMPERATURE OF THE CONDITION. 2. EFFECTIVE TEMPERATURE WITH STILL AIR.
3. COOLING PRODUCED BY THE MOVEMENT OF THE AIR.
4. VELOCITY NECESSARY TO REDUCE THE CONDITION TO 66° EFFECTIVE TEMPERATURE.

1. DRAW LINE A-B THROUGH GIVEN DRY AND WET BULB TEMPERATURES. ITS INTERSECTION WITH THE 100 FT. VELOCITY CURVE GIVES 69.0° FOR THE EFFECTIVE TEMPERATURE OF THE CONDITION.
2. FOLLOW LINE A-B TO THE RIGHT TO ITS INTERSECTION WITH THE 0 VELOCITY LINE, AND READ 70.4° FOR THE EFFECTIVE TEMPERATURE WITH STILL AIR.
3. THE COOLING PRODUCED BY THE MOVEMENT OF THE AIR IS 70.4°-69.0°=1.4° EFFECTIVE TEMPERATURE.
4. FOLLOW LINE A-B TO THE LEFT UNTIL IT CROSSES THE 66° EFF. TEMP. LINE. INTERPOLATE VELOCITY VALUE OF 340 FT. PER MIN., TO WHICH THE MOVEMENT OF THE AIR MUST BE INCREASED FOR MAXIMUM COMFORT.

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* *Jour. Am. Soc. of Heat. and Vent. Eng.*, **31**: 66; 25.

REFRIGERATING BRINES

R. S. JESSUP

Aqueous Solutions.—All data are based upon weight *in vacuo.* p = wt. % anhyd. salt, t = °C, d = gram per milliliter, η = viscosity in centipoise, c = heat capacity under atmos. pressure.

For other data *see* sections of I. C. T. on the properties of salt solutions.

DENSITY AND SPECIFIC GRAVITY

Conversion Factors

1 g ml^{-1} = 0.999973 g cm^{-3} = 0.036126 lb. in.$^{-3}$ = 62.426 lb. ft.$^{-3}$ = 8.34523 lb. gal.$^{-1}$ (U. S.) = 10.0221 lb. gal.$^{-1}$ (Brit.).

SODIUM CHLORIDE, NaCl

d_4^{25} = sp. gr. = [(0.99707 + 0.0070033p + 14.059 × 10$^{-6}p^2$ + 330.9 × 10$^{-9}p^3$) ± 0.005%] g ml^{-1}. Range, 5–25% (3, 4, 15, 20, 25).

$1/d_t = 1/d_0\ (1 + \mathrm{a}t + \mathrm{b}t^2 - \mathrm{c}t^3) \pm 0.005\ \%$ (20) whose values check those of (14, 27, 29, 30).

$d_4^t \pm < 0.01\ \%$.

p	−20°C	−10°C	0°C	10°C	20°C	30°C	a×10^4	b×10^6	c×10^9
5			1.03820	1.03659	1.03405	1.03074	1.0685	5.1425	21.750
6			1.04590	1.04403	1.04131	1.03786	1.3380	4.7100	19.000
7			1.05361	1.05150	1.04860	1.04503	1.5879	4.3162	16.547
8			1.06133	1.05900	1.05594	1.05225	1.8235	3.9350	14.000
9			1.06909	1.06654	1.06332	1.05951	2.0394	3.6062	12.047
10			1.07686	1.07411	1.07074	1.06682	2.2409	3.3037	10.297
11			1.08467	1.08173	1.07821	1.07417	2.4272	3.0362	8.875
12			1.09251	1.08939	1.08572	1.08158	2.6001	2.7962	7.703
13			1.10039	1.09709	1.09329	1.08904	2.7613	2.5725	6.578
14			1.10830	1.10483	1.10090	1.09656	2.9260	2.2575	3.750
15		1.11945	1.11626	1.11262	1.10857	1.10413	3.0629	2.0937	3.297
16		1.12765	1.12427	1.12047	1.11630	1.11177	3.1936	1.9187	2.453
17		1.13588	1.13232	1.12838	1.12409	1.11946	3.3127	1.7725	1.922
18		1.14415	1.14041	1.13634	1.13193	1.12722	3.4253	1.6300	1.328
19		1.15246	1.14857	1.14436	1.13984	1.13504	3.5290	1.5100	1.000
20		1.16082	1.15678	1.15244	1.14782	1.14293	3.6237	1.4125	0.922
21		1.16923	1.16505	1.16058	1.15586	1.15089	3.7129	1.3187	0.797
22		1.17770	1.17337	1.16880	1.16397	1.15891	3.7950	1.2375	0.750
23	1.19044	1.18622	1.18176	1.17707	1.17215	1.16702	3.8717	1.1337	
24		1.19480	1.19022	1.18542	1.18040	1.17519	3.9425	1.0675	
25			1.19874	1.19383	1.18873	1.18344	4.0090	1.0050	

CALCIUM CHLORIDE, CaCl$_2$

d_4^0 = sp. gr. = [(0.99987 + 0.0086417p + 29.17 × 10$^{-6}p^2$ + 321.3 × 10$^{-9}p^3$) ± 0.03%] g ml^{-1} (6).

$d_t = (d_0 - \mathrm{a}t - \mathrm{b}t^2) \pm 0.05\%$ (23.5).

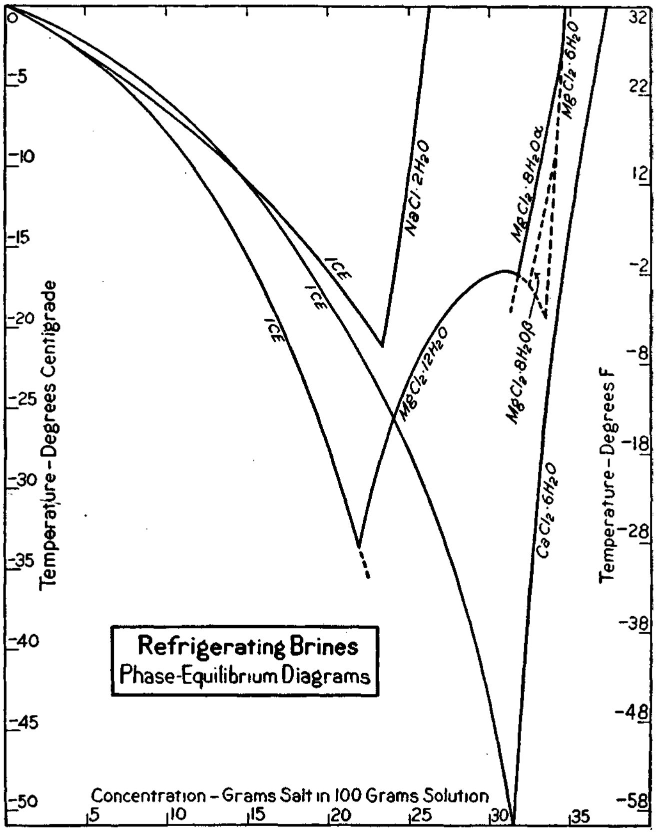
p	−30°	−20°	−10°	0°	10°	20°	30°	a×10^6	b×10^6
5				1.0438	1.0425	1.0402	1.0369	80	5.0
6				1.0528	1.0513	1.0489	1.0456	105	4.5
7				1.0619	1.0602	1.0577	1.0544	130	4.0
8				1.0710	1.0691	1.0664	1.0629	150	4.0
9				1.0802	1.0781	1.0753	1.0718	175	3.5
10				1.0895	1.0872	1.0843	1.0808	200	3.0
11				1.0989	1.0964	1.0934	1.0899	225	2.5
12				1.1083	1.1056	1.1025	1.0993	250	2.0
13				1.1178	1.1150	1.1117	1.1079	255	2.5
14				1.1274	1.1244	1.1210	1.1172	280	2.0
15			1.1396	1.1371	1.1340	1.1304	1.1261	278	2.8
16			1.1496	1.1469	1.1438	1.1399	1.1357	297	2.6
17			1.1597	1.1568	1.1534	1.1495	1.1451	315	2.5
18			1.1698	1.1667	1.1632	1.1592	1.1548	332	2.2
19			1.1801	1.1768	1.1731	1.1690	1.1645	350	2.0
20			1.1904	1.1869	1.1831	1.1788	1.1742	368	1.8
21		1.2046	1.2010	1.1972	1.1932	1.1889	1.1844	392	1.2
22		1.2150	1.2114	1.2075	1.2033	1.1989	1.1942	403	1.3
23		1.2260	1.2221	1.2180	1.2137	1.2092	1.2045	420	1.0
24		1.2369	1.2328	1.2285	1.2240	1.2194	1.2146	438	0.8
25		1.2481	1.2437	1.2392	1.2346	1.2299	1.2251	455	0.5
26	1.2634	1.2590	1.2545	1.2499	1.2452	1.2403	1.2354	467	0.6
27	1.2749	1.2703	1.2656	1.2608	1.2559	1.2510	1.2460	483	0.4
28	1.2868	1.2818	1.2768	1.2718	1.2668	1.2617	1.2567	502	0.1
29	1.2981	1.2930	1.2879	1.2828	1.2777	1.2725	1.2674	512	0.1
30	1.3098	1.3045	1.2993	1.2940	1.2888	1.2835	1.2783	525	0

MAGNESIUM CHLORIDE, MgCl$_2$

d_4^0 = sp. gr. = [(0.99987 + 0.008652p + 16.26 × 10$^{-6}p^2$ + 487.7p^3) × 10^{-9} ± 0.03%] g ml^{-1} (6).

$d_t = (d_0 - \mathrm{a}t - \mathrm{b}t^2) \pm 0.05\%$ (23.5).

p	−30°	−20°	−10°	0°	10°	20°	30°	a×10^6	b×10^6
5				1.0436	1.0426	1.0404	1.0372	50	5.5
6				1.0525	1.0513	1.0491	1.0459	70	5.0
7				1.0614	1.0600	1.0577	1.0545	95	4.5
8				1.0704	1.0689	1.0665	1.0633	105	4.5
9				1.0794	1.0778	1.0753	1.0719	115	4.5
10				1.0885	1.0867	1.0842	1.0807	145	3.5
11				1.0977	1.0958	1.0932	1.0899	155	3.5
12			1.1083	1.1069	1.1049	1.1022	1.0989	172	3.1
13			1.1177	1.1162	1.1141	1.1114	1.1081	180	3.0
14			1.1272	1.1255	1.1233	1.1205	1.1173	197	2.6
15			1.1368	1.1350	1.1327	1.1299	1.1266	205	2.5
16			1.1465	1.1445	1.1421	1.1392	1.1360	222	2.1
17			1.1561	1.1540	1.1515	1.1486	1.1453	230	2.0
18		1.1677	1.1659	1.1637	1.1611	1.1582	1.1549	238	1.8
19		1.1778	1.1758	1.1735	1.1709	1.1679	1.1647	247	1.6
20		1.1878	1.1857	1.1833	1.1806	1.1776	1.1743	255	1.5
21	1.1995	1.1977	1.1956	1.1932	1.1905	1.1874	1.1840	258	1.6
22	1.2099	1.2080	1.2058	1.2033	1.2005	1.1974	1.1940	264	1.5
23		1.2186	1.2161	1.2134	1.2105	1.2074	1.2041	280	1.0
24		1.2289	1.2263	1.2236	1.2206	1.2175	1.2142	285	1.0
25		1.2393	1.2367	1.2339	1.2310	1.2278	1.2245	288	0.8
26		1.2500	1.2473	1.2444	1.2413	1.2381	1.2347	298	0.8
27			1.2578	1.2549	1.2518	1.2486	1.2452	298	0.8
28			1.2686	1.2656	1.2625	1.2592	1.2558	307	0.7
29			1.2794	1.2763	1.2731	1.2698	1.2664	315	0.5
30			1.2903	1.2872	1.2840	1.2807	1.2773	315	0.5



HEAT CAPACITY (SPECIFIC HEAT)

Conversion Factors

1 joule g^{-1} per °C = 0.2389 g-cal_{15} g^{-1} per °C or BTU_{60} $lb.^{-1}$ per °F
= 2.778×10^{-7} kw-hr g^{-1} per °C
1 joule cm^{-3} per °C = 1.994 BTU_{60} $gal.^{-1}$ per °F (U. S.)
= 2.394 BTU_{60} $gal.^{-1}$ per °F (Brit.)

SODIUM CHLORIDE, NaCl

$c_{20} = [0.6516 + (0.3475)(0.96285)^p]$ cal_{15} g^{-1} per °C; $c_t = [c_{20} + a(t - 20) - b(t - 20)^2]$ cal_{15} g^{-1} per °C (2).

p	Joule per gram per °C ± 0.1 %					a×10⁴	b×10⁶
	−10°	0°	10°	20°	30°		
5		3.911	3.921	3.931	3.940	2.3	0
6		3.862	3.874	3.886	3.896	2.6	−1
7		3.816	3.830	3.843	3.854	2.8	−2
8		3.771	3.787	3.801	3.813	3.0	−3
9		3.730	3.747	3.761	3.772	3.0	−4
10		3.689	3.708	3.723	3.734	3.1	−5
11		3.651	3.670	3.686	3.697	3.2	−5
12		3.615	3.635	3.650	3.661	3.2	−5
13		3.580	3.600	3.615	3.627	3.2	−5
14		3.547	3.567	3.583	3.593	3.1	−6
15	3.491	3.516	3.536	3.551	3.561	3.0	−6
16	3.463	3.487	3.506	3.520	3.530	2.8	−6
17	3.435	3.458	3.477	3.491	3.500	2.7	−6
18	3.409	3.432	3.450	3.463	3.471	2.5	−6
19	3.384	3.406	3.423	3.435	3.443	2.3	−6
20	3.361	3.382	3.398	3.409	3.415	2.0	−6
21	3.338	3.358	3.374	3.384	3.389	1.8	−6
22	3.318	3.337	3.351	3.359	3.363	1.5	−6
23*	3.298	3.315	3.328	3.336	3.340	1.5	−5
24	3.279	3.295	3.306	3.313	3.316	1.2	−5
25	3.261	3.276	3.286	3.292	3.293	0.9	−5

* For $p = 23$; $c = 3.277$ at −20°.

CALCIUM CHLORIDE, CaCl₂

$c_0 = [(1.0138 - 0.018091p + 197.34 \times 10^{-6}p^2) + 0.002]$ cal_{15} g^{-1} per °C (10).

$c_t = (c_0 + at + bt^2) \pm 0.002$ cal_{15} g^{-1} per °C.

p	Joule per gram per °C								a×10⁴	b×10⁶
	−40°	−30°	−20°	−10°	0°	10°	20°	30°		
8					3.691	3.712	3.733	3.754	5.0	0
9					3.628	3.649	3.670	3.691	5.0	0
10					3.570	3.591	3.612	3.633	5.2	0
11					3.511	3.532	3.553	3.578	5.4	0
12					3.453	3.478	3.500	3.524	5.5	0
13					3.398	3.423	3.444	3.469	5.7	0
14					3.344	3.369	3.393	3.419	5.9	0
15					3.294	3.319	3.344	3.369	6.0	0
16				3.214	3.243	3.268	3.294	3.315	6.8	−4
17				3.164	3.193	3.222	3.243	3.264	6.9	−4
18				3.118	3.147	3.176	3.197	3.218	7.0	−4
19				3.072	3.101	3.130	3.155	3.176	7.1	−4
20				3.026	3.059	3.089	3.114	3.135	7.1	−4
21				2.984	3.017	3.047	3.068	3.093	7.2	−4
22			2.909	2.946	2.976	3.005	3.030	3.051	7.3	−4
23			2.871	2.904	2.938	2.967	2.992	3.017	7.4	−4
24			2.837	2.871	2.900	2.930	2.955	2.980	7.2	−3
25			2.804	2.837	2.867	2.896	2.921	2.946	7.0	−2
26		2.745	2.775	2.804	2.833	2.858	2.888	2.912	6.7	−1
27		2.716	2.745	2.775	2.800	2.829	2.854	2.883	6.6	0
28	2.662	2.687	2.716	2.745	2.770	2.800	2.825	2.854	6.5	0
29	2.653	2.674	2.695	2.716	2.741	2.770	2.796	2.825	6.0	2
30	2.641	2.657	2.670	2.691	2.716	2.741	2.766	2.796	5.7	3

MAGNESIUM CHLORIDE, MgCl₂

$c_0 = [(1.00070 - 0.016746p + 144.9 \times 10^{-6}p^2) \pm 1\%]$ cal_{15} g^{-1} per °C (23). $c_t = (c_0 + at)$ cal_{15} g^{-1} per °C (23).

p	Joule per gram per °C							a × 10⁴
	−30°	−20°	−10°	0°	10°	20°	30°	
5				3.879	3.888	3.896	3.905	1.9
6				3.817	3.825	3.838	3.846	2.4
7				3.754	3.767	3.779	3.787	2.8
8				3.691	3.704	3.720	3.733	3.3
9				3.633	3.649	3.662	3.679	3.7
10				3.574	3.591	3.607	3.624	4.1
11				3.515	3.536	3.553	3.573	4.5
12			3.440	3.461	3.482	3.503	3.520	4.8
13			3.386	3.407	3.428	3.448	3.474	5.2
14			3.327	3.352	3.373	3.398	3.419	5.5
15			3.273	3.297	3.323	3.348	3.369	5.8
16		3.197	3.222	3.248	3.273	3.297	3.323	6.0
17		3.147	3.172	3.197	3.222	3.248	3.277	6.2
18		3.093	3.122	3.147	3.172	3.202	3.227	6.3
19		3.047	3.076	3.101	3.126	3.155	3.181	6.4
20	2.976	3.001	3.030	3.055	3.084	3.109	3.139	6.5
21	2.930	2.955	2.984	3.009	3.038	3.063	3.093	6.5
22		2.912	2.938	2.967	2.992	3.022	3.047	6.5
23		2.871	2.896	2.921	2.950	2.976	3.005	6.5
24		2.829	2.854	2.883	2.909	2.938	2.963	6.5
25		2.787	2.817	2.842	2.867	2.896	2.921	6.4
26		2.750	2.779	2.804	2.829	2.858	2.883	6.4
27		2.708	2.737	2.762	2.787	2.817	2.842	6.3
28			2.699	2.729	2.754	2.779	2.808	6.2
29			2.666	2.691	2.716	2.741	2.766	6.1
30			2.632	2.657	2.683	2.708	2.733	6.0

VISCOSITY

Data for low temperatures, very meager. The information available is expressed by the following equations and tables: (*cf.* I. C. T. sections on viscosity of H_2O and salt solutions).

NaCl, $\eta = [(\eta_w + ap + bp^2) \pm 0.5\%]$. Range, 0–30° and 5–20% (18, 19, 32, 37).

CaCl₂, $\log \eta = [(\log \eta_w + ap + bp^2) \pm 3\%]$. Range 10–30°, 5–30% (37).

For $p = 30.89\%$, $\eta = [(0.139_2 + 0.00481_5 t + 47.2_7 \times 10^{-6}t^2) \pm 5\text{–}10\%?]$. Range, −50 to 30° (39).

MgCl₂, $\eta_{25°} = 0.895 + 0.0339p + 900 \times 10^{-6}p^2 + 82.14 \times 10^{-6}p^3$. Range 0–22%. Precision ±0.5%. Accuracy ? (18, 41).

		0°	5°	10°	15°	20°	25°	30°
CaCl₂	a×10³=			113.94	54.61	0	−47.69	−95.83
	b×10³=			6.0996	6.4427	6.8451	7.0553	7.6747
	c×10⁶=			380.50	381.31	375.85	370.27	352.68
21.56%	η=		3.113(17)	2.729(17)	2.412(17)			
NaCl	a×10³=	4.90	9.20	10.65	10.90	10.70	10.20	9.75
	b×10³=	1.930	1.410	1.125	0.930	0.790	0.690	0.605
0%	η_w=	1.794	1.519	1.310	1.145	1.009	0.895	0.800
20%	η=	2.663	2.269	1.973	1.733	1.538	1.376	1.240

LITERATURE

(For a key to the periodicals see end of volume)

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(20) Jessup, Peffer and Taylor, U. S. Bur. Standards, *O.* (21) Jones and Chambers, *11*, **23**: 89; 00. (22) Jones and Getman, *11*, **27**: 430; 02. (23) Koch, *148*, **29**: 37; 22. (23.5) *Idem.*, **31**: 105; 24. (24) Loomis, *8*, **51**: 500; 94. (25) Kohlrausch and Hallwachs, *8*, **53**: 14; 94. (26) Kohlrausch, *8*, **6**: 1; 79. (27) Marignac, *149*, **39**: 273; 70. *13*, **8**: 364; 70 (Suppl.). (28) Möller, *8*, **117**: 386; 62. (29) Nicol, *3*, **23**: 385; 87.

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(40) van't Hoff and Meyerhoffer, *7*, **27**: 75; 98. (41) Wagner, *7*, **5**: 31; 90.

SIEVES AND SCREENS

LEWIS V. JUDSON

INTRODUCTION

The accuracy of woven metal sieves is often very high. An idea of the accuracy which may reasonably be expected in precision testing sieves may be obtained from the data in Table 2. For many purposes, such a narrow tolerance is not necessary and should not be required. An abnormally wide separation between two adjacent parallel wires may cause a serious error, especially in sieves with narrow openings. In bolting cloth, the diameters of the threads and the widths of the openings vary, not only from brand to brand, but even from bolt to bolt of the same brand. When accuracy is required, it is necessary to select particular portions of selected bolts of the cloth. Sieves are commonly designated either by the mesh per unit of length, or by the mesh per unit of area. Several different units of length (and of area) are employed. For U. S. A. grain sieves, *see* following publications of the U. S. Department of Agriculture: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90); *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-GI-Form No. 142); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291); *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

INTRODUCTION

La précision des tamis métalliques tissés est souvent très grande. On peut se faire une idée de la précision qui peut être raisonablement attendue des tamis pour essais de précision, en consultant les données de la Table 2. Pour beaucoup de buts, une tolérance aussi étroite n'est pas nécessaire et ne doit pas être exigée. Une séparation anormalement large entre deux fils adjacents parallèles peut occasionner une sérieuse erreur spécialement dans les tamis à réseaux fins. Dans les étamines, les diamètres des fils et la largeur des ouvertures varient, non seulement de marques à marques, mais aussi souvent d'étamines à étamines de la même marque. Lorsqu'on exige de la précision, il est nécessaire de choisir des portions particulières d'étamines choisies. Les tamis sont communément désignés ou par le nombre de mailles par unité de longueur, ou par le nombre de mailles par unité de surface. On emploie plusieurs unités de longueur (et de surface) differentes. Pour les tamis de grains des États Unis, voir les publications suivantes du Département d'Agriculture des États Unis: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90) *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-Form No. 142); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291) *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S A.-GI-No. 26).

EINLEITUNG

Gewebte Metallsiebe haben häufig einen hohen Grad von Genauigkeit. Eine Vorstellung davon, wieweit sich diese bei der Präzision der Prüfung treiben lässt, erhält man aus den Angaben der Tafel 2. Für viele Zwecke ist eine so kleine Toleranz nicht notwendig und soll auch nicht gefordert werden. Eine abnormal grosse Entfernung zwischen zwei benachbarten parallelen Drähten, kann Ursache grösserer Fehler werden, besonders bei Sieben mit engen Öffnungen. Bei Siebtüchern ändert sich der Durchmesser der Fäden und die Öffnungsweite nicht nur von Marke zu Marke, sondern sogar in den Tüchern derselben Marke. Ist hier Genauigkeit gefordert, so ist es notwendig, gewisse Teile der gewählten Tücher auszusondern. Siebe sind im allgemeinen entweder durch die Zahl der Maschen pro Längen- oder pro Flächeneinheit gekennzeichnet. Es sind einige verschiedene Längen- und Flächenmasse üblich. Für die Siebe (Korn, etc.) der Vereinigten Staaten siehe die folgenden Abhandlungen des U. S. Department of Agriculture: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90) (Korn Standard); *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-GI-No. 142) (Sandzucker); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291) (Mühlen Reis); *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

INTRODUZIONE

Gli stacci di tessuto metallico hanno spesso un alto grado di esattezza. Una idea della approssimazione che può ragionevolmente attendersi con stacci per saggi di precisione, può dedursi dai dati della Tabella 2. Per molti scopi una tolleranza così stretta non è necessaria, e non potrebbe pretendersi. Una distanza anormalmente grande fra due fili paralleli adiacenti può essere causa di gravi errori, specialmente negli stacci a fori piccoli. Nelle tele da buratti, il diametro dei fili e l'ampiezza dei fori variano non solo da marca a marca, ma anche nei tessuti di una stessa marca. Se si richiede grande esattezza è necessario scegliere particolari porzioni di tessuti scelti. Gli stacci sono in genere designati in base al numero di maglie per unità di lunghezza o di superficie. Le unità adoperate sono differenti.

Per gli stacci da granaglie degli S. U. A. vedi le pubblicazioni seguenti del U. S. Department of Agriculture: *Handbook of Official Grain Standards for Wheat, Shelled Corn, Oats, and Rye* (U. S. G. S. A. Form No. 90); *Handbook of United States Grades for Grain Sorghum* (U. S. G. S. A.-GI-Form No. 142); *United States Grades for Milled Rice* (Dept. Agriculture Circular 291); *Proposed Revision of United States Grades for Rough Rice* (Mimeograph U. S. G. S. A.-GI-No. 26).

TABLE 1.—SERIES OF WOVEN SIEVES

For pharmaceutical sieves, *see* Table 3

D = diameter of wire (mm); O = width of opening (mm).

Sieve designation[a]	United States of America					Great Britain	France			Switzerland
	U. S. Standard[b]		Tyler[c, d] Standard screen scale	Howard[d, e] and Morse sieve series (old)	Newark[d, e] "Market Grade" testing sieves	Institute[d, f] Mining and Metallurgy; Standard screens	Suter-Strehler[g] sieve series	Weiller and Cie.	Franck and Cie.	Market[h] Grade testing sieve cloth
N	D	O	O	O	O	O	O			O
			*26.67					Designated by number of meshes per 27.777 mm; *cf.* preceding column. Sieves of the same designation are woven with wires of various sizes, and O varies accordingly: for example, the catalogue lists No. 20 sieve in 14 different sizes of wire.	Designated by number of meshes per 27 mm; for approximate size of openings, *see* following column.	
			22.43							
			*18.85							
			15.85							
			*13.33							
			11.20							
2			* 9.423				12.1			12
2½			7.925				9.5			9.5
3			* 6.680				8.1			7.8
3½			5.613							
4	1.27	4.76	* 4.699	5.11			5.94			5.8
5	1.12	4.00	3.962			2.540	4.66			4.5
6	1.02	3.36	* 3.327	3.33			3.83			3.7
7	0.92	2.83	2.794				3.27			3.2
8	0.84	2.38	* 2.362	2.43		1.574	2.77			2.7
9			1.981							2.4
10	0.76	2.00	* 1.651	1.86		1.270	2.18			2.1
11										1.9
12	0.69	1.68	1.397	1.49		1.056	1.81			1.75
14	0.61	1.41	* 1.168	1.23			1.54			1.45
15										1.35
16	0.54	1.19	0.991	1.07		0.792	1.34			1.30
18	0.48	1.00		0.93			1.14			1.10
20	0.42	0.84	* 0.833	0.85	0.864	0.635	1.03			0.95
22½										0.87
24			0.701	0.71						
25	0.37	0.71					0.75			0.76
27½										0.66
28			* 0.589							
30	0.33	0.59		0.54	0.516	0.421	0.65			0.62
32			0.495							
35	0.29	0.50	* 0.417	0.44			0.55			0.53
40	0.25	0.42		0.38	0.381	0.317	0.494			0.47
42			0.351							
45	0.22	0.35								
48			* 0.295							
50	0.188	0.297		0.28	0.279	0.254	0.376			
60	0.162	0.250	0.246	0.23	0.234	0.211	0.30			
65			* 0.208							
70	0.140	0.210		0.20	0.185	0.180	0.26			
80	0.119	0.177	0.175	0.174	0.173	0.157	0.227			
90				0.155	0.155	0.139	0.209			
100	0.102	0.149	* 0.147	0.142	0.140	0.127	0.178			
110				0.127	0.130					
115			0.124							
120	0.086	0.125		0.117	0.117	0.107	0.151			
130				0.104	0.109		0.134			
140	0.074	0.105		0.100	0.107		0.128			
150			* 0.104	0.091	0.104	0.084	0.125			
160				0.088	0.097					
170	0.063	0.088	0.088	0.083	0.089					
180				0.079	0.084		0.094			
190				0.079	0.079					
200	0.053	0.074	* 0.074	0.071	0.074	0.063	0.089			
230	0.046	0.062			0.065					
250			0.061		0.061					
270	0.041	0.053	0.053		0.053					
300					0.046					
325	0.036	0.044	0.043		0.043					

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[a] Sieve designation is number of meshes per linear unit. For U. S. and Great Britain the unit is the inch (=25.4 mm), excepting for the U. S. Standard, for which the unit varies slightly but always approximates closely to the inch; for the Suter-Strehler series it is 27.8 mm: and for Switzerland it is 27 mm.

[b] Specifications require a frame 8 in. in diameter (3 in. for paint pigments), and either 5 cm or 2.5 cm high (above cloth). For tolerances, *see* Table 2. This series has been tentatively adopted, as standard, by the American Society for Testing Materials, using a preferred designation of width of opening in microns. Sieves of this series now used by most A. S. T. M. committees, and specifications requiring other series, are in process of revision.

[c] Widths of openings in successive sieves are related as 1 to $\sqrt[4]{2}(=1.189)$: those starred (*), as 1 to $\sqrt{2}(=1.414)$. The scale is based upon the No. 200 sieve with openings 0.0029 in. wide. Successive sieves finer than No. 4 nominally correspond, within limits of tolerance, with successive sieves of the U. S. Standard series, but there are notable differences in the designations of the two series.

[d] $D + O = 25.4/N$.

[e] U. S. Standard is now regular with Howard and Morse, Inc., but the Old Howard and Morse Standard is obtainable.

[f] This series is the standard of British Engineering Standards Committee. [g] $D + O = 27.8/N$. [h] $D + O = 27/N$.

TABLE 2.—TOLERANCES FOR U. S. STANDARD SIEVES*

D = diameter of wire; O = width of opening; min. = minimum; max. = maximum; av. = average. Unit: 1% of specified value.

Sieves	O		D_{av}	
	Av.	Max.	Min.	Max.
4 to 18	±3	10	−15	+30
20 to 45	±5	25	−15	+30
50 to 120	±6	40	−15	+35
140 to 200	±8	60	−15	+35
230 to 325	±8	90	−15	+35

* *See* Table 1.

Example: For sieve No. 30 of U. S. Standard, the average diameter of the wire must be not more than 15 % smaller or 30 % greater than 0.33 mm (Table 1); the width of the average opening must not differ from 0.59 mm by more than ±5 % (= ±0.01 mm), and the width of the largest opening must not exceed 0.59 mm by more than 25 % (=0.15 mm).

TABLE 3.—PHARMACEUTICAL SIEVES

In the body of the table are indicated the sieves composing a complete set, and the customary designations of the several sieves: * indicates that the sieve is designated by the number of meshes per cm as given in first column (Italy is an exception: *see* note). "Width" = width of opening.

Meshes per cm	Width (mm)	Austria	Belgium	Denmark	Finland	France		Germany	Great Britain	Hungary	Italy[2]	Japan	Mexico	Netherlands[3, 4]	Norway	Russia	Sweden[6]	Switzerland[3]	U. S. A.
						Old[1]	New												
	8	I							Commercial sieves not specifically designated						1				Selected from U. S. Standard. Table 1
	6									I									
	5																		
2			*	*		5	I												
	4				I					II		1	1		2				
3			*	*		8	II												
	3	II			II							2	2						
	2	III			III					III		3	3		3				
5			*	*															
6						16	III												
	1.5																		
9						25	IV												
10		IV	*	*						IV	*	4	4	*	4	IV	No. 10		
	0.75				IV			4											
15						40	V											IV	
18																III			
20			*											*	5		No. 20		
22						60	VI												
25										V									
26		V				70	VII					5							
27																		V	
30			*	*		80	VIII				*			*	6		No. 30		
32													5			II			
	0.30				V			5											
37						100	IX											VI	
40			*							VI	*	6		*	7	I	No. 40		
45						120	X												
48		VI																	
50				*[6]									6	*					
51																		VII[6]	
52						140	XI												
	0.15				VI			6											
70													7						
Grading[5]		*a*	*b*	*c*	*a*	*d*	*d*	*e*	*h*	*a*	*a*	*c*	*d*		*d*	*f*	*g*	*d*	*i*

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[1] Numbers in this column are the number of meshes per "pouce" (=2.7 cm), and are the customary commercial designations of the sieves.

[2] Sieves designated by number of openings per cm² = square of number of meshes per cm.

[3] Also sieves with round holes; diameters, 1.5 mm, 3 mm, and 5 mm.

[4] Manufacturers commonly designate sieves by meshes per 26 mm.

[5] Material which passes a sieve of 9 or 10 meshes per cm is considered a "powder," and powders are graded, depending upon the country, in accordance with one of the following systems:

(*a*) Coarse, fine, very fine; (*b*) "farines," medium fine, fine, very fine; (*c*) coarse, medium, fine; (*d*) coarse, medium fine, fine, very fine; (*e*) coarse, medium fine, fine; (*f*) coarse, medium, fine, very fine; (*g*) coarse, medium coarse, medium fine, fine; (*h*) 20 to 30 mesh = coarse powder, 40 to 60 = powder, 80 to 120 = fine powder; (*i*) No. 12 = very coarse, No. 20 = coarse, No. 40 = moderately coarse, No. 50 = moderately fine; No. 60 = fine, No. 80 = very fine; No. 6, No. 30, and No. 100 also used.

[6] Silk sieves.

Table 4.—Bolting Cloth

Designation	Switzerland,* mesh per linear inch (=25.4 mm)		France
	Bodmer	Wydler	
No.			Designated by number of meshes per pouce (=27 mm)
0000	18	18	
000	23	23	
00	28	29	
0	38	38	
1	48	48	
2	54	54	
3	58	58	
4	62	62	
5	66	66	
6	74	74	
7	82	82	
8	86	86	
9	97	97	
10	109	109	
11	116	116	
12	124	125	
13	130	129	
14	139	140	
15	148	149	
16	157	157	
17	165	163	
18	170	166	
19	175	169	
20	180	175	
21	185	185	
25	200	197	

* The "quality" of the cloth is determined by the coarseness of the thread used. The figures given apply to the Standard, the Extra (X), and the Double Extra (XX) qualities. For the Triple Extra Heavy (XXX) quality the number of meshes per inch is in each case one less than the number given in the table. Diameter of threads is not specified. *Grit gauze* is designated by number of meshes per inch (= 25.4 mm) and is obtainable from No. 14 to No. 86.

Table 5.—Woven Sieves for Special Purposes (Metric Designation)

Sand and cement sieves, except as indicated for pharmaceutical sieves, *see* Table 3

In the body of the table are given the widths of the openings (O) in mm. If D = diameter of wire (mm) and N = number of meshes per cm, $D = 10/N - O$. Sieves are woven, except as noted. * indicates that neither D nor O is specified.

Meshes per cm^2	64	144	225	324	900	2500	4900	5000	6400	
Meshes per cm = N =	8	12	15	18	30	50	70	70.71	80	
	Millimeters									
Austria	0.85	0.53			0.23		0.09			
Argentina					0.18		0.09			a
Belgium	0.85	0.53			0.18					
Brazil					*					
China	British sieves used to some extent. *See* Table 6									
Denmark					0.222	0.13		0.09		b, c
Finland					*		*			
France				0.36	0.18		0.09			d
Germany					0.222					b, e
Germany (for coal dust, etc.)[k]	Designation is N; $O = 6/N$; $D = 4/N$									
Great Britain	*See* Table 6									
Hungary	0.85	0.53			0.23		0.09			
Italy					0.18		0.09			
Japan	0.85	0.53	0.47		0.23					
Mexico	*See* Table 6									
Netherlands					0.23		0.09			f
Norway					0.23			0.09		
Portugal					*			*		g
Rumania					*		*			
Russia	0.85	0.53	0.47		0.23		0.09			h
Spain				0.36	0.18		0.09			
Sweden					0.222					b, i
Switzerland	0.85	0.53			0.23		0.09			j
United States of America	*See* Table 6									
Uraguay					*		*			

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[a] Also copper plates with round holes 1.5 mm and 1.0 mm in diameter.

[b] Also, for cement sand, plate 0.25 mm thick with round holes 1.350 mm and 0.775 mm in diameter.

[c] For sand and pebbles, plates with round holes 60, 30, 15, 10, 5, 2, and 0.5 mm in diameter.

[d] Also plates with round holes 2, 1.5, 1, and 0.5 mm in diameter. For other woven sieves *see* Table 1.

[e] Commercial designations recognized: meshes per inch (25.4 mm), meshes per old French inch (=pouce = 27 mm), meshes per Rhenish in. (=Zoll = 26.15 mm) and meshes per cm, as well as meshes per cm^2.

[f] Sieves commonly designated by meshes per inch of 26 mm.

[g] French sieves are used in flour industry: British sieves, in mining industry.

[h] Sieves in common use are designated by meshes per linear inch, meshes per linear verchoc (44.45 mm), and meshes per cm^2.

[i] Tidbeck sieves are designated by meshes per inch of 25 mm.

[j] For other woven sieves, *see* Tables 1, 3, 4. For *Grit Gauze see* Table 4, footnote.

[k] Tolerance in mean value of $O = \pm 5\%$; max. deviation for N = 1 to 7 is ±10 %, 8 to 20 is ±20 %; 20 to 100 is ±30 %. Tolerance in mean value of D for N = 1 to 4 is ±3 %, 5 to 70 is ±4 %, 80 to 100 is ±5 %; max. deviation for same limits of N are ±6 %, ±8 %, ±10 %, respectively. Series consists of N = 1, 2, 3, 4, 5, 6, 8, 10, 11, 12, 14, 16, 20, 24, 30, 40, 50, 60, 70, 80, 100.

TABLE 6.—WOVEN WIRE SIEVES FOR SPECIAL PURPOSES* (INCH DESIGNATION)

American and British; for pharmaceutical sieves, *see* Table 3

D = diameter of wire; δD = amount by which the average D of all the wires in one direction may depart ($\pm$) from value specified for D: δn = allowable variation ($\pm$) in n per whole cm; max. [min.] = maximum [minimum] allowable value; N = approximate number of meshes per in.; n = number of meshes per cm; O = width of opening; S = specified value.

Sieve designation†	Unit of O, D, δD = 1 mm																Sieve designation‖	Unit of O, D = 1 mm		
	Cement and sand										Sand and fine highway material (cement concrete excepted). U. S. A.‡									
	U.S.‡§	Canada§	Mexico§	Great Britain††															Aggreg.‡¶ U.S.	Stone** G.B.
				O		n		D§												
N	O	O	O	S	Max.	Min.	Max.	S	Min.	Max.	O	n	δn	D	δD			O	D	D
10											2.00	3.9	0.04	0.56	0.05		3	76.0	6.3	
20	0.85	0.85		0.85	1.02	7.5	8.3	0.42	0.41	0.43	0.85	8	0.2	0.40	0.015		2	50.8	4.88	
30	0.57	0.57		0.57	0.69	11.4	12.2	0.27	0.27	0.28	0.50	12	0.4	0.33	0.012		1$\frac{1}{2}$	38.0	4.50	
40											0.36	16	0.6	0.26	0.010		1	25.4	4.12	3.7
50											0.29	20	0.8	0.21	0.010		$\frac{3}{4}$	19.0	3.42	3.7
76				0.224	0.28	29.1	30.7	0.112	0.107	0.117							$\frac{1}{2}$	12.7		3.0
80											0.17	31	1	0.15	0.008		$\frac{3}{8}$	9.5	2.33	2.6
100	0.14		0.14								0.14	39	1	0.116	0.008		$\frac{1}{4}$	6.4		2.3
180				0.097	0.127	69.3	72.4	0.046	0.041	0.051							$\frac{1}{8}$	3.2		1.8
200	0.074	0.074	0.066								0.074	79	3	0.053	0.005		$\frac{1}{16}$	1.6		1.4

* Sieves selected from the series given in Table 1 are not separately considered here.

† Designation is meshes per inch, or meshes per inch^2 in the form "10 × 10," etc.

‡ Sieves specified by American Society for Testing Materials; also wire sieves of 400 meshes per cm^2 are specified for certain chemical analyses of metals; for coke, sieves with openings, 2.5, 1.75, 1.25, 0.75, and 0.5 in. wide are used. *See also* Table 1.

§ $D + O = 25.4/N$.

‖ Designation is width of opening in inches; British use the form 3 × 3, etc.

¶ Concrete aggregates. Tolerance: average opening, ±3 %; max. O, ±10 %; D, ±10 %.

** Stone chippings. For broken stone, *see* Table 7.

†† British Engineering Standards Committee's sieves. Frames 203.20 mm square, at least 69.85 cm deep; cloth woven (not twilled).

TABLE 7.—GAGES FOR BROKEN STONE AND SLAG, ETC.

American and British

U. S. A.*						Great Britain†	
Diameter		Diameter		Diameter		Size of stone	Diameter of hole
in.	mm	in.	mm	in.	mm		mm
4	101.6	2	50.8	0.75	19.0	3-in.	76.2
3.5	88.9	1.5	38.1	0.5	12.7	2.5-in.	63.5
3	76.2	1.25	31.8	0.25	6.4	2-in.	50.8
2.5	63.5	1	25.4			1.5-in.	38.1

* Round holes, specified by their diameters in inches. For sizing gypsum rings 76, 38, and 25 mm in diameter are used.

† Gages are of sheet metal at least 5 mm thick and contain both circular holes and slots.

SACCHARIMETRY, THE PROPERTIES OF COMMERCIAL SUGARS AND THEIR SOLUTIONS

Frederick Bates, F. P. Phelps, C. F. Snyder

Properties.—Under each sugar the various properties of the sugar and its solutions are given in the following order: optical rotation, refractive index, density, solubility, mutarotation, hydrolysis and decomposition.

Propriétés.—Sous chaque sucre on trouvera les propriétés variées du sucre et de ses solutions disposées dans l'ordre suivant: rotation optique, indice de réfraction, densité, solubilité, mutarotation, hydrolyse et décomposition.

Eigenschaften.—Unter jedem Zucker werden die verschiedenen Eigenschaften und die seiner Lösungen in folgender Ordung angegeben: Rotation, Refraktions-Index, Dichte, Löslichkeit, Multirotation, Hydrolyse und Zersetzung.

Proprietà.—Per ogni zucchero, le sue proprietà e quelle delle soluzioni sono riportate nell'ordine seguente: rotazione ottica, indice di rifrazione, densità, solubilità, mutarotazione idrolisi e scomposizione.

INTRODUCTION

Saccharimetric Methods and Standards

Specific Rotation.—The specific rotation $[\alpha]$ of any substance in the dissolved state is represented and defined by the equation

$$[\alpha]_X^{t^\circ} = \frac{\alpha}{lC} = \frac{\alpha}{lpd}$$

where t designates the temperature of measurement, X is a character used to identify the wave length of the light source used, α is the observed rotation in circ. deg., l the length of the solution in dm, C its concentration in g per ml at $t°$, p its concentration in wt. %, and d its density in g/ml at $t°$. $[\alpha]$ varies with X, and to a less extent with t and C (or p). Wherever possible the values of the specific rotations of the more important sugars are given at definite intervals of concentration. $[\alpha]$ for all intermediate concentrations may be found by interpolation.

Saccharimetric Method.—Since monochromatic light sources are difficult to obtain, it is frequently more convenient to use a white-light source and a quartz-wedge saccharimeter. This saccharimeter is particularly applicable to the sugar group because the rotatory dispersions of quartz and the common sugars are very similar. The conditions for accurate observing are improved if the violet end of the spectrum is absorbed by the potassium bichromate cell. The saccharimetric scale is defined by the rotation of sucrose, its hundred point being the rotation of 26 g (in air, $d = 0.0012$, brass weights) in 100 ml of solution. Therefore in order to determine a sugar having a different rotatory power, the weight used must be adjusted to the sucrose scale, *i.e.*, the saccharimetric normal weight of the sugar in question is that weight which, dissolved in 100 ml of solution, will give a rotation of 100° on the sucrose scale. To compute this weight use, whenever the data are available, the results of direct determinations of the values of the rotations on the sucrose scale.

In the case of the first four sugars of the following table, determinations have been made of the relation between the rotation in sucrose deg. (°*S*) and circ. deg. of sodium light for the same solution. If this relation is known, the saccharimetric normal weight for the saccharimeter can be computed from the known specific rotation.

In the case of many sugars no direct determinations of the relative values of the sugar deg. and circ. deg. are available, and in these instances the saccharimetric normal weight must be computed from the relative specific rotations of sucrose and of the sugar in question on the assumption that the rotation dispersion of all the sugars is the same as that of sucrose, which is not strictly true. Saccharimetric normal weights so computed must therefore be considered only as the nearest approximation at present available. The computation depends upon the assumption that the saccharimetric normal weights of the sugars vary inversely as their specific rotations.

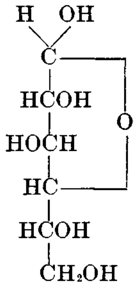
SACCHARIMETRIC NORMAL WEIGHTS, W_N

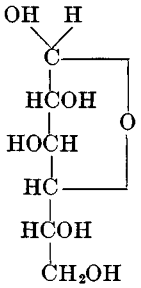
In air, $d = 0.0012$, brass weights

Sugar	1°*S* =	W_N
Dextrose	0.3448	32.24$_8$
Lactose	.3452	32.85$_7$
Maltose	.3449	12.47$_4$
Raffinose ($5H_2O$)	.3450	16.50$_7$
Levulose	calc.	18.59$_2$
Invert sugar	calc.	86.45$_0$

Thus in the determination of these sugars it is merely necessary to weigh out the appropriate normal weight of the sugar and proceed exactly as in the analysis of sucrose. The specific rotation is in general not exactly proportional to the concentration of the sugar, and for accurate work a correction should be applied for readings which vary much from the 100° point. Many experimenters advise using a variable saccharimetric normal weight according to the concentration of the sugar taken, but this requires a previous knowledge of the quantity of sugar present or a preliminary assay of the material. It is more convenient to use a uniform saccharimetric normal weight and to apply a correction for the various parts of the sugar scale.

Mutarotation.—In a very large class of sugars a considerable lapse of time is required for the dissolved sugar to exhibit a stable rotatory power. The rotation of the freshly prepared solution in general steadily changes according to the laws of unimolecular reactions, to a steady state, where no further change occurs. This phenomenon is called "mutarotation." The specific rotation of the sugar is commonly expressed in terms of this equilibrium condition. Mutarotation has been satisfactorily explained by the discovery of two modifications of each of the sugars in which the phenomenon exists. These two modifications have been designated the α- and β-forms. When the sugar crystallizes, but one of these forms separates from solution, usually on account of a considerable difference in solubility, and, consequently, when a fresh solution is prepared the rotatory power of this form is exhibited. The most plausible explanation of the isomerism of the α- and β-forms is connected with the end carbon atom which is capable of changing its relation to the rest of the molecule. For example, in the case of dextrose the mutarotation reaction is regarded as a balanced reaction between the two forms:—


α-*d*-Glucose
$[\alpha]_D^{20} = 113.4°$


β-*d*-Glucose
$[\alpha]_D^{20} = +19.0°$

The steady state is, under this hypothesis, a state in which the reaction velocities $\alpha \rightarrow \beta$ and $\beta \rightarrow \alpha$ are equal.

As the change of one form into the other obeys the laws of mass action and appears to be a unimolecular reaction, the mutarotation constant is expressed by the formula

$$k_1 + k_2 = \frac{1}{t} \log_{10} \frac{r_0 - r_\infty}{r_t - r_\infty},$$

r_0 and r_∞ being the initial and final rotations, and r_t the rotation at the time, t, from the start.

International Sugar Scale.—The Ventzke sugar scale, although in general use for many years, has never been fully understood by polariscopists generally. This has led to much confusion and to the use of 100 ml flasks on instruments standardized for use with the Mohr flask. In addition, 17.5°C is well below the temperature of the average laboratory. Because of these and other considerations the International Sugar Commission at the Paris meeting in 1900 recommended the use of a new definition of the 100° point based upon true ml and a standard temperature of 20°C. In order to divorce it as completely as possible from confusion with the Ventzke scale, the new scale is referred to as the international sugar scale because of its origin. The change to 20°C necessitated a change in the saccharimetric normal weight in order to keep the new scale comparable with the Ventzke. Correcting for the change in the specific rotation (−0.000184), the expansion of a glass tube (+0.000008), quartz wedge (−0.000130), and metal scale (−0.000018), the new weight becomes 26.000+ g. The *international sugar scale* was then defined at the Paris meeting as follows: The graduation of the saccharimeter and all readings shall be made at 20°C; 26 g (in air, $d = 0.0012$, brass weights) of sucrose are dissolved in water and the volume made up to 100 ml at 20°C. This will determine the 100° point.

Standardization of International Sugar Scale.—The 100°*S* point on the international sugar scale was determined by Herzfeld and Schönrock in 1900–1904 (33, 82), with the result that 100°*S* = 34.657° (λ = 589.25mμ). In 1916 Bates and Jackson (9) of the Bureau of Standards, as the result of an elaborate investigation, found that 100°*S* = 34.620 (λ = 589.25mμ). They found that the saccharimetric normal sucrose solution as defined by the International Sugar Commission did not read 100°*S* on saccharimeters standardized on the Herzfeld-Schönrock basis. Subsequently additional investigations were carried out at the Institut für Zucker-Industrie (52) and at the Research Institute for the Czechoslovakian Sugar Industry (87). The readings of the saccharimetric normal sucrose solution on the original Herzfeld-Schönrock scale are given in the following table:

Original Herzfeld-Schönrock determination	1900–1904	100.00°*S* (33, 82)
Bates and Jackson	1916	99.895 (99.870–99.91) (9)
Stanek	1921	(99.81–99.90) (87)
Kraisy and Traegel	1924	99.834 (99.775–99.895) (52)

Saccharimetric Scale Conversion Factors.—Comparisons may be made between the readings of different scales by means of the following conversion factors: 1° International sugar scale = 0.34620° angular rotation *D;* 1° French sugar scale = 0.21666° angular rotation *D;* 1° Wild sugar scale = 0.13284° angular rotation *D.* (Saccharimetric normal weight = 26.00 g International scale = 16.29 g French scale = 10.00 g Wild scale.)

Quartz Control Plates.—The accuracy of the readings on the quartz wedge saccharimeter is checked by means of quartz control plates accurately standardized for the mercury line, λ = 546.1mμ. In order to obtain a quartz rotation for λ = 589.25, use the equation

$$\frac{\phi_{\lambda=589.25}}{\phi_{\lambda=546.1}} = 0.85085 \ (^{6,\,9})$$

where ϕ is the rotation in circ. deg. By this method the errors due to the character of the sodium source of light are eliminated and the measurements of one observer may be readily compared with those of another. The rotation of quartz in circ. deg. at a temperature t is given by:

$$\phi_t = \phi_0\,(1 + 0.000144t), \text{ between 4 and 50°C}$$

THICKNESS OF THE NORMAL QUARTZ PLATE (^{9})

Wave length of light source, Å	Rotation of normal plate (Bates and Jackson)	Rotation of 1 mm of quartz at 20°C; light parallel to optic axis	Thickness of normal plate, mm
5892.5	34.620°	21.7182° (Gumlich)	1.5940
5892.5	34.620°	21.7283° (Lowry)	1.5934
5461	40.690°	25.5371° (Lowry)	1.5934

Rotation of Normal Quartz Plate (^{9}). Normal quartz plate = 100°*S* = 34.620° (λ = 5892.5 Å) at 20°C; 1° (λ = 5892.5 Å) = 2.8885°*S*. Normal quartz plate = 100°*S* = 40.690° (λ = 5461 Å) at 20°C; 1° (λ = 5461 Å) = 2.4576°*S*.

Absolute Rotation of Saccharimetric Normal Sucrose Solutions (^{9}).—The rotation of the saccharimetric normal sucrose solution for λ = 5461 Å by direct measurement is: 100° sucrose = 40.763° of arc. Since the rotation ratio for the saccharimetric normal solution for λ = 5892.5 Å and λ = 5461 Å is 0.84922° the rotation of the saccharimetric normal solution for λ = 5892.5 Å is 34.617°.

Rotation Ratios for Quartz and for Sucrose Solutions (^{9}).—The ratios of the rotations in circ. deg. of quartz and of sucrose solutions for two wave lengths are as follows: For quartz $\frac{\phi^{20}_{\lambda=5892.5\text{Å}}}{\phi^{20}_{\lambda=5461\text{Å}}}$ = 0.85085 and for sucrose $\frac{\phi^{20}_{=5892.5\text{Å}}}{\phi^{20}_{=5461\text{Å}}} = 0.84922$.

Rotatory Dispersion Curves of Quartz and of Sucrose Solution (^{9}).—The difference between the rotations of the normal quartz plate and the saccharimetric normal sucrose solution for λ = 589.25mμ is 0.003° and for λ = 546.1mμ, 0.073°. The values indicate that the rotatory dispersion curves of plate and solution cross at about λ = 585mμ. The reading of the saccharimetric normal solution on the true saccharimeter scale with the source λ = 589.25mμ has been calculated to be 99.99°*S*.

Rotation Difference, in Sucrose Degrees, for Saccharimetric Normal Sucrose Solution between λ = 5461 Å *and* λ = 5892.5 Å.—Saccharimeter reading (λ = 5461 Å) − saccharimeter reading (λ = 5892.5 Å) = 0.19_2°*S* (^{9}).

$C_{12}H_{22}O_{11}$, SUCROSE

(Composition: Levulose < > Dextrose)

Optical Rotation

IN H_2O

(p = wt. % sucrose; C = g sucrose per 100 ml solution). $[\alpha]^{20}_{\mathrm{D}} = 66.386° + 0.01503_5 p - 0.0003986 p^2$ [Tollens (^{88})]. $[\alpha]^{20}_{\mathrm{D}} = 66.438° + 0.01031_2 p - 0.0003545 p^2$ [Nasini and Villavecchia (^{67})]. Landolt (^{55}) has combined the above giving: $[\alpha]^{20}_{\mathrm{D}} = 66.435° + 0.00870C - 0.00023C^2$, ($C$ from 0 to 65) or, $[\alpha]^{20}_{\mathrm{D}} = 66.412° + 0.01267_3 p - 0.0003765 p^2$ between p = 0 and 50 wt. %; all weights *in vacuo.*

λ, (mμ)	589.25 (*D*)		546.1		Based on weights *in vacuo*
$[\alpha]^{20}_{\lambda}$	66.53	66.50	78.34	78.29	
Lit.	(^{9})	(^{84})	(^{9})	(^{84})	

SPECIFIC ROTATION OF SUCROSE IN H_2O FOR DIFFERENT WAVE LENGTHS

λ, mμ	$[\alpha]^{18}$ (^{70})
589	66.8
500	99.8
450	122.2
400	149.9
350	192.9
300	297.7
250	543.0

λ, mμ	$[\alpha]^{22}$ (^{46})
1300	11.93
1200	14.21
1100	17.02
1000	20.76
900	26.32
800	33.93
700	44.68
600	62.48

λ, mμ	$[\alpha]^{20}$ (^{59})
Li, 670.8	50.51
Cd, 643.8	55.04
Zn, 636.2	56.51
Na, 589.3	66.45
Cu, 578.2	69.10
Hg, 578.0	69.22
Cu, 570.0	71.24

λ, mμ	$[\alpha]^{20}$ (^{59})
Hg, 546.1	78.16
Cu, 521.8	86.21
Cu, 515.3	88.68
Cu, 510.6	90.46
Cd, 508.6	91.16
Zn, 481.1	103.07
Cd, 480.0	103.62
Zn, 472.2	107.38
Zn, 468.0	109.49
Cd, 467.8	109.69
Fe, 438.4	126.5
Fe, 437.6	127.2
Hg, 435.8	128.49
Fe, 435.3	128.5
Fe, 433.7	129.8
Fe, 431.5	130.7
Fe, 428.2	133.6
Fe, 427.2	134.2
Fe, 426.1	134.9
Fe, 419.1	140.0
Fe, 414.4	144.2
Fe, 388.9	166.7
Fe, 383.3	171.8
Fe, 382.6	173.1

VALUES OF $[\alpha]^{20}_{\lambda}$ FOR SUCROSE IN WATER AND IN PYRIDINE (^{30})

C = moles sucrose per liter of solution

C	Water			Pyridine		
λ, (mμ)	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{32}$
656	53.18	53.32	53.48	64.86	65.44	65.98
589	66.5	66.71	66.81	84.37	85.10	85.89
535	82.25	82.76	82.93	99.22	100.87	101.86
508	91.53	91.79	92.59	114.37	116.15	118.01
479	104.24	104.67	105.42	133.67	135.5	137.23
447	121.63	122.80	123.80	152.25	154.38	156.57

SUCROSE IN PYRIDINE (^{96})

% *S*.	0	1	2	4	6.25
d^{25}_4.	0.9735	0.9805	0.9829	0.9912	1.0010
$[\alpha]^{25}_{\mathrm{D}}$		86.7	85.9	84.7	83.6

t, °C.	−10	0	+10	25	45	65	85	105
d^t_4.	1.034	1.0248	1.0510	1.0005	0.9811	0.9619	0.9420	0.9220
$[\alpha]^t_{\mathrm{D}}$.	88.7	87.3	85.6	83.8	82.0	80.3	78.5	77.0

EFFECT OF SALTS ON THE ROTATION OF SUCROSE IN H_2O AT 20°C

The rotation in deg. *S* of a saccharimetric normal sucrose solution containing *m* grams of salt per 100 ml of solution is expressed by the equation $R = 100 - am$, where a has the following values:

Salt	NaCl	NH_4Cl	$K_2C_2O_4$	$CaCl_2$	Pb $(C_2H_3O_2)_2$; *v.* Fig. 1			
a	0.265	0.169	0.234	0.339	m	1.0	2.0	5.0
m_{max}	3.7	6.8	4.0	3.3	$R - 100$	0.03	0.04	0.11

$[\alpha]_D^{25}$ for a 9.60% sucrose solution containing NaCl is expressed by the equation $[\alpha]_D^{25} = 66.410 - 1.456r$ for values of r up to 1.3; r = ratio, g NaCl to g sugar (91, 92, 93).

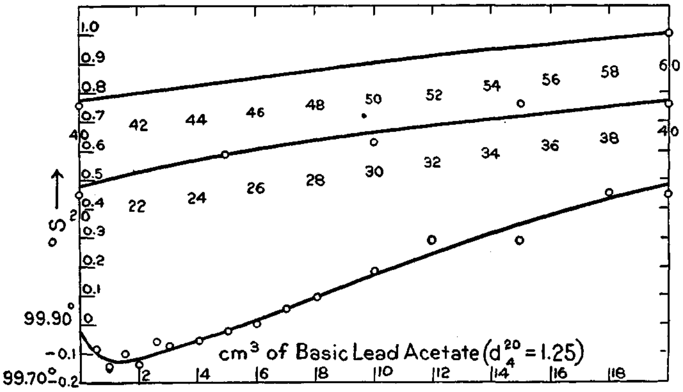


FIG. 1.

Refractive Index

REFRACTIVE INDEX OF AQUEOUS SUCROSE SOLUTIONS AT 20°C (83)

Schönrock's table for determining water in sucrose solutions by means of the Abbe refractometer (83)

n_D^{20}	%H_2O
1.3330	100.0
1.3331	99.9
1.3333	99.8
1.3334	99.7
1.3336	99.6
1.3337	99.5
1.3338	99.4
1.3340	99.3
1.3341	99.2
1.3342	99.1
1.3344	99.0
1.3345	98.9
1.3347	98.8
1.3348	98.7
1.3350	98.6
1.3351	98.5
1.3353	98.4
1.3355	98.3
1.3356	98.2
1.3357	98.1
1.3359	98.0
1.3361	97.9
1.3362	97.8
1.3363	97.7
1.3365	97.6
1.3367	97.5
1.3368	97.4
1.3369	97.3
1.3371	97.2
1.3373	97.1
1.3374	97.0
1.3375	96.9
1.3377	96.8
1.3378	96.7
1.3380	96.6
1.3381	96.5
1.3382	96.4
1.3384	96.3
1.3385	96.2
1.3387	96.1
1.3388	96.0
1.3389	95.9
1.3391	95.8
1.3393	95.7
1.3394	95.6
1.3395	95.5
1.3397	95.4
1.3399	95.3
1.3400	95.2
1.3401	95.1
1.3403	95.0
1.3405	94.9
1.3406	94.8
1.3407	94.7
1.3409	94.6
1.3411	94.5
1.3412	94.4
1.3413	94.3
1.3415	94.2
1.3417	94.1
1.3418	94.0
1.3419	93.9
1.3421	93.8
1.3423	93.7
1.3424	93.6
1.3425	93.5
1.3427	93.4
1.3429	93.3
1.3430	93.2
1.3431	93.1
1.3433	93.0
1.3435	92.9
1.3436	92.8
1.3437	92.7
1.3439	92.6
1.3441	92.5
1.3442	92.4
1.3443	92.3
1.3445	92.2
1.3447	92.1
1.3448	92.0
1.3450	91.9
1.3451	91.8
1.3453	91.7
1.3454	91.6
1.3456	91.5
1.3458	91.4
1.3459	91.3
1.3461	91.2
1.3462	91.1
1.3464	91.0
1.3465	90.9
1.3467	90.8
1.3469	90.7
1.3470	90.6
1.3471	90.5
1.3473	90.4
1.3475	90.3
1.3476	90.2
1.3477	90.1
1.3479	90.0
1.3481	89.9
1.3482	89.8
1.3483	89.7
1.3485	89.6
1.3487	89.5
1.3488	89.4
1.3489	89.3
1.3491	89.2
1.3493	89.1
1.3494	89.0
1.3496	88.9
1.3497	88.8
1.3499	88.7
1.3500	88.6
1.3502	88.5
1.3504	88.4
1.3505	88.3
1.3507	88.2
1.3508	88.1
1.3510	88.0
1.3512	87.9
1.3513	87.8
1.3515	87.7
1.3516	87.6
1.3518	87.5
1.3520	87.4
1.3521	87.3
1.3523	87.2
1.3524	87.1
1.3526	87.0
1.3527	86.9
1.3529	86.8
1.3531	86.7
1.3532	86.6
1.3533	86.5
1.3535	86.4
1.3537	86.3
1.3538	86.2
1.3539	86.1
1.3541	86.0
1.3543	85.9
1.3544	85.8
1.3546	85.7
1.3547	85.6
1.3549	85.5
1.3551	85.4
1.3552	85.3
1.3554	85.2
1.3555	85.1
1.3557	85.0
1.3559	84.9
1.3560	84.8
1.3562	84.7
1.3563	84.6
1.3565	84.5
1.3567	84.4
1.3568	84.3
1.3570	84.2
1.3571	84.1
1.3573	84.0
1.3575	83.9
1.3576	83.8
1.3578	83.7
1.3580	83.6
1.3582	83.5
1.3583	83.4
1.3585	83.3
1.3587	83.2
1.3588	83.1
1.3590	83.0
1.3592	82.9
1.3593	82.8
1.3595	82.7
1.3596	82.6
1.3598	82.5
1.3600	82.4
1.3601	82.3
1.3603	82.2
1.3604	82.1
1.3606	82.0
1.3608	81.9
1.3609	81.8
1.3611	81.7
1.3612	81.6
1.3614	81.5
1.3616	81.4
1.3617	81.3
1.3619	81.2
1.3620	81.1
1.3622	81.0
1.3624	80.9
1.3625	80.8
1.3627	80.7
1.3629	80.6
1.3631	80.5
1.3632	80.4
1.3634	80.3
1.3636	80.2
1.3637	80.1
1.3639	80.0
1.3641	79.9
1.3642	79.8
1.3644	79.7
1.3645	79.6
1.3647	79.5
1.3649	79.4
1.3650	79.3
1.3652	79.2
1.3653	79.1
1.3655	79.0
1.3657	78.9
1.3658	78.8
1.3660	78.7
1.3662	78.6
1.3663	78.5
1.3665	78.4
1.3667	78.3
1.3669	78.2
1.3670	78.1
1.3672	78.0
1.3674	77.9
1.3675	77.8
1.3677	77.7
1.3679	77.6
1.3681	77.5
1.3682	77.4
1.3684	77.3
1.3686	77.2
1.3687	77.1
1.3689	77.0
1.3691	76.9
1.3692	76.8
1.3694	76.7
1.3696	76.6
1.3698	76.5
1.3699	76.4
1.3701	76.3
1.3703	76.2
1.3704	76.1
1.3706	76.0
1.3708	75.9
1.3709	75.8
1.3711	75.7
1.3713	75.6
1.3715	75.5
1.3716	75.4
1.3718	75.3
1.3720	75.2
1.3721	75.1
1.3723	75.0
1.3725	74.9
1.3726	74.8
1.3728	74.7
1.3730	74.6

n_D^{20}	%H_2O	n_D^{20}	%H_2O	n_D^{20}	%H_2O	n_D^{20}	%H_2O	n_D^{20}	%H_2O	n_D^{20}	%H_2O
1.3731	74.5	1.3829	69.0	1.3929	63.5	1.4036	58.0	1.4147	52.5	1.4264	47.0
1.3733	74.4	1.3831	68.9	1.3931	63.4	1.4038	57.9	1.4150	52.4	1.4266	46.9
1.3735	74.3	1.3833	68.8	1.3933	63.3	1.4040	57.8	1.4152	52.3	1.4268	46.8
1.3737	74.2	1.3834	68.7	1.3935	63.2	1.4042	57.7	1.4154	52.2	1.4270	46.7
1.3738	74.1	1.3836	68.6	1.3937	63.1	1.4044	57.6	1.4156	52.1	1.4272	46.6
1.3740	74.0	1.3838	68.5	1.3939	63.0	1.4046	57.5	1.4158	52.0	1.4275	46.5
1.3742	73.9	1.3840	68.4	1.3941	62.9	1.4048	57.4	1.4160	51.9	1.4277	46.4
1.3744	73.8	1.3842	68.3	1.3943	62.8	1.4050	57.3	1.4162	51.8	1.4279	46.3
1.3745	73.7	1.3843	68.2	1.3945	62.7	1.4052	57.2	1.4164	51.7	1.4281	46.2
1.3747	73.6	1.3845	68.1	1.3947	62.6	1.4054	57.1	1.4166	51.6	1.4283	46.1
1.3749	73.5	1.3847	68.0	1.3949	62.5	1.4056	57.0	1.4169	51.5	1.4285	46.0
1.3751	73.4	1.3849	67.9	1.3950	62.4	1.4058	56.9	1.4171	51.4	1.4287	45.9
1.3753	73.3	1.3851	67.8	1.3952	62.3	1.4060	56.8	1.4173	51.3	1.4289	45.8
1.3754	73.2	1.3852	67.7	1.3954	62.2	1.4062	56.7	1.4175	51.2	1.4292	45.7
1.3756	73.1	1.3854	67.6	1.3956	62.1	1.4064	56.6	1.4177	51.1	1.4294	45.6
1.3758	73.0	1.3856	67.5	1.3958	62.0	1.4066	56.5	1.4179	51.0	1.4296	45.5
1.3760	72.9	1.3858	67.4	1.3960	61.9	1.4068	56.4	1.4181	50.9	1.4298	45.4
1.3761	72.8	1.3860	67.3	1.3962	61.8	1.4070	56.3	1.4183	50.8	1.4300	45.3
1.3763	72.7	1.3861	67.2	1.3964	61.7	1.4072	56.2	1.4185	50.7	1.4303	45.2
1.3765	72.6	1.3863	67.1	1.3966	61.6	1.4074	56.1	1.4187	50.6	1.4305	45.1
1.3767	72.5	1.3865	67.0	1.3968	61.5	1.4076	56.0	1.4189	50.5	1.4307	45.0
1.3768	72.4	1.3867	66.9	1.3970	61.4	1.4078	55.9	1.4192	50.4	1.4309	44.9
1.3770	72.3	1.3869	66.8	1.3972	61.3	1.4080	55.8	1.4194	50.3	1.4311	44 8
1.3772	72.2	1.3870	66.7	1.3974	61.2	1.4082	55.7	1.4196	50.2	1.4313	44.7
1.3773	72.1	1.3872	66.6	1.3976	61.1	1.4084	55.6	1.4198	50.1	1.4316	44.6
1.3775	72.0	1.3874	66.5	1.3978	61.0	1.4086	55.5	1.4200	50.0	1.4318	44.5
1.3777	71.9	1.3876	66.4	1.3980	60.9	1.4088	55.4	1.4202	49.9	1.4320	44.4
1.3779	71.8	1.3878	66.3	1.3982	60.8	1.4090	55.3	1.4204	49.8	1.4322	44.3
1.3780	71.7	1.3879	66.2	1.3984	60.7	1.4092	55.2	1.4206	49.7	1.4325	44.2
1.3782	71.6	1.3881	66.1	1.3986	60.6	1.4094	55.1	1.4208	49.6	1.4327	44.1
1.3784	71.5	1.3883	66.0	1.3987	60.5	1.4096	55.0	1.4211	49.5	1.4329	44.0
1.3786	71.4	1.3885	65.9	1.3989	60.4	1.4098	54.9	1.4213	49.4	1.4331	43.9
1.3788	71.3	1.3887	65.8	1.3991	60.3	1.4100	54.8	1.4215	49.3	1.4333	43.8
1.3789	71.2	1.3889	65.7	1.3993	60.2	1.4102	54.7	1.4217	49.2	1.4336	43.7
1.3791	71.1	1.3891	65.6	1.3995	60.1	1.4104	54.6	1.4219	49.1	1.4338	43.6
1.3793	71.0	1.3893	65.5	1.3997	60.0	1.4107	54.5	1.4221	49.0	1.4340	43.5
1.3795	70.9	1.3894	65.4	1.3999	59.9	1.4109	54.4	1.4223	48.9	1.4342	43.4
1.3797	70.8	1.3896	65.3	1.4001	59.8	1.4111	54.3	1.4225	48.8	1.4344	43.3
1.3798	70.7	1.3898	65.2	1.4003	59.7	1.4113	54.2	1.4227	48.7	1.4347	43.2
1.3800	70.6	1.3900	65.1	1.4005	59.6	1.4115	54.1	1.4229	48.6	1.4349	43.1
1.3802	70.5	1.3902	65.0	1.4007	59.5	1.4117	54.0	1.4231	48.5	1.4351	43.0
1.3804	70.4	1.3904	64.9	1.4008	59.4	1.4119	53.9	1.4234	48.4	1.4353	42.9
1.3806	70.3	1.3906	64.8	1.4010	59.3	1.4121	53.8	1.4236	48.3	1.4355	42.8
1.3807	70.2	1.3907	64.7	1.4012	59.2	1.4123	53.7	1.4238	48.2	1.4358	42.7
1.3809	70.1	1.3909	64.6	1.4014	59.1	1.4125	53.6	1.4240	48.1	1.4360	42.6
1.3811	70.0	1.3911	64.5	1.4016	59.0	1.4127	53.5	1.4242	48.0	1.4362	42.5
1.3813	69.9	1.3913	64.4	1.4018	58.9	1.4129	53.4	1.4244	47.9	1.4364	42.4
1.3815	69.8	1.3915	64.3	1.4020	58.8	1.4131	53.3	1.4246	47.8	1.4366	42.3
1.3816	69.7	1.3916	64.2	1.4022	58.7	1.4133	53.2	1.4249	47.7	1.4369	42.2
1.3818	69.6	1.3918	64.1	1.4024	58.6	1.4135	53.1	1.4251	47.6	1.4371	42.1
1.3820	69.5	1.3920	64.0	1.4026	58.5	1.4137	53.0	1.4253	47.5	1.4373	42.0
1.3822	69.4	1.3922	63.9	1.4028	58.4	1.4139	52.9	1.4255	47.4	1.4375	41.9
1.3824	69.3	1.3924	63.8	1.4030	58.3	1.4141	52.8	1.4257	47.3	1.4378	41.8
1.3825	69.2	1.3926	63.7	1.4032	58.2	1.4143	52.7	1.4260	47.2	1.4380	41.7
1.3827	69.1	1.3928	63.6	1.4034	58.1	1.4145	52.6	1.4262	47.1	1.4382	41.6

n_D^{20}	$\%H_2O$
1.4385	41.5
1.4387	41.4
1.4389	41.3
1.4391	41.2
1.4394	41.1
1.4396	41.0
1.4398	40.9
1.4400	40.8
1.4403	40.7
1.4405	40.6
1.4407	40.5
1.4409	40.4
1.4411	40.3
1.4414	40.2
1.4416	40.1
1.4418	40.0
1.4420	39.9
1.4423	39.8
1.4425	39.7
1.4427	39.6
1.4429	39.5
1.4432	39.4
1.4434	39.3
1.4436	39.2
1.4439	39.1
1.4441	39.0
1.4443	38.9
1.4446	38.8
1.4448	38.7
1.4450	38.6
1.4453	38.5
1.4455	38.4
1.4457	38.3
1.4459	38.2
1.4462	38.1
1.4464	38.0
1.4466	37.9
1.4468	37.8
1.4471	37.7
1.4473	37.6
1.4475	37.5
1.4477	37.4
1.4479	37.3
1.4482	37.2
1.4484	37.1
1.4486	37.0
1.4488	36.9
1.4491	36.8
1.4493	36.7
1.4495	36.6
1.4497	36.5
1.4500	36.4
1.4502	36.3
1.4504	36.2
1.4507	36.1
1.4509	36.0
1.4511	35.9
1.4514	35.8
1.4516	35.7
1.4518	35.6
1.4521	35.5
1.4523	35.4
1.4525	35.3
1.4527	35.2
1.4530	35.1
1.4532	35.0
1.4534	34.9
1.4537	34.8
1.4539	34.7
1.4541	34.6
1.4544	34.5
1.4546	34.4
1.4548	34.3
1.4550	34.2
1.4553	34.1
1.4555	34.0*
1.4558	34.0
1.4561	33.9
1.4563	33.8
1.4565	33.7
1.4567	33.6
1.4570	33.5
1.4572	33.4
1.4574	33.3
1.4577	33.2
1.4579	33.1
1.4581	33.0
1.4584	32.9
1.4586	32.8
1.4588	32.7
1.4591	32.6
1.4593	32.5
1.4595	32.4
1.4598	32.3
1.4600	32.2
1.4602	32.1
1.4605	32.0
1.4607	31.9
1.4609	31.8
1.4612	31.7
1.4614	31.6
1.4616	31.5
1.4619	31.4
1.4621	31.3
1.4623	31.2
1.4625	31.1
1.4628	31.0
1.4630	30.9
1.4632	30.8
1.4635	30.7
1.4637	30.6
1.4639	30.5
1.4642	30.4
1.4644	30.3
1.4646	30.2
1.4649	30.1
1.4651	30.0
1.4653	29.9
1.4656	29.8
1.4658	29.7
1.4661	29.6
1.4663	29.5
1.4666	29.4
1.4668	29.3
1.4671	29.2
1.4673	29.1
1.4676	29.0
1.4678	28.9
1.4681	28.8
1.4683	28.7
1.4685	28.6
1.4688	28.5
1.4690	28.4
1.4693	28.3
1.4695	28.2
1.4698	28.1
1.4700	28.0
1.4703	27.9
1.4705	27.8
1.4708	27.7
1.4710	27.6
1.4713	27.5
1.4715	27.4
1.4717	27.3
1.4720	27.2
1.4722	27.1
1.4725	27.0
1.4727	26.9
1.4730	26.8
1.4732	26.7
1.4735	26.6
1.4737	26.5
1.4740	26.4
1.4742	26.3
1.4744	26.2
1.4747	26.1
1.4749	26.0
1.4752	25.9
1.4754	25.8
1.4757	25.7
1.4759	25.6
1.4762	25.5
1.4764	25.4
1.4767	25.3
1.4769	25.2
1.4772	25.1
1.4774	25.0
1.4777	24.9
1.4779	24.8
1.4782	24.7
1.4784	24.6
1.4787	24.5
1.4789	24.4
1.4792	24.3
1.4794	24.2
1.4797	24.1
1.4799	24.0
1.4802	23.9
1.4804	23.8
1.4807	23.7
1.4810	23.6
1.4812	23.5
1.4815	23.4
1.4817	23.3
1.4820	23.2
1.4822	23.1
1.4825	23.0
1.4827	22.9
1.4830	22.8
1.4832	22.7
1.4835	22.6
1.4838	22.5
1.4840	22.4
1.4843	22.3
1.4845	22.2
1.4848	22.1
1.4850	22.0
1.4853	21.9
1.4855	21.8
1.4858	21.7
1.4860	21.6
1.4863	21.5
1.4865	21.4
1.4868	21.3
1.4871	21.2
1.4873	21.1
1.4876	21.0
1.4878	20.9
1.4881	20.8
1.4883	20.7
1.4886	20.6
1.4888	20.5
1.4891	20.4
1.4893	20.3
1.4896	20.2
1.4898	20.1
1.4901	20.0
1.4904	19.9
1.4906	19.8
1.4909	19.7
1.4912	19.6
1.4914	19.5
1.4917	19.4
1.4919	19.3
1.4922	19.2
1.4925	19.1
1.4927	19.0
1.4930	18.9
1.4933	18.8
1.4935	18.7
1.4938	18.6
1.4941	18.5
1.4943	18.4
1.4946	18.3
1.4949	18.2
1.4951	18.1
1.4954	18.0
1.4956	17.9
1.4959	17.8
1.4962	17.7
1.4964	17.6
1.4967	17.5
1.4970	17.4
1.4972	17.3
1.4975	17.2
1.4978	17.1
1.4980	17.0
1.4983	16.9
1.4985	16.8
1.4988	16.7
1.4991	16.6
1.4993	16.5
1.4996	16.4
1.4999	16.3
1.5001	16.2
1.5004	16.1
1.5007	16.0
1.5009	15.9
1.5012	15.8
1.5015	15.7
1.5017	15.6
1.5020	15.5
1.5022	15.4
1.5025	15.3
1.5028	15.2
1.5030	15.1
1.5033	15.0

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* The values of the refractive index from 34 to 15% are taken from Main's table ($^{61.5}$).

REFRACTIVE INDEX CORRECTION TABLE FOR READINGS AT TEMPERATURES OTHER THAN 20°C (^{86})

$\%H_2O$ / °C	95	90	85	80	70	60	50	40	30	25
	To be added to % water									
15	0.25	0.27	0.31	0.31	0.34	0.35	0.36	0.37	0.36	0.36
16	0.21	0.23	0.26	0.27	0.29	0.31	0.31	0.32	0.31	0.29
17	0.16	0.18	0.20	0.20	0.22	0.23	0.23	0.23	0.20	0.17
18	0.11	0.12	0.14	0.14	0.15	0.16	0.16	0.15	0.12	0.09
19	0.06	0.07	0.08	0.08	0.08	0.09	0.09	0.08	0.07	0.05
	To be subtracted from % water									
21	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
22	0.12	0.14	0.14	0.14	0.14	0.14	0.15	0.14	0.14	0.14
23	0.18	0.20	0.20	0.21	0.21	0.21	0.23	0.21	0.22	0.22
24	0.24	0.26	0.26	0.27	0.28	0.28	0.30	0.28	0.29	0.29
25	0.30	0.32	0.32	0.34	0.36	0.36	0.38	0.36	0.36	0.37
26	0.36	0.39	0.39	0.41	0.43	0.43	0.46	0.44	0.43	0.44
27	0.43	0.46	0.46	0.48	0.50	0.51	0.55	0.52*	0.50	0.51
28	0.50	0.53	0.53	0.55	0.58	0.59	0.63	0.60*	0.57	0.59
29	0.57	0.60	0.61	0.62	0.66	0.67	0.71	0.68*	0.65	0.67
30	0.64	0.67	0.70	0.71	0.74	0.75	0.80	0.76*	0.73	0.75
% H_2O	95	90	85	80	70	60	50	40	30	25

* These are corrected values. Stanek's original table gives values 0.10 higher.

TABLE FOR USE WITH ZEISS IMMERSION REFRACTOMETER (57.5) R = scale reading; $\% S$ = % sucrose

R	$\% S$	R	$\% S$	R	$\% S$	R	$\% S$	R	$\% S$	R	$\% S$	R	$\% S$	R	$\% S$
15.0	0.00	21.0	1.58	27.0	3.16	33.0	4.74	39.0	6.31	45.0	7.84	51.0	9.32	57.0	10.78
.1	.03	.1	.61	.1	.19	.1	.77	.1	.33	.1	.87	.1	.34	.1	.80
.2	.05	.2	.64	.2	.21	.2	.79	.2	.36	.2	.90	.2	.36	.2	.83
.3	.08	.3	.66	.3	.24	.3	.82	.3	.39	.3	.92	.3	.39	.3	.85
.4	.11	.4	.69	.4	.26	.4	.84	.4	.41	.4	.95	.4	.41	.4	.88
.5	.13	.5	.71	.5	.29	.5	.87	.5	.43	.5	.97	.5	.44	.5	.90
.6	.16	.6	.74	.6	.32	.6	.90	.6	.46	.6	8.00	.6	.46	.6	.92
.7	.19	.7	.77	.7	.34	.7	.92	.7	.49	.7	.03	.7	.49	.7	.95
.8	.21	.8	.79	.8	.37	.8	.95	.8	.51	.8	.05	.8	.51	.8	.97
.9	.24	.9	.82	.9	.40	.9	.98	.9	.54	.9	.07	.9	.53	.9	11.00
16.0	.26	22.0	.84	28.0	.42	34.0	5.00	40.0	.56	46.0	.10	52.0	.56	58.0	.03
.1	.29	.1	.87	.1	.45	.1	.03	.1	.59	.1	.12	.1	.58	.1	.05
.2	.32	.2	.90	.2	.48	.2	.05	.2	.61	.2	.15	.2	.60	.2	.07
.3	.34	.3	.92	.3	.50	.3	.08	.3	.64	.3	.17	.3	.63	.3	.10
.4	.37	.4	.95	.4	.53	.4	.11	.4	.66	.4	.19	.4	.66	.4	.12
.5	.40	.5	.98	.5	.56	.5	.13	.5	.69	.5	.22	.5	.68	.5	.15
.6	.42	.6	2.00	.6	.58	.6	.16	.6	.72	.6	.24	.6	.70	.6	.17
.7	.45	.7	.03	.7	.61	.7	.19	.7	.74	.7	.27	.7	.73	.7	.19
.8	.48	.8	.05	.8	.64	.8	.21	.8	.77	.8	.29	.8	.75	.8	.22
.9	.50	.9	.08	.9	.66	.9	.24	.9	.79	.9	.32	.9	.78	.9	.24
17.0	.53	23.0	.11	29.0	.69	35.0	.26	41.0	.82	47.0	.34	53.0	.80	59.0	.27
.1	.56	.1	.13	.1	.71	.1	.29	.1	.84	.1	.36	.1	.83	.1	.29
.2	.58	.2	.16	.2	.74	.2	.32	.2	.87	.2	.39	.2	.85	.2	.32
.3	.61	.3	.19	.3	.77	.3	.34	.3	.90	.3	.41	.3	.88	.3	.34
.4	.64	.4	.21	.4	.79	.4	.37	.4	.92	.4	.44	.4	.90	.4	.36
.5	.66	.5	.24	.5	.82	.5	.40	.5	.95	.5	.46	.5	.92	.5	.39
.6	.69	.6	.26	.6	.84	.6	.42	.6	.97	.6	.49	.6	.95	.6	.41
.7	.71	.7	.29	.7	.87	.7	.45	.7	7.00	.7	.51	.7	.97	.7	.44
.8	.74	.8	.32	.8	.90	.8	.48	.8	.03	.8	.53	.8	10.00	.8	.46
.9	.77	.9	.34	.9	.92	.9	.50	.9	.05	.9	.56	.9	.03	.9	.49
18.0	.79	24.0	.37	30.0	.95	36.0	.53	42.0	.08	48.0	.58	54.0	.05	60.0	.51
.1	.82	.1	.40	.1	.98	.1	.56	.1	.10	.1	.60	.1	.07	.1	.53
.2	.84	.2	.42	.2	4.00	.2	.58	.2	.13	.2	.63	.2	.10	.2	.56
.3	.87	.3	.45	.3	.03	.3	.61	.3	.15	.3	.66	.3	.12	.3	.58
.4	.90	.4	.48	.4	.05	.4	.64	.4	.18	.4	.68	.4	.15	.4	.60
.5	.92	.5	.50	.5	.08	.5	.66	.5	.20	.5	.70	.5	.17	.5	.63
.6	.95	.6	.53	.6	.11	.6	.69	.6	.23	.6	.73	.6	.19	.6	.66
.7	.98	.7	.56	.7	.13	.7	.71	.7	.26	.7	.75	.7	.22	.7	.68
.8	1.00	.8	.58	.8	.16	.8	.74	.8	.28	.8	.78	.8	.24	.8	.70
.9	.03	.9	.61	.9	.19	.9	.77	.9	.31	.9	.80	.9	.27	.9	.73
19.0	.05	25.0	.64	31.0	.21	37.0	.79	43.0	.33	49.0	.83	55.0	.29	61.0	.75
.1	.08	.1	.66	.1	.24	.1	.82	.1	.36	.1	.85	.1	.32	.1	.78
.2	.11	.2	.69	.2	.26	.2	.84	.2	.39	.2	.88	.2	.34	.2	.80
.3	.13	.3	.71	.3	.29	.3	.87	.3	.41	.3	.90	.3	.36	.3	.83
.4	.16	.4	.74	.4	.32	.4	.90	.4	.43	.4	.92	.4	.39	.4	.85
.5	.19	.5	.77	.5	.34	.5	.92	.5	.46	.5	.95	.5	.41	.5	.88
.6	.21	.6	.79	.6	.37	.6	.95	.6	.49	.6	.97	.6	.44	.6	.90
.7	.24	.7	.82	.7	.39	.7	.98	.7	.51	.7	9.00	.7	.46	.7	.92
.8	.26	.8	.84	.8	.42	.8	6.00	.8	.54	.8	.03	.8	.49	.8	.95
.9	.29	.9	.87	.9	.45	.9	.03	.9	.56	.9	.05	.9	.51	.9	.97
20.0	.32	26.0	.90	32.0	.48	38.0	.05	44.0	.59	50.0	.07	56.0	.53	62.0	12.00
.1	.34	.1	.92	.1	.50	.1	.08	.1	.61	.1	.10	.1	.56	.1	.03
.2	.37	.2	.95	.2	.53	.2	.10	.2	.64	.2	.12	.2	.58	.2	.05
.3	.40	.3	.98	.3	.56	.3	.13	.3	.66	.3	.15	.3	.60	.3	.07
.4	.42	.4	3.00	.4	.58	.4	.15	.4	.69	.4	.17	.4	.63	.4	.09
.5	.45	.5	.03	.5	.61	.5	.17	.5	.72	.5	.19	.5	.66	.5	.12
.6	.48	.6	.05	.6	.64	.6	.20	.6	.74	.6	.22	.6	.68	.6	.14
.7	.50	.7	.08	.7	.66	.7	.23	.7	.77	.7	.24	.7	.70	.7	.16
.8	.53	.8	.11	.8	.69	.8	.26	.8	.79	.8	.27	.8	.73	.8	.18
.9	.56	.9	.13	.9	.71	.9	.28	.9	.82	.9	.29	.9	.75	.9	.21

R	% *S*
63.0	12.23
.1	.25
.2	.28
.3	.30
.4	.32
.5	.35
.6	.37
.7	.39
.8	.42
.9	.44
64.0	.46
.1	.49
.2	.51
.3	.53
.4	.56
.5	.58
.6	.60
.7	.63
.8	.65
.9	.67
65.0	.69
.1	.72
.2	.74
.3	.76
.4	.79
.5	.81
.6	.83
.7	.86
.8	.88
.9	.90
66.0	.93
.1	.95
.2	.97
.3	13.00
.4	.03
.5	.05
.6	.07
.7	.09
.8	.11
.9	.14
67.0	.16
.1	.18
.2	.20
.3	.23
.4	.25
.5	.27
.6	.29
.7	.32
.8	.34
.9	.36
68.0	.38
.1	.40
.2	.43
.3	.45
.4	.48
.5	.50
.6	.52
.7	.54
.8	.57
.9	.59
69.0	13.61
.1	.63
.2	.66
.3	.68
.4	.70
.5	.73
.6	.75
.7	.77
.8	.79
.9	.82
70.0	.84
.1	.87
.2	.89
.3	.92
.4	.94
.5	.96
.6	.98
.7	14.00
.8	.03
.9	.05
71.0	.07
.1	.09
.2	.11
.3	.14
.4	.16
.5	.18
.6	.20
.7	.23
.8	.25
.9	.27
72.0	.29
.1	.32
.2	.34
.3	.36
.4	.38
.5	.40
.6	.43
.7	.45
.8	.48
.9	.50
73.0	.52
.1	.54
.2	.57
.3	.59
.4	.61
.5	.63
.6	.66
.7	.68
.8	.70
.9	.73
74.0	.75
.1	.77
.2	.79
.3	.82
.4	.84
.5	.87
.6	.89
.7	.92
.8	.94
.9	.96
75.0	14.98
.1	15.00
.2	.03
.3	.05
.4	.07
.5	.09
.6	.11
.7	.13
.8	.16
.9	.18
76.0	.20
.1	.22
.2	.24
.3	.26
.4	.28
.5	.30
.6	.32
.7	.34
.8	.36
.9	.38
77.0	.40
.1	.42
.2	.44
.3	.47
.4	.49
.5	.51
.6	.54
.7	.56
.8	.59
.9	.61
78.0	.63
.1	.65
.2	.68
.3	.70
.4	.72
.5	.74
.6	.76
.7	.79
.8	.81
.9	.83
79.0	.85
.1	.88
.2	.90
.3	.92
.4	.95
.5	.97
.6	16.00
.7	.03
.8	.05
.9	.07
80.0	.09
.1	.11
.2	.13
.3	.16
.4	.18
.5	.20
.6	.22
.7	.24
.8	.27
.9	.29
81.0	16.31
.1	33
.2	.35
.3	.38
.4	.40
.5	.42
.6	.44
.7	.47
.8	.49
.9	.51
82.0	.54
.1	.56
.2	.59
.3	.61
.4	.63
.5	.65
.6	.68
.7	.70
.8	.72
.9	.74
83.0	.76
.1	.79
.2	.81
.3	.83
.4	.85
.5	.88
.6	.90
.7	.92
.8	.95
.9	.97
84.0	17.00
.1	.02
.2	.04
.3	.07
.4	.09
.5	.11
.6	.13
.7	.15
.8	.18
.9	.20
85.0	.22
.1	.24
.2	.27
.3	.29
.4	.31
.5	.33
.6	.35
.7	.38
.8	.40
.9	.42
86.0	.44
.1	.47
.2	.49
.3	.51
.4	.53
.5	.55
.6	.58
.7	.60
.8	.62
.9	.64
87.0	17.66
.1	.68
.2	.71
.3	.73
.4	.75
.5	.77
.6	.79
.7	.82
.8	.84
.9	.86
88.0	.89
.1	.91
.2	.93
.3	.95
.4	.98
.5	18.00
.6	.02
.7	.04
.8	.06
.9	.08
89.0	.10
.1	.13
.2	.15
.3	.17
.4	.19
.5	.21
.6	.23
.7	.25
.8	.27
.9	.29
90.0	.31
.1	.34
.2	.36
.3	.38
.4	.40
.5	.42
.6	.44
.7	.47
.8	.49
.9	.51
91.0	.53
.1	.55
.2	.57
.3	.59
.4	.61
.5	.63
.6	.66
.7	.68
.8	.70
.9	.72
92.0	18.74
.1	.76
.2	.78
.3	.80
.4	.82
.5	.85
.6	.87
.7	.89
.8	.91
.9	.93
93.0	.95
.1	.97
.2	19.00
.3	.02
.4	.04
.5	.06
.6	.08
.7	.10
.8	.13
.9	.15
94.0	.17
.1	.19
.2	.21
.3	.23
.4	.25
.5	.27
.6	.29
.7	.31
.8	.34
.9	.36
95.0	.38
.1	.40
2	.42
.3	.44
.4	.47
.5	.49
.6	.51
.7	.53
.8	.55
.9	.57
96.0	.59
.1	.61
.2	.63
.3	.66
.4	.68
.5	.70
.6	.72
.7	.74
.8	.76
.9	.78
97.0	19.80
.1	.82
.2	.85
.3	.87
.4	.89
.5	.91
.6	.93
.7	.95
.8	.97
.9	20.00
98.0	.02
.1	.04
.2	.06
.3	.08
.4	.10
.5	.13
.6	.15
.7	.17
.8	.19
.9	.21
99.0	.23
.1	.25
.2	.27
.3	.29
.4	.31
.5	.34
.6	.36
.7	.38
.8	.40
.9	.42
100.0	.44
.1	.47
.2	.49
.3	.51
.4	.53
.5	.55
.6	.57
.7	.59
.8	.61
.9	.63
101.0	.66
.1	.68
.2	.70
.3	.72
.4	.74
.5	.76
.6	.78
.7	.80
.8	.82
.9	.85
102.0	20.87
.1	.89
.2	.91
.3	.93
.4	.95
.5	.97
.6	21.00
.7	.02
.8	.04
.9	.06
103.0	.08
.1	.10
.2	.13
.3	.15
.4	.17
.5	.19
.6	.21
.7	.23
.8	.25
.9	.27
104.0	.29
.1	.31
.2	.34
.3	.36
.4	.38
.5	.40
.6	.42
.7	.44
.8	.47
.9	.49
105.0	.51
.1	.53
.2	.55
.3	.57
.4	.59
.5	.61
.6	.63
.7	.66
.8	.68
.9	.70
106.0	.71

DRY SUBSTANCE (D) IN SUGAR-HOUSE PRODUCTS AT 28°C (76)

n_D^{28}	% D	Decimals	
1.3335	1	0.0001=0.05	0.0010=0.75
1.3349	2	0.0002=0.1	0.0011=0.8
1.3364	3	0.0003=0.2	0.0012=0.8
1.3379	4	0.0004=0.25	0.0013=0.85
1.3394	5	0.0005=0.3	0.0014=0.9
1.3409	6	0.0006=0.4	0.0015=1.0
1.3424	7	0.0007=0.5	
1.3439	8	0.0008=0.6	
1.3454	9	0.0009=0.7	
1.3469	10		
1.3484	11	0.0001=0.05	
1.3500	12	0.0002=0.1	
1.3516	13	0.0003=0.2	
1.3530	14	0.0004=0.25	
1.3546	15	0.0005=0.3	
1.3562	16	0.0006=0.4	
1.3578	17	0.0007=0.45	
1.3594	18	0.0008=0.5	
1.3611	19	0.0009=0.6	
1.3627	20	0.0010=0.65	
1.3644	21	0.0011=0.7	
1.3661	22	0.0012=0.75	
1.3678	23	0.0013=0.8	
1.3695	24	0.0014=0.85	
1.3712	25	0.0015=0.9	
1.3729	26	0.0016=0.95	
1.3746	27		
1.3764	28		
1.3782	29	0.0001=0.05	0.0012=0.6
1.3800	30	0.0002=0.1	0.0013=0.65
1.3818	31	0.0003=0.15	0.0014=0.7
1.3836	32	0.0004=0.2	0.0015=0.75
1.3854	33	0.0005=0.25	0.0016=0.8
1.3872	34	0.0006=0.3	0.0017=0.85
1.3890	35	0.0007=0.35	0.0018=0.9
1.3909	36	0.0008=0.4	0.0019=0.95
1.3928	37	0.0009=0.45	0.0020=1.0
1.3947	38	0.0010=0.5	0.0021=1.0
1.3966	39	0.0011=0.55	
1.3984	40		
1.4003	41		
1.4023	42		
1.4043	43	0.0001=0.05	0.0012=0.6
1.4063	44	0.0002=0.1	0.0013=0.65
1.4083	45	0.0003=0.15	0.0014=0.7
1.4104	46	0.0004=0.2	0.0015=0.75
1.4124	47	0.0005=0.25	0.0016=0.8
1.4145	48	0.0006=0.3	0.0017=0.85
1.4166	49	0.0007=0.35	0.0018=0.9
1.4186	50	0.0008=0.4	0.0019=0.95
1.4207	51	0.0009=0.45	0.0020=1.0
1.4228	52	0.0010=0.5	0.0021=1.0
1.4249	53	0.0011=0.55	
1.4270	54		
1.4292	55	0.0001=0.05	0.0013=0.55
1.4314	56	0.0002=0.1	0.0014=0.6
1.4337	57	0.0003=0.1	0.0015=0.65
1.4359	58	0.0004=0.15	0.0016=0.7
1.4382	59	0.0005=0.2	0.0017=0.75
1.4405	60	0.0006=0.25	0.0018=0.8
1.4428	61	0.0007=0.3	0.0019=0.85
1.4451	62	0.0008=0.35	0.0020=0.9
1.4474	63	0.0009=0.4	0.0021=0.9
1.4497	64	0.0010=0.45	0.0022=0.95
1.4520	65	0.0011=0.5	0.0023=1.0
1.4543	66	0.0012=0.5	0.0024=1.0
1.4567	67		
1.4591	68		
1.4615	69		
1.4639	70		
1.4663	71		
1.4687	72		
1.4711	73		
1.4736	74		
1.4761	75	0.0001=0.0	0.0015=0.55
1.4786	76	0.0002=0.05	0.0016=0.6
1.4811	77	0.0003=0.1	0.0017=0.65
1.4836	78	0.0004=0.15	0.0018=0.65
1.4862	79	0.0005=0.2	0.0019=0.7
1.4888	80	0.0006=0.2	0.0020=0.75
1.4914	81	0.0007=0.25	0.0021=0.8
1.4940	82	0.0008=0.3	0.0022=0.8
1.4966	83	0.0009=0.35	0.0023=0.85
1.4992	84	0.0010=0.35	0.0024=0.9
1.5019	85	0.0011=0.4	0.0025=0.9
1.5046	86	0.0012=0.45	0.0026=0.95
1.5073	87	0.0013=0.5	0.0027=1.0
1.5100	88	0.0014=0.5	0.0028=1.0
1.5127	89		
1.5155	90		

CORRECTIONS FOR THE TEMPERATURE (76)

%D / °C	Dry substance												
	0	5	10	15	20	25	30	40	50	60	70	80	90
	Subtract												
20	0.53	0.54	0.55	0.56	0.57	0.58	0.60	0.62	0.64	0.62	0.61	0.60	0.58
21	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.56	0.54	0.53	0.52	0.50
22	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.47	0.48	0.47	0.46	0.45	0.44
23	0.33	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.39	0.38	0.38	0.38
24	0.26	0.26	0.27	0.28	0.28	0.29	0.30	0.31	0.32	0.31	0.31	0.30	0.30
25	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.23	0.23	0.23	0.22
26	0.12	0.12	0.13	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.15	0.14
27	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.07
	Add												
29	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.07
30	0.12	0.12	0.13	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.16	0.15	0.14
31	0.20	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.24	0.23	0.23	0.23	0.22
32	0.26	0.26	0.27	0.28	0.28	0.29	0.30	0.31	0.32	0.31	0.31	0.30	0.30
33	0.33	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.39	0.38	0.38	0.38
34	0.40	0.41	0.42	0.42	0.43	0.44	0.45	0.47	0.48	0.47	0.46	0.45	0.44
35	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.54	0.56	0.54	0.53	0.52	0.50

Density of Aqueous Sucrose Solutions at 20°C, g/ml

All weights *in vacuo*. For hydrometer conversion formulae *see* vol. I, p. 31 and for computed conversion tables and temperature corrections *v.* (17.5, 61.5, 75). For conversion table giving deg. Brix, d_4^{20}, d_{20}^{20} and deg. Baumé, based upon the formula, °Bé = 145 − 145/sp. gr., d_{20}^{20} *v.* (7).

Density of Aqueous Sucrose Solutions at 20°C, g/ml.

% sucrose	d_4^{20}									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.998234	0.998622	0.999010	0.999398	0.999786	1.000174	1.000563	1.000952	1.001342	1.001731
1	1.002120	1.002509	1.002897	1.003286	1.003675	1.004064	1.004453	1.004844	1.005234	1.005624
2	1.006015	1.006405	1.006796	1.007188	1.007580	1.007972	1.008363	1.008755	1.009148	1.009541
3	1.009934	1.010327	1.010721	1.011115	1.011510	1.011904	1.012298	1.012694	1.013089	1.013485
4	1.013881	1.014277	1.014673	1.015070	1.015467	1.015864	1.016261	1.016659	1.017058	1.017456
5	1.017854	1.018253	1.018652	1.019052	1.019451	1.019851	1.020251	1.020651	1.021053	1.021454
6	1.021855	1.022257	1.022659	1.023061	1.023463	1.023867	1.024270	1.024673	1.025077	1.025481
7	1.025885	1.026289	1.026694	1.027099	1.027504	1.027910	1.028316	1.028722	1.029128	1.029535
8	1.029942	1.030349	1.030757	1.031165	1.031573	1.031982	1.032391	1.032800	1.033209	1.033619
9	1.034029	1.034439	1.034850	1.035260	1.035671	1.036082	1.036494	1.036906	1.037318	1.037730
10	1.038143	1.038556	1.038970	1.039383	1.039797	1.040212	1.040626	1.041041	1.041456	1.041872
11	1.042288	1.042704	1.043121	1.043537	1.043954	1.044370	1.044788	1.045206	1.045625	1.046043
12	1.046462	1.046881	1.047300	1.047720	1.048140	1.048559	1.048980	1.049401	1.049822	1.050243
13	1.050665	1.051087	1.051510	1.051933	1.052356	1.052778	1.053202	1.053626	1.054050	1.054475
14	1.054900	1.055325	1.055751	1.056176	1.056602	1.057029	1.057455	1.057882	1.058310	1.058737
15	1.059165	1.059593	1.060022	1.060451	1.060880	1.061308	1.061738	1.062168	1.062598	1.063029
16	1.063460	1.063892	1.064324	1.064756	1.065188	1.065621	1.066054	1.066487	1.066921	1.067355
17	1.067789	1.068223	1.068658	1.069093	1.069529	1.069964	1.070400	1.070836	1.071273	1.071710
18	1.072147	1.072585	1.073023	1.073461	1.073900	1.074338	1.074777	1.075217	1.075657	1.076097
19	1.076537	1.076978	1.077419	1.077860	1.078302	1.078744	1.079187	1.079629	1.080072	1.080515
20	1.080959	1.081403	1.081848	1.082292	1.082737	1.083182	1.083628	1.084074	1.084520	1.084967
21	1.085414	1.085861	1.086309	1.086757	1.087205	1.087652	1.088101	1.088550	1.089000	1.089450
22	1.089900	1.090351	1.090802	1.091253	1.091704	1.092155	1.092607	1.093060	1.093513	1.093966
23	1.094420	1.094874	1.095328	1.095782	1.096236	1.096691	1.097147	1.097603	1.098058	1.098514
24	1.098971	1.099428	1.099886	1.100344	1.100802	1.101259	1.101718	1.102177	1.102637	1.103097
25	1.103557	1.104017	1.104478	1.104938	1.105400	1.105862	1.106324	1.106786	1.107248	1.107711
26	1.108175	1.108639	1.109103	1.109568	1.110033	1.110497	1.110963	1.111429	1.111895	1.112361
27	1.112828	1.113295	1.113763	1.114229	1.114697	1.115166	1.115635	1.116104	1.116572	1.117042
28	1.117512	1.117982	1.118453	1.118923	1.119395	1.119867	1.120339	1.120812	1.121284	1.121757
29	1.122231	1.122705	1.123179	1.123653	1.124128	1.124603	1.125079	1.125555	1.126030	1.126507
30	1.126984	1.127461	1.127939	1.128417	1.128896	1.129374	1.129853	1.130332	1.130812	1.131292
31	1.131773	1.132254	1.132735	1.133216	1.133698	1.134180	1.134663	1.135146	1.135628	1.136112
32	1.136596	1.137080	1.137565	1.138049	1.138534	1.139020	1.139506	1.139993	1.140479	1.140966
33	1.141453	1.141941	1.142429	1.142916	1.143405	1.143894	1.144384	1.144874	1.145363	1.145854
34	1.146345	1.146836	1.147328	1.147820	1.148313	1.148805	1.149298	1.149792	1.150286	1.150780
35	1.151275	1.151770	1.152265	1.152760	1.153256	1.153752	1.154249	1.154746	1.155242	1.155740
36	1.156238	1.156736	1.157235	1.157733	1.158233	1.158733	1.159233	1.159733	1.160233	1.160734
37	1.161236	1.161738	1.162240	1.162742	1.163245	1.163748	1.164252	1.164756	1.165259	1.165764
38	1.166269	1.166775	1.167281	1.167786	1.168293	1.168880	1.169307	1.169815	1.170322	1.170831
39	1.171340	1.171849	1.172359	1.172869	1.173379	1.173889	1.174400	1.174911	1.175423	1.175935
40	1.176447	1.176960	1.177473	1.177987	1.178501	1.179014	1.179527	1.180044	1.180560	1.181076
41	1.181592	1.182108	1.182625	1.183142	1.183660	1.184178	1.184696	1.185215	1.185734	1.186253
42	1.186773	1.187293	1.187814	1.188335	1.188856	1.189379	1.189901	1.190423	1.190946	1.191469
43	1.191993	1.192517	1.193041	1.193565	1.194090	1.194616	1.195141	1.195667	1.196193	1.196720
44	1.197247	1.197775	1.198303	1.198832	1.199360	1.199890	1.200420	1.200950	1.201480	1.202010
45	1.202540	1.203071	1.203603	1.204136	1.204668	1.205200	1.205733	1.206266	1.206801	1.207335
46	1.207870	1.208405	1.208940	1.209477	1.210013	1.210549	1.211086	1.211623	1.212162	1.212700
47	1.213238	1.213777	1.214317	1.214856	1.215395	1.215936	1.216476	1.217017	1.217559	1.218101
48	1.218643	1.219185	1.219729	1.220272	1.220815	1.221360	1.221904	1.222449	1.222995	1.223540
49	1.224086	1.224632	1.225180	1.225727	1.226274	1.226823	1.227371	1.227919	1.228469	1.229018

Density of Aqueous Sucrose Solutions at 20°C, g/ml.—(*Continued*)

% sucrose	d_4^{20}									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
50	1.229567	1.230117	1.230668	1.231219	1.231770	1.232322	1.232874	1.233426	1.233979	1.234532
51	1.235085	1.235639	1.236194	1.236748	1.237303	1.237859	1.238414	1.238970	1.239527	1.240084
52	1.240641	1.241198	1.241757	1.242315	1.242873	1.243433	1.243992	1.244552	1.245113	1.245673
53	1.246234	1.246795	1.247358	1.247920	1.248482	1.249046	1.249609	1.250172	1.250737	1.251301
54	1.251866	1.252431	1.252997	1.253563	1.254129	1.254697	1.255264	1.255831	1.256400	1.256967
55	1.257535	1.258104	1.258674	1.259244	1.259815	1.260385	1.260955	1.261527	1.262099	1.262671
56	1.263243	1.263816	1.264390	1.264963	1.265537	1.266112	1.266686	1.267261	1.267837	1.268413
57	1.268989	1.269565	1.270143	1.270720	1.271299	1.271877	1.272455	1.273035	1.273614	1.274194
58	1.274774	1.275354	1.275936	1.276517	1.277098	1.277680	1.278262	1.278844	1.279428	1.280011
59	1.280595	1.281179	1.281764	1.282349	1.282935	1.283521	1.284107	1.284694	1.285281	1.285869
60	1.286456	1.287044	1.287633	1.288222	1.288811	1.289401	1.289991	1.290581	1.291172	1.291763
61	1.292354	1.292946	1.293539	1.294131	1.294725	1.295318	1.295911	1.296506	1.297100	1.297696
62	1.298291	1.298886	1.299483	1.300079	1.300677	1.301274	1.301871	1.302470	1.303068	1.303668
63	1.304267	1.304867	1.305467	1.306068	1.306669	1.307271	1.307872	1.308475	1.309077	1.309680
64	1.310282	1.310885	1.311489	1.312093	1.312699	1.313304	1.313909	1.314515	1.315121	1.315728
65	1.316334	1.316941	1.317549	1.318157	1.318766	1.319374	1.319983	1.320593	1.321203	1.321814
66	1.322425	1.323036	1.323648	1.324259	1.324872	1.325484	1.326097	1.326711	1.327325	1.327940
67	1.328554	1.329170	1.329785	1.330401	1.331017	1.331633	1.332250	1.332868	1.333485	1.334103
68	1.334722	1.335342	1.335961	1.336581	1.337200	1.337821	1.338441	1.339063	1.339684	1.340306
69	1.340928	1.341551	1.342174	1.342798	1.343421	1.344046	1.344671	1.345296	1.345922	1.346547
70	1.347174	1.347801	1.348427	1.349055	1.349682	1.350311	1.350939	1.351568	1.352197	1.352827
71	1.353456	1.354087	1.354717	1.355349	1.355980	1.356612	1.357245	1.357877	1.358511	1.359144
72	1.359778	1.360413	1.361047	1.361682	1.362317	1.362953	1.363590	1.364226	1.364864	1.365501
73	1.366139	1.366777	1.367415	1.368054	1.368693	1.369333	1.369973	1.370613	1.371254	1.371894
74	1.372536	1.373178	1.373820	1.374463	1.375105	1.375749	1.376392	1.377036	1.377680	1.378326
75	1.378971	1.379617	1.380262	1.380909	1.381555	1.382203	1.382851	1.383499	1.384148	1.384796
76	1.385446	1.386096	1.386745	1.387396	1.388045	1.388696	1.389347	1.389999	1.390651	1.391303
77	1.391956	1.392610	1.393263	1.393917	1.394571	1.395226	1.395881	1.396536	1.397192	1.397848
78	1.398505	1.399162	1.399819	1.400477	1.401134	1.401793	1.403452	1.403111	1.403771	1.404430
79	1.405091	1.405752	1.406412	1.407074	1.407735	1.408398	1.409061	1.409723	1.410387	1.411051
80	1.411715	1.412380	1.413044	1.413709	1.414374	1.415040	1.415706	1.416373	1.417039	1.417707
81	1.418374	1.419043	1.419711	1.420380	1.421049	1.421719	1.422390	1.423059	1.423730	1.424400
82	1.425072	1.425744	1.426416	1.427089	1.427761	1.428435	1.429109	1.429782	1.430457	1.431131
83	1.431807	1.432483	1.433158	1.433835	1.434511	1.435188	1.435866	1.436543	1.437222	1.437900
84	1.438579	1.439259	1.439938	1.440619	1.441299	1.441980	1.442661	1.443342	1.444024	1.444705
85	1.445388	1.446071	1.446754	1.447438	1.448121	1.448806	1.449491	1.450175	1.450860	1.451545
86	1.452232	1.452919	1.453605	1.454292	1.454980	1.455668	1.456357	1.457045	1.457735	1.458424
87	1.459114	1.459805	1.460495	1.461186	1.461877	1.462568	1.463260	1.463953	1.464645	1.465338
88	1.466032	1.466726	1.467420	1.468115	1.468810	1.469504	1.470200	1.470896	1.471592	1.472289
89	1.472986	1.473684	1.474381	1.475080	1.475779	1.476477	1.477176	1.477876	1.478575	1.479275

Solubility

Solubility of Sucrose in Water (32)

°C	% wt.	°C	% wt.	°C	% wt.	°C	% wt.
0	64.18	10	65.58	19	66.93	28	68.37
1	64.31	11	6-.73	20	67.09	29	68.53
2	64.45	12	65.88	21	67.25	30	68.70
3	64.59	13	66.03	22	67.41	31	68.87
4	64.73	14	66.18	23	67.57	32	69.04
5	64.87	15	66.33	24	67.73	33	69.21
6	65.01	16	66.48	25	67.89	34	69.38
7	65.15	17	66.63	26	68.05	35	69.55
8	65.29	18	66.78	27	68.21	36	69.72
9	65.43						

Solubility of Sucrose in Water (32).—(*Continued*)

°C	% wt.	°C	% wt.	°C	% wt.	°C	% wt.
37	69.89	49	72.06	61	74.38	73	76.85
38	70.06	50	72.25	62	74.58	74	77.06
39	70.24	51	72.44	63	74.78	75	77.27
40	70.42	52	72.63	64	74.98	76	77.48
41	70.60	53	72.82	65	75.18	77	77.70
42	70.78	54	73.01	66	75.38	78	77.92
43	70.96	55	73.20	67	75.59	79	78.14
44	71.14	56	73.39	68	75.80	80	78.36
45	71.32	57	73.58	69	76.01	81	78.58
46	71.50	58	73.78	70	76.22	82	78.80
47	71.68	59	73.98	71	76.43	83	79.02
48	71.87	60	74.18	72	76.64	84	79.24

SOLUBILITY OF SUCROSE IN WATER (32).—(*Continued*)

°C	% wt.	°C	% wt.	°C	% wt.	°C	% wt.
85	79.46	89	80.38	93	81.30	97	82.25
86	79.69	90	80.61	94	81.53	98	82.49
87	79.92	91	80.84	95	81.77	99	82.73
88	80.15	92	81.07	96	82.01	100	82.97

FREEZING POINT-SOLUBILITY DATA (64)

System $C_{12}H_{22}O_{11}$-H_2O, E = eutectic, m = metastable

°C	g/100 g H_2O	°C	g/100 g H_2O
Ice		Ice + $C_{12}H_{22}O_{11}$	
± 0.0	0.0	−13.9 E	166.0
− 4.03	60.0	$C_{12}H_{22}O_{11}$	
−10.42	130.0	+ 0.9	180.5
−12.68	150.0	+15.8	196.0
−13.68	164.0	+25.6	210.5
−17.08 m	200.0	+30.5	218.0

SOLUBILITY OF SUCROSE IN AQUEOUS METHYL ALCOHOL AT 15°C (31)

Vol. %CH_3OH in solvent	100	90	80
g sucrose per 100 cm³ solution	0.3	1.6	3.8

Hydrolysis

HYDROLYSIS (INVERSION) OF SUCROSE

Sucrose	Acid	°C	*k*	Lit.
17.1%	0.099*N* HCl	35	0.00161	(72)

1000 g H_2O + 0.25 g-mole of sucrose + 1 g-mole of acid, 25°C

HNO_3	HCl	H_2SO_4	Lit.
k = 0.00464	0.00500	0.00549	(1)

TIME NECESSARY FOR VARYING PERCENTAGES OF HYDROLYSIS (INVERSION) OF SUCROSE WITH HCL (0.01*N* AT 20°C) AS THE CATALYZER (50)

°C	*k*	50% inversion, min	90% inversion, min	99.9% inversion, hr
50	0.001145	262.9	873.4	43.5
60	0.003806	79.1	262.9	13.1
70	0.01182	25.5	84.6	4.2
80	0.03303	9.11	30.3	1.5
90	0.08922	3.37	11.21	33.4*
100	0.26797	1.12	3.73	11.2*

* Minutes.

The reaction velocities for lower acidities may be computed without appreciable error by considering the velocity proportional to the concentration of acid. Thus, the velocities at 0.005*N* HCl will be very closely half those at 0.01*N* and the time of reaction twice as great.

REACTION VELOCITIES AT VARIOUS TEMPERATURES

$$k = \frac{1}{t}\log_{10}\frac{r_0 - r}{r_t - r},\ t \text{ in min}$$

$$k_{T_2} = k_{T_1}e^x, \text{ where } x = \frac{Q}{R}\,\frac{T_2 - T_1}{T_2T_1}$$

Sucrose, 50%; HCl, 0.1*N* at 20°C. Q/R = 12 925.2 (48)

°C	*k*	°C	*k*
0	0.0000077	59.903	0.04003
15.098	0.000092	69.974	0.1236
30.000	(0.0008732)	80.130	0.3687
39.916	0.00334	90.292	1.033
49.840	(0.01206)	90.316	1.020

Sucrose, 50%; HCl, 0.01*N* at 20°C. Q/R = 12 940.05 (48)

°C	*k*	°C	*k*
30.00	0.0008148	69.97	0.01194
49.85	0.001122	80.10	0.03429
59.90	0.003766	90.30	0.0939

Sucrose, 60%; HCl, 0.7925*N* at 20°C. Q/R = 13 087.6 (48)

°C	*k*	°C	*k*
20	0.002156	35.072	0.01882
30.117	0.00983	40.078	0.03780
30.093	0.01001	40.088	0.03791

INVERSION OF SUCROSE WITH INVERTASE (69)

$$t = \frac{1}{n}\log_{10}\frac{100}{100 - p} + 0.002642p - 0.000008860p^2 - 0.0000001034\,p^3;$$

t = minutes; p = % inversion; n is proportional to the amount of active invertase and depends upon the temperature.

Range of invertase concentration from 12 to 1; temperature from 15 to 35°; H-ion concentration 4×10^{-5} to 3.2×10^{-7}.

At any given temperature *n* may be used to measure the activity of an invertase solution.

LENGTH OF TIME REQUIRED TO FORM CARAMEL EQUIVALENT TO 0.01 % INVERT SUGAR (9)

The time, in hours, required to form caramel equivalent to 0.01% invert sugar at any temperature *t* (°C) between 39 and 100° may be computed from the equation:

$$\log_{10} \text{hr} = 5.0026 - 0.0595t.$$

LACTOSE

$C_{12}H_{22}O_{11}$ (Galactose < Dextrose <)

TRANSITION TEMPERATURES AND MELTING POINTS (85)

α-hydrate → β-anhydrous, 93.5°. α-anhydrous → liquid, 222.8°. β-anhydrous → liquid, 252.2°. α-anhydrous is metastable below its melting point. α-hydrate → liquid, 201.6°.

Optical Rotation

IN H_2O

$[\alpha]^t_D = 52.4_2 + 0.072\,(20° - t)$; 5 g/100 ml (4); $[\alpha]^t_{546.1} = 61.9_4 + 0.085\,(20° - t)$; 5 g/100 ml (4); $[\alpha]^{20}_D = 52.53$ (21); $[\alpha]^{25}_{546} = 61.36$; $[\alpha]^{25}_{589} = 51.90$ (78).

ROTATION DISPERSION AT EQUILIBRIUM (30)

Values of $[\alpha]^{20}_\lambda$; C = g hydrate/100 ml

λ	H_2O, $C = 2$	Pyridine, $C = 0.5$	Formic acid, $C = 5.9$
656	39.82	31.00	78.64
589	52.42	41.33	97.76
535	62.09	49.66	117.92
508	72.25	60.00	134.38
479	83.25	73.66	160.79
447	98.17	91.66	180.92

$[\alpha]_D$ IN VARIOUS SOLVENTS

Solvent	Anhydrous lactose, g/100 ml	°C	$[\alpha]^t_D$			$10^3(k_1 + k_2)$	Lit.
			α	$\alpha \rightleftarrows \beta$	β		
H_2O	2.316	14	84.4	55.25		3.78	(60)
Formamide	2.27	15	82.4	51.2		0.387	(60)
H_2O	2.75	17		55.23	35.97	2.97	(60)
Formamide	1.85	17		51.22	29.11	0.4	(60)
H_2O		20	86.		34.5		(38)
H_2O		20	90.0	55.3	35.0	4.65	(44)
40%, C_2H_5OH		20	81.0	55.3	33.0		(44)
H_2O		0				0.5	(35)

$d[\alpha]_D/dt = -0.08$ between $t = 10 - 25$°C (60).

EFFECT OF H_2SO_4 (11)

N = normality

N, H_2SO_4	0	10	12	14	16	18	20	22	24	26
$[\alpha]_D^{25}$........	52.5	56.7	59.0	61.5	63.5	65.5*	68.5	72.5	76.0	99.0

* Noticeable inversion begins.

Refractive Index and Density of Aqueous Solutions (77)

% anhydrous lactose..........	23.38	17.06	11.66	5.80	2.78	1.28
d_4^{25}.............	1.0969	1.0681	1.0448	1.0204	1.0092	1.0018
n_D^{25}.............	1.3716	1.3605	1.3517	1.3423	1.3380	1.3350

Solubility

SOLUBILITY IN WATER (38)

S_0 = initial, S_∞ = final solubility in millimoles of anhydrous lactose per 100 g H_2O

(*a*) Solid phase: the hydrate

°C..........	0.0	15.0	25.0	39.0	49.0	64.0	74.0	89.0
S_∞..........	34.8	49.7	63.4	92.7	124.0	193.0	253.0	407.0
S_0...........	14.8	20.9	25.3	37.0*	52.0*	77.0*	101.0*	163.0*

(*b*) Solid phase: β-anhydrous. Final solubility: at 0°, 42.9; at 100°, 61.2 wt. % anhydrous

(*c*) Solid phase: β-anhydrous

°C.....................	0.0	0.0	100
S_0.....................	132	(124) (extrap.)	227
S_∞.....................	220		461

* Calculated from final solubility and equilibrium ratio.

PER CENT β-ANHYDROUS AT EQUILIBRIUM IN A SOLUTION SATURATED WITH THE HYDRATE (38)

°C	0	15	25	39	49	64	74	89
%	5.8	7.7	9.6	14.0	18.0	24.0	27.0	35.0

Per cent hydrate at equilibrium in solution saturated with the β-anhydrous = 17 at 0°C; = 24 at 100°C (38).

SOLUBILITY IN AQUEOUS C_2H_5OH (44)

g anhydrous lactose in 100 cm³ 40% C_2H_5OH at 20°C = 1.1 initial; = 2.4 final.

SOLUBILITY AND FREEZING POINT LOWERING

Solubility in H_2O. Solid phase: lactose hydrate

°C	% lac.	Lit.	°C	% lac.	Lit.	°C	% lac.	Lit.
0	10.6	(39)	57.1	34.9	(28)	100	60.5	(39)
15	14.4	(39)	63.9	39.1	(28)	107.0	63.9	(28)
21.5	16.7	(79)	64.0	39.7	(39)	121.5	69.4	(28)
25	17.8	(39)	73.5	45.8	(28)	133.6	73.2	(28)
28	19.4	(79)	74.0	46.2	(39)	138.8	75.2	(28)
38	23.5	(79)	79.1	49.6	(28)	158.8	81.1	(28)
39	24.0	(39)	87.2	55.1	(28)	178.8	86.7	(28)
49	29.7	(39)	88.2	56.0	(28)	200	92.5	(27)

FREEZING POINT LOWERING (38, 58)

Between 1 and 30 millimoles lactose per 100 g H_2O the molal lowering is 1.86°/mole and at 48 millimoles 1.89°/mole.

Cryohydrate Points.—Initial, −0.279° and 14.8 millimoles per 100 g H_2O; final for hydrate, −0.65°; initial for β-anhydrous, −2.3°; final for β-anhydrous, −4.1°.

Mutarotation

MUTAROTATION IN H_2O

°C..........	0.0	15.0	25.0	0	14.0	17.0	20.0
$10^3(k_1 + k_2)$.	0.51	2.97	7.92		3.78	2.97	6.2
10^3k_1........	0.29	1.55	4.65	0.24			
10^3k_2........	0.21	1.08	3.08				
Lit.........	(35)	(35)	(35)	(38)	(60)	(60)	(11)

COMPOSITION OF AN AQUEOUS SOLUTION AT EQUILIBRIUM (27)

°C................	0	25	50	75	92	100
$\% \beta / \% \alpha$..........	1.65	1.58	1.51	1.45	1.39	1.33

Hydrolysis (10)

$$k_H = \frac{1}{t} \log_{10} \frac{r_0 - r_\infty}{r_t - r_\infty} \quad t \text{ in min}$$

Anhydrous lactose, g/l	Acid	10^3k_H	°C
50	$22N$ H_2SO_4..................	4.4	20
50	$24N$ H_2SO_4..................	7.7	20
80	HCl, d = 1.185...............	1.1	15
80	HCl, d = 1.185...............	2.1	20
80	HCl, d = 1.185...............	4.3	25
80	HCl, d = 1.185...............	8.2	30
80	HCl, d = 1.185...............	17.1	35
80	HCl, d = 1.185...............	35.2	40
40	HCl, d = 1.185...............	5.1	25
120	HCl, d = 1.185...............	3.4	25
200	HCl, d = 1.185...............	1.5	25
80	$HClO_4$, d = 1.67..............	24.2	20
	$HClO_4$, d = 1.67..............	50.0	25

$C_{12}H_{22}O_{11}$, MALTOSE

Composition: (Glucose < Glucose <)

Optical Rotation

IN H_2O (21)

$[\alpha]_D^{20}$ = 138.475 − 0.01837p for values of p from 5 to 35 wt. % *in vacuo*. $\alpha]_{546}^{25}$ = 153.75. $[\alpha]_{589}^{25}$ = 131.25 (78).

IN VARIOUS SOLVENTS AT 20°C

Solvent	Maltose, g/100 ml	$[\alpha]_D^{20}$			$10^3(k_1 + k_2)$	Lit.
		α	$\alpha \rightleftarrows \beta$	β		
H_2O...........		168*	136.0	118.0	7.2	(44)
60% C_2H_5OH...		158*	128.1	111.0		(44)
H_2O...........	2.52		136.2	123	5.03	(61)
Formamide.....	2.12		130.3	113	1.63	(61)
H_2O...........			137	119		(39)
H_2O...........			137			(81)
Pyridine........			122.0			(81)
H_2O...........			137			(30)
Pyridine........			124			(30)
Formic acid.....			175			(30)

* Calculated.

EFFECT OF PYRIDINE

Two g maltose in 200 cm³ of a 5% aqueous pyridine solution (34)

After, days.......	0	1	2	After heating for, hr...	0	0.5	1.5
R, °arc..........	6.75	6.70		R, °arc..............	6.7	5.6	4.8

EFFECT OF H_2SO_4

Maltose 5 g/100 ml (11)

N of H_2SO_4..........	0	10	12	18	22
$[\alpha]_D^{25}$................	135.5	129.0	127.5	129.5	132.0

Equilibrium Rotation

Values of $[\alpha]_\lambda^{20}$ for $\alpha \rightleftarrows \beta$ in various solvents; maltose < 5 g/100 ml (30)

λ, mμ	656	589	535	508	479	447
H_2O	111	137	167	180	229	236
Pyridine	100	124	152	180	212	231
Formic acid	140	175	210	248	292	320

Refractive Index and Density of Aqueous Solutions (77)

% anhydrous maltose	19.40	9.60	4.77	2.32	1.16
d_4^{25}	1.0777	1.0362	1.0160	1.0064	1.0017
n_D^{25}	1.3639	1.3482	1.3406	1.3368	1.3354

Solubility

In H_2O (29)

°C	0.6	21.0	29.6	34.4	43.5	49.4
% M.	36.1	44.1	48.0	49.6	55.3	58.3

°C	54.2	59.8	66.3	74.2	87.0	96.5
% M.	60.2	63.7	66.7	72.3	79.3	85.1

In 60% C_2H_5OH at 20°C (44)

Initial, 3.0; final 4.75, g/100 cm³ of solution. Equilibrium mixture contains 64% β and 36% α.

Freezing Point Lowering (29)

In H_2O	% anhydrous maltose	24.0	16.7	12.4	7.16(58)
	Δt_F, °C	1.87	1.16	0.79	0.395
In 0.1*N* NH_4OH aq. soln.	% anhydrous maltose	25.1	18.3	28.9	16.9
	Δt_F, °C	1.94	1.25	2.44	1.17

$C_6H_{12}O_6$, DEXTROSE (*d*-Glucose)

Optical Rotation

The saccharimetric normal weight for dextrose is 32.231 g (in air, $d = 0.0012$, brass weights) (47).

Rotations for λ = 546.1 mμ, 20°C; 200 mm Tube; Aqueous Solution

Saccharimetric normality	1	$\frac{4}{5}$	$\frac{3}{5}$	$\frac{2}{5}$	$\frac{1}{5}$
R, °arc	40.897	32.574₅	24.328	16.142	8.042

Corrections to Be Added to Saccharimetric Readings of Dextrose Solutions (47)

°*S*	Corr.	°*S*	Corr.	°*S*	Corr.
100	0	65	0.50	30	0.46
95	0.10	60	0.52	25	0.41
90	0.20	55	0.54	20	0.35
85	0.28	50	0.55	15	0.28
80	0.35	45	0.54	10	0.20
75	0.41	40	0.53	5	0.10
70	0.46	35	0.50	2	0.05

Specific Rotatory Power in H_2O

$[\alpha]_{546.1}^{20} = 62.032 + 0.04257\,C$; $= 62.032 + 0.0422\,p + 0.0001897\,p^2$. Valid from $C = 6$ to 32 g/100 ml soln. p = wt. %. All weights *in vacuo* (47). $[\alpha]_D^{20} = 52.50 + 0.0188p + 0.000517p^2$. Valid from $p = 0$ to 35 wt. %. All weights *in vacuo* (21, 89). $\alpha]_{546}^{25} = 62.02$; $[\alpha]_{589}^{25} = 52.48$ (78).

In Water, in Pyridine and in Formic Acid

Values of $[\alpha]_\lambda^{20}$ (30)

λ	In H_2O, $\frac{1}{4}$ to $\frac{1}{32}N$	In pyridine, $\frac{1}{4}N$	In formic acid
656	41.47	60.87	96.0
589	52.52	75.64	122.8
535	64.90	93.55	150.0
508	73.03	104.00	176
479	83.05	118.02	203
447	95.79	136.90	224

In Various Solvents at 20°C

Solvent	Dextrose, g/100 ml	$[\alpha]_D^{20}$ α	$[\alpha]_D^{20}$ $\alpha \rightleftarrows \beta$	$[\alpha]_D^{20}$ β	$10^3 (k_1 + k_2)$	Lit.
H_2O	9.1	108.5	52.2		6.27	(60)
Formamide	2.5	122.7	57.27		1.09	(60)
H_2O	2.3		52.02	20.76	6.9	(61)
Formamide	1.7		56.28	15.74	0.996	(61)
H_2O		113.4	52.2	19.7		(44)
80% C_2H_5OH		115.2	59.0	20.3		(44)
C_2H_5OH		121.5	70.45	16.5		(44)
Pyridine			75.56			(30)
Formic acid			122.8			(30)

Effect of Propyl Alcohol

Alcohol used had $d_4^{19} = 0.810$. Dextrose concn. < 50 g/l (26)

Alc., g/l	100	200	300	400	500	600	700
$[\alpha]_D^{19}$	52.20	52.81	53.22	53.48	55.35	55.44	56.81

Effect of Salts (66)

Salt	$[\alpha]_D^{20}$	Salt	$[\alpha]_D^{20}$
Nil	**52.8**	2*N* NH_4Cl	52.3
4*N* KI	47.4	2*N* CH_3COONH_4	52.3
4*N* KBr	48.5	*N* CH_3COOK	52.3
4*N* KCl	49.6	4*N* $MgCl_2$	52.8
4*N* NH_4NO_3	50.6	*N* $MgCl_2$	52.8
2*N* KNO_3	50.6	2*N* $MgSO_4$	52.8
4*N* NH_4Cl	51.2	2*N* CH_3COONa	52.8
2*N* KCl	51.2	*N* CH_3COONa	52.8
N K_2SO_4	51.2	*N* CH_3COONH_4	52.8
2*N* $(NH_4)_2SO_4$	51.7	2*N* $BaCl_2$	54.7
2*N* CH_3COOK	51.7	3*N* $BaCl_2$	55.5
4*N* $NaNO_3$	52.3	2*N* $CaCl_2$	56.0
2*N* Na_2SO_4	52.3	4*N* $CaCl_2$	61.2

Effect of HCl (97)

Dextrose concn., 5 g/100 ml

% HCl	3.65	19.25	30.4	34.4	37.6	39.9	41.4	44.5
$[\alpha]_D^{16-17}$	+54.5	57.2	61.0	67.0	82.5	97.5	106.0	164.6

% HCl	0	42.0	46.6	46.7
°C	8	8	−12	−12
$[\alpha]_D^t$	52.2	113.3	200.0	202.0

Effect of H_2SO_4 (11)

Dextrose concn. = 50 g/l at 25°. The table gives values of $[\alpha]_D^{25}$ in acid of the normality stated. In acid above 22*N*, mutarotation is found. At 20°, 50 g/l in 24*N* acid gives $k = 0.0020$.

0	10*N*	16*N*	18*N*	20*N*	22*N*	24*N*	26*N*	28*N*
52.8	56.0	62.5	65.0	67.5	72.5	80.0	91.0	107.0

Refractive Index and Density of Aqueous Solutions (77)

% wt.	24.03	20.14	15.72	10.20	4.36	2.11	1.00
d_4^{25}	1.0962	1.0795	1.0604	1.0370	1.0146	1.0051	1.0007
n_D^{25}	1.3710	1.3646	1.3575	1.3486	1.3401	1.3366	1.3351

Density of Aqueous Solutions (47)

$d_4^{20} = 0.99840 + 0.003788\,p + 0.00001412p^2$. Range of p, 4 to 30, wt. % dextrose. All weights *in vacuo*.

Solubility

System: Dextrose-Water (49); *v.* Fig. 2

The solid curves show the final equilibria with respect to the solid phases, ice, dextrose hydrate, and anhydrous dextrose. The dotted curve shows the instantaneous solubility before mutarotation. All data are expressed in terms of anhydrous dextrose.

SYSTEM: DEXTROSE-ETHYL ALCOHOL-(WATER), 20°C

S_0 (resp. S_∞) = initial (resp. final) solubility, g anhyd. dextrose per liter of solution (44)

% wt., C_2H_5OH	α-anhydrous		α-hydrate		β-anhydrous	
	S_0	S_∞	S_0	S	S_0	S_∞
80	20	45	13	30	49	91
100	8.5	16				

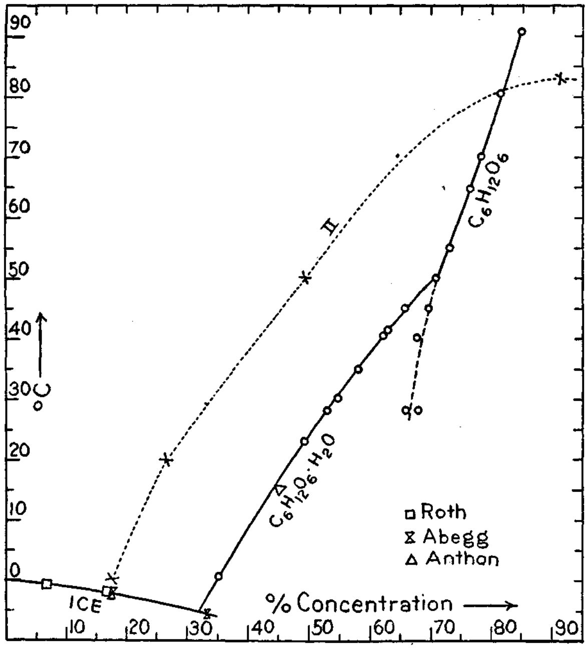

FIG. 2.

Mutarotation

MUTAROTATION AT 20°C (24)

B = moles buffer per l solution

pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$
B = 0.1		B = 0.1		B = 0.01		B = 0.05	
4.88	13.0	3.08	7.7	4.96	7.28	4.87	10.7
4.28	9.0	2.66	8.1	3.43	6.74	B = 0.2	
4.08	8.7	2.04	9.5	2.54	7.20	4.80	17.9
3.44	7.8	1.02	20.0	1.75	8.72	B = 0	
						4.93	7.22

VARIATION OF pH WITH TEMPERATURE AND CONCENTRATION OF DEXTROSE (68)

$[\alpha]_D$ = +111.2 for α-form; = +17.5 for β-form; = 52.5 for equilibrium mixture; at all temperatures and concentrations used

pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$	pH	$10^3 (k_1 + k_2)$
α-form, 0.15°C		37°C		6.50	34.3	6.43	0.78
1.33	2.42	1.0	118.6	6.55	33.0	6.70	0.80
2.38	0.91	1.72	50.0	6.75	51.7	7.51	1.86
3.05	0.79	2.06	37.6	7.27	86.7	8.00	3.30
3.98	0.79	2.53	32.6	7.55	118.1	37°C	
5.07	0.77	2.73	32.0	8.50	220.5	1.72	48.6
5.35	0.77	3.36	30.0	β-form, 0.15°C		2.60	31.3
6.84	0.92	3.99	29.9	1.33	2.10	2.92	30.0
7.51	2.2	5.58	30.5	2.02	0.93	4.82	30.0
		5.95	29.8	4.80	0.78	5.90	30.4
		6.37	32.2	6.00	0.76	6.30	32.5

$k_1 + k_2 = 0.0096 + 0.258[H^+] + 9750[OH^-]$ at 25° (36)

HCl, m/l....	0.0	0.001	0.005	0.01	0.03	0.06	0.10	t, °C
$10^3 (k_1 + k_2)$.	10.6	9.8	11.2	12.1	16.9	25.3	35.4	24.7

$k_1 + k_2 = 0.0167 + 0.44[H^+]$ at 30° in HCl solutions (37)

HCl, m/l.......	0.0	0.0 + invertase	0.5	0.10	0.20
$10^3 (k_1 + k_2)$....	16.7	16.7	38.3	62.0	10.5

MUTAROTATION AT 5.4°C (25)

Minimum rate occurs at pH = 5.0 which corresponds to a dissociation constant for dextrose of 5×10^{-18}. An average value for Q is 17 500

Form	Reagent	pH	$10^3 (k_1 + k_2)$
α	1.3N HCl....................	−0.08	108.6
β	1.3N HCl....................	−0.06	107.2
α	0.3N HCl....................	+0.54	14.38
α	0.1N HCl....................	1.05	4.35
β	0.1N HCl....................	1.06	4.14
α	0.03N HCl..................	1.52	2.26
α	0.01N HCl..................	1.98	1.61
β	0.01N HCl..................	1.99	1.55
α	0.002N HCl................	2.74	1.38
β	0.045N HCl................	5.13	1.19
α	0.001N $NaHCO_3$.............	7.34	1.33
β	0.003N $NaHCO_3$.............	7.84	1.46
α	0.01N $NaHCO_3$..............	8.14	1.56
β	0.01N $NaHCO_3$..............	8.25	1.90
β	0.0015N Na_2CO_3............	9.13	7.82
α	0.003N Na_2CO_3..............	9.41	12.48
α	0.01N Na_2CO_3................	10.07	41.10
β	0.01N Na_2CO_3................	10.11	41.75
α	0.003N NaOH................	10.41	83.76

VARIATION WITH CONCENTRATION AND TEMPERATURE. AQUEOUS SOLUTIONS (42)

g/100 ml	$10^3 (k_1 + k_2)$25°C	Dextrose < 100 g/l		
		°C	$10^3 (k_1 + k_2)$	
			α	β
3	10.50			
3	10.57			
3	10.68	0.7	0.74	0.74
6	10.48	5	1.29	1.50
9.6	10.59	10	2.25	2.23
16	11.04	15	3.99	3.79
25	11.35	20	6.35	6.54
32	10.68	25	10.50	10.57
37	10.60	30	1.75	1.68
52	10.08	40	4.37	3.95
64	9.31			

$\log_{10} (k_1 + k_2) = 11.0198 - 3873/T$.

MUTAROTATION IN METHYL ALCOHOL (5)

Concentration dextrose *ca.* 12.3 g/l

CH_3OH		CH_3OH + 0.5% H_2O		CH_3OH + 1% H_2O		CH_3OH + 2% H_2O	
Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$
0.25	111.2	0.28	111.5	0.28	109.6	0.28	110.9
.43	110.0	.72	105.2	.53	106.9	.52	107.5
.83	106.3	1.32	102.4	.88	104.3	.77	105.2
1.38	104.8	1.63	98.5	1.47	99.2	1.13	99.9
2.63	97.7	2.22	96.9	1.92	95.9	1.82	90.1
4.05	88.4	3.22	91.0	3.22	85.8	2.33	85.9
5.53	83.2	4.00	86.9	4.33	81.7	3.42	79.5
6.83	79.5	5.85	80.5	5.88	74.8	4.22	76.9
		6.92	76.8	8.08	69.7	5.38	72.6
		8.38	73.1	11.42	66.7	6.75	69.7

Mutarotation in Methyl Alcohol (5).—(*Continued*)

CH_3OH		CH_3OH + 0.5% H_2O		CH_3OH + 1% H_2O		CH_3OH + 2% H_2O	
Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$	Time, hr	$[\alpha]_D^{44.8}$
		12.05	69.9	24.0	64.0	8.93	66.1
		23.18	64.5			11.58	64.1
		25.08	64.5			24.25	64.1

Mutarotation in Ethyl Alcohol of Varying Concentrations at 20°C (44)

% C_2H_5OH	0	20	40	60	70	80
10^3 $(k_1 + k_2)$	6.5	4.8	3.0	1.82	1.56	1.14

$C_6H_{12}O_6$, LEVULOSE

Optical Rotation

In Water (90)

$[\alpha]_D^{25} = -(88.50 + 0.145p)$; $= -(88.50 + 0.150\ C - 0.00086\ C^2)$, from p = 2.6 to 18.6 wt. % and from C = 2.6 to 20 g/100 ml. $[\alpha]_D^t = [\alpha]_D^{25} + (0.566 + 0.0028C)\ (t° - 25°)$; from 15 to 37°C. $[\alpha]_{589}^{20}/[\alpha]_{546}^{20} = 0.8467$. $[\alpha]_D^{20} = -(88.16 + 0.258p)$ (21). $[\alpha]_{546}^{25} = -105.30$; $[\alpha]_{589}^{25} = -89.40$ (78).

In Water, in Pyridine and in Formic Acid at 20°

Values of $-[\alpha]_\lambda^{20}$ for different concentrations (C) of levulose (30)

λ	In H_2O				In pyridine			
	$\frac{1}{4}N$	$\frac{1}{8}N$	$\frac{1}{16}N$	$\frac{1}{32}N$	$\frac{1}{4}N$	$\frac{1}{8}N$	$\frac{1}{16}N$	$\frac{1}{32}N$
656	76.39	75.30	74.86	74.04	26.44	25.81	25.39	24.77
589	90.46	89.96	88.36	87.49	35.48	35.26	34.96	34.51
535	107.21	106.66	105.70	104.84	42.59	42.22	41.71	41.24
508	136.85	135.8	133.35	130.12	49.10	48.77	48.36	47.62
479	151.11	149.27	147.20	146.20	56.0	55.37	54.78	54.07
447	166.55	163.88	160.49	158.10	63.93	62.70	62.11	61.33

Formic acid, C = 8.6 g/100 ml	λ	656	589	535	508	479	447
	$[\alpha]_\lambda^{20}$	37.25	46.77	52.83	64.66	75.54	85.84

Pyridine, C = 1.8 g/100 ml	°C	22	35	45
	$[\alpha]_{656}^t$	26.38	24.44	22.77

In Aqueous Ethyl Alcohol (2)

Composition: 2 moles levulose + 100 moles H_2O + x moles C_2H_5OH. Values of $[\alpha]_\lambda^{25}$

x \ λ	578 (HgY)	546 (HgG)	436 (HgB)
0	−93.73	−106.03	−175.29
9.28	−87.08	− 98.55	−162.65
24.65	−80.13	− 90.69	−149.62
54.9	−73.50	− 83.17	−137.48
167.0	−64.22	− 72.52	−120.59
1724.0	−49.7	− 55.7	− 93.7

In Various Solvents

Solvent	Levulose, g/100 ml	$[\alpha]_D^{20}$			10^3 $(k_1 + k_2)$	Lit.
		α*	$\alpha \leftrightarrows \beta$	β		
Formamide	2.26		−109.51	−151.76	8.39	(60)
H_2O	10		− 92.0	−133.5		(44)
80% C_2H_5OH	10	−7	− 68.6	−133.5		(44)
95% C_2H_5OH		0	− 52.5	−122		(44)
CH_3OH		−8	− 61.4	−122		(44)

In Various Solvents.—(*Continued*)

Solvent	Levulose, g/100 ml	$[\alpha]_D^{20}$			10^3 $(k_1 + k_2)$	Lit.
		α*	$\alpha \leftrightarrows \beta$	β		
80% C_2H_5OH					9.1†	(44)
H_2O	$\frac{1}{4}N$		− 90.5			(30)
Pyridine	$\frac{1}{4}N$		− 35.5			(30)
Formic acid	5 to 8		− 53.0			(30)

Solvent	t,°C	Levulose, g/100 ml		$[\alpha]_{546}^t$		10^3 $(k_1 + k_2)$	Lit.
H_2O	14.3	9.942		−115.7	−161	65	(71)
H_2O	0.0	4.9		−123.6	−155	17	(71)
Aq., C_2H_5OH							
$d_4^{14} = 0.930$	15.3	10.06		− 96.4	−156	22	(71)
$d_4^{15} = 0.876$	0.0	4.9		− 96.1	−154	1	(71)

* Computed from solubilities and $[\alpha]_D$ for β-form. † $k_1 = 0.0047$.

Effect of HCl in H_2O (97)

% HCl	0	25	37.6	40.0	42.0
°C	9	8	8	8	8
$[\alpha]_D^t$	−95.1	−116	−133	−154	−180

Solubility

In H_2O (51)	°C	20	25	30	35	40	45	50	55
	% levulose	78.94	80.29	81.64	82.98	84.34	85.64	86.90	88.10

Solvent	g/100 ml solution		Composition, at equilibrium	Lit.
	Initial	Final		
80% C_2H_5OH	13.4	27.4	48% β, 51% α	(44)
95% C_2H_5OH	1.8	4.2	43% β, 57% α	(44)
CH_3OH	5.2	11.1	47% β, 53% α	(44)

Mutarotation

With HCl at 30°C (37)

HCl, mole/l	0	0.0005	0.0010	0.0040	0.0100
10^3 $(k_1 + k_2)$	186	140	128	130	196

Effect of pH and Temperature (68)

0.15°C		15°C		25°C		37°C	
pH	10^3 $(k_1 + k_2)$	pH	10^3 $(k_1 + k_2)$	pH	10^3 $(k_1 + k_2)$	pH	10^3 $(k_1 + k_2)$
1.33	101.0	2.5	64.7	2.5	118.9	1.70	460
2.48	16.2	3.3	36.8	3.4	86.0	2.06	350
3.17	8.5	5.1	41.5	5.1	99.2	3.36	195
5.07	8.7	5.8	53.5	5.7	107.6	4.62	205
6.00	10.4	6.3	64.7	6.4	156.1	5.10	236
6.28	17.8					6.10	275
						7.67	741

°C	0.15	15	25	37
$[\alpha]_D^t$ initial	−130.8	−130.8	−130.8	−130.8
$[\alpha]_D^t$ final	−100	− 94	− 88	− 81

Effect of Boric Acid (12)

Levulose, 1 molal, 0°C	H_3BO_3, m/l	0.22 molal	0.11 molal	0
	10^3 $(k_1 + k_2)$	40	39	12.4

Velocity of Conversion of Artichoke Juices under Varying Conditions of Acidity and Temperature (51)

$$k = \frac{1}{t}\log_{10}\frac{R_0 - R_\infty}{R_t - R_\infty}$$

R_0, initial rotation; R_∞, rotation at completion of conversion

	t,°C	Acidity (apparent) normality	k
$R_0 = +0.08$, $R_\infty = -26.43$	79.8	0.10 H_2SO_4	0.0137
	79.8	.20 H_2SO_4	.0788
	78.2	.10 HCl	.0381
$R_0 = -2.40$, $R_\infty = -25.88$	99.0	0.0294 HCl	0.00327
	99.0	.0516 HCl	.02737
	99.0	.0667 HCl	.1371
$R_0 = -1.29$, $R_\infty = -34.48$	99.0	0.0240 HCl	0.0010
	99.0	.0462 HCl	.00593
	99.0	.0571 HCl	.0163
	99.0	.0676 HCl	.0353
	99.0	.0773 HCl	.0707
	99.0	.1041 HCl	.3172

The "apparent" acidities are those which would have been produced in pure water. A portion of the acid in each instance was rendered ineffective by inorganic impurities.

Velocity of Conversion of Inulin in the Presence of Varying Concentrations of Hydrochloric Acid at 100°C

Normality of HCl	Velocity constant, k	k (ash-free) in 0.01N HCl
0.0095	0.00641	$\frac{k(3-2)}{N(3-2)} = 0.0184$
0.0199	.0394	$\frac{k(4-3)}{N(4-3)} = 0.0212$
0.0545	.1022	$\frac{k(4-2)}{N(4-2)} = 0.0199$
0.1034	.2057	
Mean		0.020

By taking the differences in velocity at the higher acidities the neutralizing action of inorganic impurities is arithmetically eliminated.

Decomposition of Levulose in the Presence of Sulfuric Acid (51)

t,°C	Time in min	Acidity normality	Polarization in saccharimeter deg.
			86.25*
100	15	0.0304	83.70
100	30	.0304	82.90
100	15	.0584	83.30
100	30	.0584	81.16
			85.89*
70	15	.0474	85.87
70	30	.0474	85.63
70	15	.0891	85.79
70	30	.0891	85.26

* Control solution.

INVERT SUGAR

Mixture of equal parts of dextrose and levulose obtained by hydrolysis of sucrose.

Optical Rotation

In H_2O

$[\alpha]_D^{20} = -19.447 - 0.06068p + 0.000221p^2$ between $p = 9$ and 68 wt. %. All weights *in vacuo* (21). $[\alpha]_{546}^{25} = -21.50$. $[\alpha]_{589}^{25} = -18.39$ (78).

Effect of Various Substances on the Rotation

R (in°S) $= -42.00^0 - 10^{-3}\,am$, where m = g anhyd. reagent per 100 ml of solution and R is twice the rotation (in°S) observed with 13 g of inverted sucrose per 100 ml. Ac = $C_2H_3O_2$ (48).

Reagent	HCl	NaCl	NH_4Cl	$CaCl_2$	$K_2C_2O_4$	HAc	H_3PO_4
a	540.7	540	563	710	510	82.3	77.6
For $m \ngtr$	9.3	3.7	3.7	7.5	12.9	41	5.5

Reagent	xPbAc$_2\cdot y$PbO	PbAc	NH_4NO_2	KCl	Na_2HPO_4. 12 aq.	NaAc. 3 aq.
a	−1430	20	399	486	161	189
At m =	2.57	3.03	2.68	11.8	12.26	12.85

Decomposition in the Presence of HCl, 0.7925N (48)

50°C	Min	0	38	78	128	235
	°S	33.25	33.04	32.95	32.80	32.44

60°C	Min	0	8	18	33	48	63	93
	°S	33.25	33.11	32.93	32.76	32.60	32.31	32.02

70°C	Min	0	4	8	12	17	22	32
	°S	33.25	33.00	32.62	32.46	32.26	31.89	31.45

80°C	Min	0	3	6	10	14	19
	°S	33.25	32.61	32.00	31.30	30.82	30.07

$C_6H_{12}O_6$, MANNOSE

Optical Rotation

In H_2O

C = g anhyd. mannose per 100 cm³ solution at 20°C (44)

C	3.25	4.53	10.2	16.9	20.5_5
$[\alpha]_D^{20}$	14.6	14.5	14.1	13.6	13.4

C	30.1_5	39.7	50	60	70	80
$[\alpha]_D^{20}$	13.1	12.8	12.3	11.9	11.4	10.9

In Various Solvents

Solvent	Mannose, g/100 ml	°C	$[\alpha]_D^t$			Lit.
			α	$\alpha \rightleftarrows \beta$	β	
H_2O	2.8	19		+14.40	−19.9	(61)
Formamide	2.0	20		11.84	−26.9	(61)
H_2O		20	+34*	14.6	−17.	(44)
80% C_2H_5OH		20	+34*	25.7	−14.9	(44)
CH_3OH		20	39*	30.1	−16.5	(44)
H_2O		20	30			(56)
80% C_2H_5OH		20	35			(56)

* Computed from initial and final solubilities and rotations of the β-form.

Effect of HCl on d-mannose

Ca. 5 g anhyd. mannose per 100 ml solution (97)

% HCl	0	8	25	31	37.6	40.0	42.0
°C	13	10	10	10	10	10	10
$[\alpha]_D^t$	+14.1	+10.5	+4.0	+3.0	+13.3	+31.3	+54.6

Effect of H_2SO_4

1.25 g anhyd. mannose in 25 cm³; H_2SO_4 = 24N; 25°C (11)

t, min	5	10	20	30	60	120	240	360
α, °arc	−8.3	−8.3	−7.5	−6.7	−5.0	−1.8	±0.0	+2.5

Solubility

Solid phase: β-mannose; 20°C; g/100 cm³ solution (44)

Solvent	Initial	Final	α ⇄ β mix.	
			%α	%β
100% CH_3OH	0.78	4.4		
80% C_2H_5OH	2.4	13.0	82	18

Mutarotation

IN H_2O

C = g mannose per 100 cm³ of solution; 19.7°C (43)

C	5.13	8.0	10.0	10.2	19.1	24.7
$10^3 (k_1 + k_2)$	17.7	17.9	17.5	17.8	18.1	19.1

C	27.1	36.8	45.0	50.0	52.0	56.0
$10^3 (k_1 + k_2)$	19.2	19.7	20.0	19.2	18.9	17.9

IN DILUTE (≯10%) SOLUTION (43)

Between 0 and 45°C, $k_1 + k_2$ may be computed with an accuracy of *ca.* 5% by means of the equation: $\log_{10} 10^3 (k_1 + k_2) = 13.132 - 3472/T$ where T is the absolute temperature.

EFFECT OF HCL AT 19.7°C (43)

HCl, N	0	0.001	0.010	0.0125	0.0166	0.025	0.05	0.10
$10^3 (k_1 + k_2)$	17.7	19.0	39.6	46.0	55.8	70.8	125	238

IN VARIOUS SOLVENTS

Solvent	°C	$10^3(k_1 + k_2)$		$10^3 k_1$	$10^3 k_2$	Lit.
		α	β			
H_2O	1.5	2.9	2.9			(57)
80% C_2H_5OH	25	5.4	5.75			(57)
80% C_2H_5OH	15.0			0.41	1.93	(57)
80% C_2H_5OH	20.0		3.63	.77	2.86	(44)
H_2O	18.0		17.			(11)
H_2O	19.0		27.3			(61)
Formamide	20.0		3.26			(61)

$C_6H_{12}O_6$, GALACTOSE

Optical Rotation

IN VARIOUS SOLVENTS

Solvent	Galactose, g/100 ml	°C	$[\alpha]^t_D$			$10^3 (k_1 + k_2)$	Lit.
			α	α ⇄ β	β		
H_2O	2.18	12.5	+139.3	+79.3		4.79	(60)
Formamide	2.01	18.0	154.5	85.45		0.84	(60)
H_2O	2.25	20.0	139.4	79.25		9.60	(61)
Formamide	1.75	20.0	155.3	87.77		1.98	(61)
H_2O	1.87	20.0		79.01	+56.51	7.22	(61)
Formamide	1.81	20.0		87.19	62.30	1.57	(61)
H_2O			144.0	80.05	47.0*		(44)
60% C_2H_5OH		20.0	140.6	72.8	33*		(44)
80% C_2H_5OH		20.0	127.2	73.1	34*		(44)
H_2O		20.0			52		(44)
H_2O	1.0	20.0		80.2			(30)

* Calculated from initial and final solubilities and rotations.

$$\frac{d[\alpha]^t_D}{dt} = -0.23 \text{ at } 12.5°C = -0.34 \text{ at } 18°C \ (60).$$

EFFECT OF HCL IN H_2O (97)

% HCl	0	25	37.6	40.0	42.0
°C	8	6	6	6	6
$[\alpha]^t_D$	83.3	94.2	113.8	133.6	160.4

EFFECT OF H_2SO_4 IN H_2O (11)

N of H_2SO_4	0	10	16	18	20	24	26
$[\alpha]^{25}_D$	79.0	88.0	95.0	99.5	102.5	110.0	122.0

EQUILIBRIUM ROTATION

In Aqueous C_2H_5OH (13)

% C_2H_5OH	$[\alpha]^{20}_D$	$[\alpha]^{30}_D$	$[\alpha]^{38}_D$
30	71.2	66.4	63.3
60	63.3	60.5	57.4
80	57.0	51.0	41.6

In Aqueous *n*-Propyl Alcohol (13, 26)

C_3H_7OH, g/l solution	100	200	300	400	500	600
$[\alpha]^{20}_D$	79.66	76.13	74.04	71.56	68.97	64.96

In Various Solvents

Values of $[\alpha]^{20}_\lambda$ (30)

Galactose, g/100 ml	1	1	2.98
λ, mμ	In H_2O	Pyridine	Formic acid
656	60.50	46.50	101.42
589	80.17	59.83	127.30
535	96.66	76.66	155.30
508	117.50	85.33	175.80
479	131.00	98.66	221.10
447	150.66	115.33	250.80

Index of Refraction and Density of Aqueous Solution (77)

% anhydrous galactose	18.24	9.12	4.60	2.30	1.15
d^{25}_4	1.0730	1.0335	1.0150	1.0058	1.0012
n^{25}_D	1.3620	1.3470	1.3400	1.3366	1.3349

Solubility

g α-galactose per 100 cm³ solution

Solvent	Initial	Final	Lit.
80% C_2H_5OH	0.27	0.65	(38)
60% C_2H_5OH	1.1	3.1	(38)

Mutarotation (12)

Solvent	Galactose, g/100 ml	°C	$10^3(k_1 + k_2)$
Conductivity H_2O	9.0	25.0	1.41
0.5N H_3BO_3	9.0	25.0	1.45

$C_5H_{10}O_5$, ARABINOSE

Optical Rotation and Mutarotation

IN VARIOUS SOLVENTS

Solvent	Arabinose, g/100 ml	°C	$[\alpha]^t_D$			$10^3 (k_1 + k_2)$	Lit.
			α	α ⇄ β	β		
H_2O	2.61	12		+105.9(*l*-)	+186(*l*-)	13.4	(60)
H_2O		20	−54*(*d*-)	−105.0(*d*-)	−175(*d*-)	31	(44)
80 % C_2H_5OH		20	−28*(*d*-)	− 81.7(*d*-)	−173(*d*-)		(44)
Formamide	2.40	13		+116.3(*l*-)	+189(*l*-)	1.54	(60)

* Calculated from initial and final solubilities and rotations.

EFFECT OF HCL IN AQUEOUS SOLUTION

Arabinose, *ca.* 5 g/100 ml (97)

% HCl	0	25	37.6	40	42
°C	9	8	8	8	8
$[\alpha]^t_D$	+105.1	117.6	142.0	166.2	202.9

40% HCl	t, min	6	18	48	64
	$[\alpha]^{10}_D$	+166.3	167.0	167.0	167.0

Solubility (44)

In 80% aqueous C_2H_5OH: Initial $S_\beta = 0.74$, final $S_\beta = 1.94$ g per 100 cm³ solution. Equilibrium mixture = 38% β, 62% α.

$C_5H_{10}O_5$, XYLOSE

Optical Rotation and Mutarotation

In Various Solvents

Solvent	Xylose, g/100 ml	°C	$[\alpha]^t_D$			10^3 $(k_1 + k_2)$	Lit.
			α	$\alpha \rightleftarrows \beta$	β		
H_2O		20	+ 92.0	+19.0	−20*		(44)
80% C_2H_5OH		20	+ 94.5	+32.1	−20*		(44)
H_2O		1				2.8	(44)
H_2O		10				7.5	(44)
H_2O		20				20.7	(44)
H_2O		30				53.2	(44)
H_2O		40				133	(44)
H_2O	2.72	20	+ 90.3	+19.13		18.8	(60)
Formamide	4.04	20	+109.4	+25.12		3.06	(60)
H_2O		20		+18.2			(30)
Pyridine		20		+40.5			(30)
Formic acid		20		+66.6			(30)

* Calculated from initial and final solubilities and rotations of the α-form.

Effect of HCl in Aqueous Solution (*ca.* 5 g/100 ml) (97)

% HCl	0	8	25	37.6	40.0	42.0
°C	13	9	9	9	9	9
$[\alpha]^t_D$	+17.6	21.3	27.4	46.4	68.7	96.6

Rotation at Equilibrium (30)

Values of $[\alpha]^{20}_\lambda$ for $\alpha \rightleftarrows \beta$

Xylose, g/100 ml	0.866	1.28	5.48
λ, mμ	In H_2O	Pyridine	Formic acid
656	+13.28	32.04	55.74
589	18.19	40.64	66.60
535	21.08	48.64	82.66
508	24.50	59.90	95.80
479	27.70	68.34	116.13
447	31.94	72.47	125.95

Solubility

In 80% C_2H_5OH at 20°C: Initial 2.7 g, final 6.2 g per 100 cm^3 solution. Equilibrium mixture, 44% α, 56% β (44).

$C_{18}H_{32}O_{16} + 5H_2O$, RAFFINOSE (MELITRIOSE, GOSSYPOSE)

(Composition: *d*-Galactose < *d*-Glucose < > *d*-Fructose)

Raffinose may be hydrolyzed to (1) fructose and melibiose; (2) galactose and sucrose; (3) fructose, glucose, and galactose. It is nonreducing.

Optical Rotation

In H_2O

Form		Lit.
$R \cdot 5H_2O$	$[\alpha]^{20}_D = 104.5$	(16, 54)
Anhyd	$[\alpha]^{25}_{589.25} = 123.00$	(62, 91, 93)
Anhyd	$[\alpha]^{25}_{546.1} = 144.55$	(94)

$\frac{d[\alpha]_\lambda}{dt}$ = *ca.* 0.0 between 3° and 20°C (23).

In Various Solvents (30)

C = 3.7125 g anhyd. raffinose per 100 ml solution. Values of $[\alpha]^{20}_\lambda$

λ, mμ =	656	589	535	508	479	447
In H_2O	79.63	105.20	131.71	150.75	163.77	188.55
Pyridine	94.22	117.17	142.76	167.00	188.52	218.26

Effect of Salts in H_2O (91, 92, 93, 94)

0.1 formula weight $C_{18}H_{32}O_{16}$ in 1000 g H_2O

Salt	Moles/1000 g H_2O	$[\alpha]^{25}_{589.25}$
	0.0	123.00
KCl	1.3	123.08
NaCl	1.71	123.12
LiCl	1.30	123.24
		$[\alpha]^{24}_{546.1}$
	0.0	144.55
CsCl	1.2	144.64

Density of Aqueous Solution

d^{20}_{20} of aqueous solution containing 28.4% raffinose = 1.12474. Since this corresponds to 29.10° sucrose Brix, 1% raffinose = 1.025° sucrose Brix (80).

C = formula weights of raffinose · $5H_2O$ per liter of solution at t°C, all weights *in vacuo* (95).

C	°C	d^t_t	C	°C	d^t_t
0.038083	0.00	1.00796	0.102297	24.94	1.01179
.037973	24.94	1.00483	.131202	0.00	1.02752
.037615	49.87	.99556	.130727	24.96	1.02378
.058632	0.00	1.01218	.129787	50.12	1.01407
.058466	24.94	1.00897	.176625	0.00	1.03645
.057925	49.87	.99964	.175818	24.00	1.03172
.102676	0.00	1.02147	.174336	49.84	1.02302

Solubility

In H_2O. Per Cent Anhyd. Raffinose

°C	0	10	16	24
%	6.5	10.0	14.5	28.4
Lit.	(15)	(15)	(15)	(80)

In Aqueous CH_3OH at 15°C

S in g anhyd. raffinose per 100 cm^3 solution (31)

Vol. % CH_3OH	100	95	90	85	80	60	20
S	10.2	7.5	2.4	1.8	1.8	2.8	5.0

Hydrolysis of Raffinose by Acids at 25°C (1)

100 g H_2O + 0.25 mole of anhyd. raffinose + 1 mole of acid

Acid	HNO_3	HCl	H_2SO_4
$k = \frac{1}{t} \log_{10} \frac{a}{a - x}$	0.00390	0.00419	0.00446

SYSTEMS CONTAINING MORE THAN ONE SUGAR

Solubilities

System: Sucrose, Dextrose, Water, 30°C (50)

Solid phase	% sucrose	% dextrose	d^{30}_4
$C_{12}H_{22}O_{11}$	68.11	0	1.3301
	64.22	4.89	1.3356
	60.40	9.70	1.3411
	53.19	18.58	1.3507
	48.60	24.61	1.3588
$C_{12}H_{22}O_{11} + C_6H_{12}O_6.H_2O$	47.10	26.59	
$C_6H_{12}O_6.H_2O$	33.79	33.88	1.3227
	19.66	41.97	1.2867
	7.35	50.00	1.2592
	0	54.64	1.2434

Solubility of Sucrose, Dextrose, and Levulose in the Presence of One Another

Solid phase sucrose (50)

23.15°C	% invert sugar	0	11.90	25.39	36.90
	% sucrose	67.59	57.84	47.31	38.66

At 30°C

% invert sugar	% sucrose	d_4^{30}	% invert sugar	% sucrose	% invert sugar	% sucrose
0	68.11	1.3301	24.52	48.93	47.62*	31.85
14.94	56.32	1.3485	28.01	46.36	56.37	26.03
21.86	50.97	1.3571	37.48	39.23	63.68	21.18
23.21	49.91	1.3587	47.02*	32.06	64.47	20.59
24.46	48.95	1.3608				

* $d_4^{30} = 1.3957$.

At 50°C

% invert sugar	0	11.42	22.65	32.32	46.05	57.06
% sucrose....	72.25	62.81	53.80	46.20	35.75	28.18

Both sugars present as solid phases (50)

°C................	0	10	15	23.15	30	40	50
% sucrose..........	43.7	40.9	39.1	36.3	33.6	31.1	27.7
% invert sugar......	27.2	31.8	34.8	39.9	45.4	50.7	58.0

System: Dextrose, Levulose, Water, 30°C

Solid phase dextrose monohydrate (50)

% anhyd. dextrose	% levulose	d_4^{30}	% anhyd. dextrose	% levulose	d_4^{30}
54.64	0.00		35.76	33.09	1.3286
49.34	8.94	1.2639	34.48	35.69	1.3359
49.32	8.94	1.2650	33.67	37.10	1.3408
45.97	14.50	1.2779	32.55	39.39	1.3480
41.01	23.23	1.3000			

System: Dextrose, Levulose, Water

Solid phase, dextrose. A = % dextrose, in water alone. B = % dextrose in solution containing an equivalent amount of levulose. Saturation with crystalline dextrose in both cases (50).

°C	A	B	°C	A	B
0	35.0	50.8	30.0	54.64	69.7
10.0	40.8	56.6	35.0	58.02	72.2
15.0	44.0	59.8	40.0	61.87	74.8
20.0	47.2	62.6	45.0	65.71	78.0
25.0	50.80	66.2	50.0	70.91	81.9

Clerget Analysis for Sucrose (48)

The estimation of sucrose in the presence of other optically active substances by the Clerget Method depends upon the change of rotation which the sugar undergoes upon inversion. The difference in saccharimeter deg. between the rotation of 26 g of pure sucrose in 100 ml of solution observed in a 200 mm column and the rotation of invert sugar calculated to a concentration of 26 g of inverted sucrose in 100 ml is known as the Clerget Divisor. Two general methods of inversion are employed:

(*a*) Inversion by the enzyme, invertase.[1]
(*b*) Inversion by hydrochloric acid.[2]

Values of Clerget Divisor

(m_s, resp. m_A, resp. m_N, resp. m_{Na} = g inverted sucrose, resp. HCl, resp. NH_4Cl, resp. NaCl in 100 ml of solution. t = °C.)

(*a*) Invertase inversion.

Positive constituent	Negative constituent
+100	$-42.1 - 0.0676\,(m_s - 13) + t/2$

(*b*) HCl inversion, 2.312 g anhyd. HCl in 100 ml of inverted solution, equivalent to 10 ml of HCl ($d_4^{20} = 1.1029$).

Positive constituent	Negative constituent
+100	$-43.25 - 0.0676\,(m_s - 13) + t/2$

(*c*) HCl inversion and subsequent neutralization with NH_4OH equivalent to 10 ml HCl ($d_4^{20} = 1.1029$) in 100 ml of inverted solution.

Positive constituent	Negative constituent
+100	$-43.91 - 0.0676\,(m_s - 13) + t/2$

(*d*) HCl inversion with 10 ml of HCl ($d_4^{20} = 1.1029$) in 100 ml of inverted solution; 2.315 g NaCl contained in 100 ml of solution for direct polarization (in order to equalize the effect of HCl upon invert sugar when present as an impurity).

Positive constituent	Negative constituent
+99.38	$-42.1 - 0.0676\,(m_s - 13) + t/2$

(*e*) HCl inversion with 10 ml HCl ($d_4^{20} = 1.1029$) in 100 ml of inverted solution and subsequent neutralization with NH_4OH; 3.392 g NH_4Cl contained in 100 ml of solution for direct polarization.

Positive constituent	Negative constituent
+99.43	$-43.91 - 0.0676\,(m_s - 13) + t/2$

Generalized Formulae

Positive constituent: $R = 100 - 0.265\,m_{Na} = 100 - 0.169\,m_N$.

Negative constituent: $R_{HCl} = -41.12 - 0.5407m_A - 0.0676\,m_s + 0.5\,t$. $R_{NH_4Cl} = -41.12 - 0.563m_N - 0.0676m_s + 0.5t$.

Reducing Powers toward Fehling's Solution

For Munson and Walker's table for calculating dextrose, invert sugar, in mixtures containing sucrose, lactose and maltose *v.* (18, 65). For Allihn's tables *v.* (14, 20).

ROTATIONS AND MELTING POINTS OF PURE SUGARS AND SUGAR DERIVATIVES (40·5)

	Formula	Mol. wt.	M. P.	$[\alpha]_D^{20}$	$[M]_D^{20}$	Solvent
β-*d*-Arabinose..................	$C_5H_{10}O_5$	150		−175	− 26 300	H_2O
α-*l*-Arabinose tetraacetate..................	$C_{13}H_{18}O_9$	318	97	+ 42.5	+ 13 500	$CHCl_3$
β-*l*-Arabinose tetraacetate..................	$C_{13}H_{18}O_9$	318	86	+147.2	+ 46 800	$CHCl_3$
l-Arabonic amide..................	$C_5H_{11}O_5N$	165	136	+ 37.5	+ 6 190	H_2O
d-Arabonic phenylhydrazide..................	$C_{11}H_{16}O_5N_2$	256		− 14.5	− 3 710	H_2O
β-Bromoacetyl *d*-arabinose..................	$C_{11}H_{15}O_7Br$	339		−288	− 97 600	$CHCl_3$
β-Bromoacetyl *l*-arabinose..................	$C_{11}H_{15}O_7Br$	339		+288	+ 97 600	$CHCl_3$
α-Bromoacetyl lactose..................	$C_{26}H_{35}O_{17}Br$	699	145	+109	+ 76 200	$CHCl_3$
α-Bromoacetyl *d*-xylose..................	$C_{11}H_{15}O_7Br$	339	102	+212	+ 71 900	$CHCl_3$
β-Cellobiose..................	$C_{12}H_{22}O_{11}$	342		+ 16.0	+ 5 470	H_2O
α-Cellobiose octaacetate..................	$C_{28}H_{38}O_{19}$	678	229	+ 41	+ 27 800	$CHCl_3$
β-Cellobiose octaacetate..................	$C_{28}H_{38}O_{19}$	678	202	− 14.6	− 9 900	$CHCl_3$
α-Chondrosamine pentaacetate..................	$C_{16}H_{23}O_{10}N$	389	183	+101.3	+ 39 400	$CHCl_3$
β-Chondrosamine pentaacetate..................	$C_{16}H_{23}O_{10}N$	389	220 d	+ 10.5	+ 4 080	$CHCl_3$
β-Chloroacetyl *d*-arabinose..................	$C_{11}H_{15}O_7Cl$	295		−244	− 72 000	$CHCl_3$

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[1] For detailed description of methods of inversion by invertase, *v.* (3).

[2] For detailed description of methods of inversion by hydrochloric acid, *v.* (48).

ROTATIONS AND MELTING POINTS OF PURE SUGARS AND SUGAR DERIVATIVES (40.5).—(*Continued*)

	Formula	Mol. wt.	M. P.	$[\alpha]_D^{20}$	$[M]_D^{20}$	Solvent
β-Chloroacetyl *l*-arabinose	$C_{11}H_{15}O_7Cl$	295		+244	+ 72 000	$CHCl_3$
Chloroacetyl celtrobiose(40)	$C_{26}H_{35}O_{17}Cl$	655	138	+ 59.2	+ 38 800	$CHCl_3$
Chloroacetyl *d*-galactose (second)	$C_{14}H_{19}O_9Cl$	367	67	− 78	− 28 600	$CHCl_3$
α-Chloroacetyl lactose	$C_{26}H_{35}O_{17}Cl$	655	121	+ 84	+ 55 000	$CHCl_3$
α-Chloroacetyl neolactose (53)	$C_{26}H_{35}O_{17}Cl$	655	182	+ 71.2	+ 46 700	$CHCl_3$
β-*d*-Fructose	$C_6H_{12}O_6$	180		−133.5	− 24 000	H_2O
α-*d*-Fructose pentaacetate	$C_{16}H_{22}O_{11}$	390	70	+ 34.7	+ 13 500	$CHCl_3$
β-*d*-Fructose pentaacetate	$C_{16}H_{22}O_{11}$	390		−120.9	− 47 200	$CHCl_3$
β-*d*-Fructose tetraacetate	$C_{14}H_{20}O_{10}$	348		− 91.6	− 31 900	$CHCl_3$
d-Galactonic amide	$C_6H_{13}O_6N$	195	172	+ 30.2	+ 5 890	H_2O
α-*d*-Galactose	$C_6H_{12}O_6$	180		+144	+ 25 900	H_2O
β-*d*-Galactose	$C_6H_{12}O_6$	180		+ 52	+ 9 360	H_2O
d-Galactose pentaacetate (first)	$C_{16}H_{22}O_{11}$	390	142	+ 23	+ 8 970	$CHCl_3$
d-Galactose pentaacetate (second)	$C_{16}H_{22}O_{11}$	390	96	+107	+ 41 700	$CHCl_3$
d-Galactose pentaacetate (third)	$C_{16}H_{22}O_{11}$	390	98	− 42	− 16 400	$CHCl_3$
d-Galactose pentaacetate (fourth)	$C_{16}H_{22}O_{11}$	390	87	+ 61	+ 23 800	$CHCl_3$
d-Galactose tetraacetate (third)	$C_{14}H_{20}O_{10}$	348	73	− 17.8	− 6 190	$CHCl_3$
d-Galactose phenylhydrazone	$C_{20}H_{26}O_9N_2$	438	95	+ 15.5	+ 6 790	$CHCl_3$
d-α-Galaheptonic amide	$C_7H_{15}O_7N$	225	206	+ 14.3	+ 3 220	H_2O
d-α-Galaheptonic phenylhydrazide	$C_{13}H_{20}O_7N_2$	316		+ 8.5*	+ 2 700*	H_2O
α-Gentiobiose octaacetate	$C_{28}H_{38}O_{19}$	678	189	+ 52.4	+ 35 500	$CHCl_3$
β-Gentiobiose octaacetate	$C_{28}H_{38}O_{19}$	678	193	− 5.3	− 3 590	$CHCl_3$
d-α-Glucoheptonic amide	$C_7H_{15}O_7N$	225	134	+ 10.6	+ 2 390	H_2O
d-β-Glucoheptonic amide	$C_7H_{15}O_7N$	225	158	− 30.2	− 6 790	H_2O
d-α-Glucoheptonic phenylhydrazide	$C_{13}H_{20}O_7N_2$	316		+ 9.3	+ 2 940	H_2O
β-*d*-α-Glucoheptose	$C_7H_{14}O_7$	210		− 28.4	− 5 960	H_2O
α-*d*-α-Glucoheptose hexaacetate	$C_{19}H_{26}O_{13}$	462	164	+ 87.0	+ 40 200	$CHCl_3$
β-*d*-α-Glucoheptose hexaacetate	$C_{19}H_{26}O_{13}$	462	135	+ 4.8	+ 2 220	$CHCl_3$
d-Gluconic amide	$C_6H_{13}O_6N$	195	144	+ 31.2	+ 6 080	H_2O
α-*d*-Glucosamine pentaacetate	$C_{16}H_{23}O_{10}N$	389	140	+ 93.5	+ 36 400	$CHCl_3$
β-*d*-Glucosamine pentaacetate	$C_{16}H_{23}O_{10}N$	389	189	+ 1.2	+ 467	$CHCl_3$
α-*d*-Glucose	$C_6H_{12}O_6$	180		+113	+ 20 300	H_2O
β-*d*-Glucose	$C_6H_{12}O_6$	180		+ 19	+ 3 420	H_2O
α-*d*-Glucose pentaacetate	$C_{16}H_{22}O_{11}$	390	113	+101.6	+ 39 600	$CHCl_3$
β-*d*-Glucose pentaacetate	$C_{16}H_{22}O_{11}$	390	132	+ 3.8	+ 1 480	$CHCl_3$
d-Gulonic amide	$C_6H_{13}O_6N$	195	123	+ 15.2	+ 2 960	H_2O
α-Iodoacetyl lactose	$C_{26}H_{35}O_{17}I$	746	145	+137	+102 000	$CHCl_3$
α-Lactose	$C_{12}H_{22}O_{11}$	342		+ 90	+ 30 800	H_2O
β-Lactose	$C_{12}H_{22}O_{11}$	342		+ 35	+ 12 000	H_2O
α-Lactose octaacetate	$C_{28}H_{38}O_{19}$	678	152	+ 53.9	+ 36 500	$CHCl_3$
β-Lactose octaacetate	$C_{28}H_{38}O_{19}$	678	90	− 4.3	− 2 920	$CHCl_3$
α-*d*-Lyxose	$C_5H_{10}O_5$	150		+ 5.5	+ 825	H_2O
β-Maltose	$C_6H_{12}O_6$	342		+118	+ 40 400	H_2O
β-Maltose heptaacetate	$C_{26}H_{36}O_{18}$	636	181	+ 67.8	+ 43 100	$CHCl_3$
α-Maltose octaacetate	$C_{28}H_{38}O_{19}$	678	125	+122.4	+ 83 000	$CHCl_3$
β-Maltose octaacetate	$C_{28}H_{38}O_{19}$	678	160	+ 62.7	+ 42 500	$CHCl_3$
d-Mannitol hexaacetate	$C_{18}H_{26}O_{12}$	434	120	+ 26	+ 11 300	$CHCl_3$
d-α-Mannoheptonic amide	$C_7H_{15}O_7N$	225	194	+ 28	+ 6 300	H_2O
d-α-Mannoheptonic phenylhydrazide	$C_{13}H_{20}O_7N$	316		+ 21	+ 6 640	H_2O
d-α-Mannoheptose hexaacetate (first)	$C_{19}H_{26}O_{13}$	462	106	+ 24.2	+ 11 200	$CHCl_3$
d-α-Mannoheptose hexaacetate (second)	$C_{19}H_{26}O_{13}$	462	140	− 31	− 14 300	$CHCl_3$
d-Mannonic amide	$C_6H_{13}O_6N$	195	173	− 17.3	− 3 370	H_2O
d-Mannonic phenylhydrazide	$C_{12}H_{18}O_6N_2$	286		− 8.1*	− 2 320*	H_2O
d-Mannosaccharic diamide	$C_6H_{12}O_6N_2$	208	189	− 24.5	− 5 100	H_2O
β-*d*-Mannose	$C_6H_{12}O_6$	180		− 17	− 3 060	H_2O
α-*d*-Mannose pentaacetate	$C_{16}H_{22}O_{11}$	390	64	+ 55.0	− 21 500	$CHCl_3$
β-*d*-Mannose pentaacetate	$C_{16}H_{22}O_{11}$	390	118	− 25.2	− 9 830	$CHCl_3$
Melezitose	$C_{15}H_{32}O_{16}$	504	148	+ 88.2	+ 44 500	H_2O
Melezitose hendekaacetate	$C_{40}H_{54}O_{27}$	966	117	+103.8	+100 000	$CHCl_3$
β-Melibiose	$C_{12}H_{22}O_{11}$	342		+ 12.4	+ 42 400	H_2O
β-Melibiose octaacetate	$C_{28}H_{38}O_{19}$	678	177	+102.5	+ 69 500	$CHCl_3$

ROTATION AND MELTING POINTS OF PURE SUGARS AND SUGAR DERIVATIVES (40.5)—*(Continued)*

	Formula	Mol. wt.	M. P.	$[\alpha]_D^{20}$	$[M]_D^{20}$	Solvent
α-Methyl *l*-arabinoside	$C_6H_{12}O_5$	164	131	+ 17.3	+ 2 840	H_2O
β-Methyl *l*-arabinoside	$C_6H_{12}O_5$	164	169	+245.5	+ 40 300	H_2O
β-Methyl *l*-arabinoside triacetate	$C_{12}H_{18}O_8$	290	85	+182.0†	+ 52 800†	$CHCl_3$
β-Methyl cellobioside heptaacetate	$C_{27}H_{38}O_{18}$	650	187	− 25.4	− 16 500	$CHCl_3$
β-Methyl *d*-fructoside	$C_7H_{14}O_6$	194	120	−172.1	− 33 400	H_2O
β-Methyl *d*-fructoside tetraacetate	$C_{15}H_{22}O_{10}$	362	76	−124.6	− 45 100	$CHCl_3$
α-Methyl *d*-galactoside tetraacetate	$C_{15}H_{22}O_{10}$	362		+133.0	+ 48 100	$CHCl_3$
β-Methyl *d*-galactoside tetraacetate	$C_{15}H_{22}O_{10}$	362		− 13.0	− 4 710	$CHCl_3$
β-Methyl gentiobioside	$C_{13}H_{24}O_{11}$	356	98	− 36.0	− 12 800	H_2O
β-Methyl gentiobioside heptaacetate	$C_{27}H_{38}O_{18}$	650	82	− 18.9	− 12 300	$CHCl_3$
α-Methyl *d*-glucoside tetraacetate	$C_{15}H_{22}O_{10}$	362	101	+130.6	+ 47 300	$CHCl_3$
β-Methyl *d*-glucoside tetraacetate	$C_{15}H_{22}O_{10}$	362	105	− 18.3	− 6 620	$CHCl_3$
α-Methyl *d*-lyxoside (73)	$C_6H_{12}O_5$	164	109	+ 59.4		H_2O
β-Methyl maltoside heptaacetate	$C_{27}H_{38}O_{18}$	650	125	+ 53.7	+ 34 900	$CHCl_3$
α-Methyl *d*-xyloside	$C_6H_{12}O_5$	164		+153.9	+ 25 200	H_2O
β-Methyl *d*-xyloside	$C_6H_{12}O_5$	164	157	− 65.5	− 10 700	H_2O
α-Methyl *d*-xyloside triacetate	$C_{12}H_{18}O_8$	290	86	+119.6	+ 34 700	$CHCl_3$
β-Methyl *d*-xyloside triacetate	$C_{12}H_{18}O_8$	290	115	− 60.7	− 17 600	$CHCl_3$
α-Neolactose octaacetate (53)	$C_{28}H_{38}O_{19}$	678	178	+ 53.4	+ 36 200	$CHCl_3$
β-Neolactose octaacetate (53)	$C_{28}H_{38}O_{19}$	678	148	− 7.1	− 4 810	$CHCl_3$
l-Rhamnomethyltetronic amide	$C_5H_{11}O_4N$	149	135	+ 54.8	+ 8 170	H_2O
l-Rhamnomethyltetronic lactone	$C_5H_8O_4$	132	123	− 44.7	− 5 900	H_2O
l-Rhamnonic phenylhydrazide	$C_{12}H_{18}O_5N_2$	270		+ 17.2	+ 4 640	H_2O
α-*l*-Rhamnose	$C_6H_{12}O_5$	164		− 7.7	− 1 260	H_2O
l-Ribonic amide	$C_5H_{11}O_5N$	165	138	− 16.4	− 2 710	H_2O
d-Saccharic diamide	$C_6H_{12}O_6N_2$	208	173	+ 13.3	+ 2 770	H_2O
Sedoheptose (anhydro-)	$C_7H_{12}O_6$	210		−146.3	− 30 720	H_2O
Sucrose octaacetate	$C_{28}H_{38}O_{19}$	678	69	+ 59.6	+ 40 400	$CHCl_3$
Trehalose octaacetate	$C_{28}H_{38}O_{19}$	678	98	+162.3	+110 000	$CHCl_3$
α-*d*-Xylose	$C_5H_{10}O_5$	150		+ 92	+ 13 800	H_2O
α-*d*-Xylose tetraacetate	$C_{13}H_{18}O_9$	318	59	+ 89.1	+ 28 300	$CHCl_3$
β-*d*-Xylose tetraacetate	$C_{13}H_{18}O_9$	318	128	− 24.9	− 7 920	$CHCl_3$
d-Xylose triacetate	$C_{11}H_{16}O_8$	276	141	+ 70†	+ 19 300†	$CHCl_3$

* At 80°C. † At 23°C.

LITERATURE

(For a key to the periodicals see end of volume)

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X-RAY DIFFRACTION DATA—
MISCELLANEOUS NATURAL AND INDUSTRIAL MATERIALS

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The following bibliography contains references to qualitative and quantitative studies by means of X-rays on various natural and industrial materials, and supplements the quantitative data on pure metals, alloys, soaps, etc., presented in vol. I, p. 338–353. The following classes of materials are covered: I. Structure of Alloys. II. Non-ferrous Metals and Alloys. III. Iron and Steel. IV. Worked Metals and Alloys. V. Orientation of Crystals in Electrodeposited Metals. VI. Fibrous or Deformed Substances. VII. Cellulose and Related Compounds. VIII. Rubber and Related Compounds. IX. Ceramic Materials and Products. X. Glass and Silica. XI. Catalysts. XII. Amorphous and Colloidal Materials. XIII. Application to the Identification of Compounds.

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(20) Aborn and Burgmann, *The Tech Engineering News*, April, 1926, p. 2 (ultimate structure of metals). (21) Rinne, *95*, **18**: 37, 81; 26 (models for the mechanics of metals). (22) Tammann, *8*, **79**: 81; 26 (distribution of two kinds of atoms in mixed crystals). (23) Westgren and Phragmén, *95*, **18**: 279; 26 (metallic systems). (24) Westgren and Phragmén, *20*, **19B**: No. 12; 26 (structure analogies of alloys).

II. STRUCTURES OF NON-FERROUS METALS AND ALLOYS

(1) Imai, *159*, **11**: 313; 22 (Cu-Zn). (2) McKeehan, *Ann. Postes, Télég. Téléph*, **12**: 1303; 23. *47*, **32**: 564; 24 (K, Be, BeO, and Ag-Pd and Au-Ag alloys). (3) Davey, *2*, **26**: 736; 25 (W). (4) Johansson and Linde, *8*, **78**: 439; 25 (Au-Cu and Pd-Cu). (5) Krüger and Sacklowski, *8*, **78**: 72; 25 (Pd-Ag alloys containing H). (6) Anderson, *143*, **201**: 465; 26 (duralumin and its crystal structure). (7) Bradley and Ollard, *58*, **117**: 122; 26 (Cr). (8) Freeman and Brandt, *31A*, **20**: 661, 695; 26 (Zn). (9) Friauf, *1*, **48**: 1906; 26 (magnesium plumbide).

(10) Harang, *63*, **27**: 204; 26 (Heusler alloys). (11) Holgersson, *8*, **79**: 35; 26 (Au-Ag and Ni-Cu). (12) Sillers, *31A*, **20**: 686; 26. *Cf.* Pierce, Anderson and Van Dyck, *143*, **200**: 363; 25 (Zn). (13) Westgren and Phragmén, *468*, **2**; 1926 (Cr-C). (14) Westgren and Phragmén, *93*, **156**: 27; 26 (W-C and Mo-C).

III. CRYSTAL STRUCTURE OF IRON AND STEEL

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(1) Iokibe, *159*, **9**: 275; 20 (graphite and temper-carbon from cast iron). (2) Westgren, *220*, **105**: 401; 21 (steel). (3) Westgren, *140*, **103**: 303; 21. *115*, **111**: 727, 757; 21 (iron and steel). (4) Westgren and Lindh, *7*, **98**: 181; 21 (iron and steel). (5) Wever, *226*, **3**: 45; 21 (arrangement of iron atoms in austenitic steel). (6) Bain, *33*, **26**: 543; 22 (martensite formed spontaneously from austenite). (7) Tammann, *77*, **42**: 772; 22 (transformation of cementite at 210°). (8) Westgren and Phragmén, *140*, **105**: 241; 22 (steel). (9) Westgren and Phragmén, *7*, **102**: 1; 22 (iron and steel).

(10) Wever, *226*, **4**: 67; 22 (iron carbide). (11) Wever, *226*, **4**: 81; 22 (graphite and temper-carbon). (12) Bain and Jeffries, *430*, **112**: 805; 23 (red hardness in high-speed steel). (13) Heaps, *2*, **22**: 486; 23 (crystal structure and magneto-striction). (14) Okochi, *469*, **2**: 13; 23 (brittleness in electrolytic iron). (15) Westgren and Phragmén, *220*, **1923**: 449 (steel). (16) Zorning, *471*, **4**: 77; 23 (examination of steel by X-ray spectrometer). (17) Bain, *80*, advance copy, Feb., 1924 (martensite). (18) Greene, *430*, **114**: 615, 670; 24 (troostite and sorbite). (19) Heindlhofer, *2*, **24**: 426; 24 (martensite).

(20) Heindlhofer and Wright, *212*, **7**: 34; 24 (hardened ball steel). (21) Honda, *212*, **6**: 187; 24 (transformation in pure Fe). (22) Lucas, *212*, **6**: 669; 24 (austenite and martensite). (23) Westgren and Phragmén, *58*, **114**: 94; 24. *140*, **109**: 159; 24 (steel). (24) Wever, *9*, **30**: 376; 24 (technical iron). (25) Wever and Rütten, *226*, **6**: 1; 24 (solid solution γ-Fe-C). (26) Williams, *417*, **13**: 175; 24 (hardened steel). (27) Benedicks, *58*, **115**: 230; 25 (hardness of Mn-steel). (28) Foley, *80*, **73**: 850; 26 (amorphous cement and the formation of ferrite). (29) Honda, *159*, **14**: 165; 25 (formation of martensite in C-steels).

(30) Wever, *77*, **45**: 1208; 25 (Fe). (31) Davey, *120*, **29**: 440; 26 (iron and steel). (32) Fink and Campbell, *212*, **9**: 717; 26 (influence of heat treatment and carbon content on pure Fe-C alloys). (33) Osawa, *140*, **113**: 447; 26 (lattice-constant and density of Fe-Ni alloys). (34) Phragmén, *140*, **1926**, advance paper (Fe-Si alloys).

IV. X-RAY DIFFRACTION OF WORKED METALS AND ALLOYS

(1) Owen and Blake, *58*, **92**: 686; 14 (metallic crystals). (2) Schmidt, *63*, **17**: 554; 16 (metals). (3) Gross and Blassmann, *190B*, **42**: 728; 19 (wire-forming W crystals). (4) Nishikawa and Asahara, *2*, **15**: 38; 20 (metals). (5) Bain and Jeffries, *33*, **25**: 775; 21 (mixed orientation in crystals of ductile metals). (6) Ettisch, Polanyi and Weissenberg, *63*, **22**: 646; 21 (metals). (7) Ettisch, Polanyi and Weissenberg, *96*, **7**: 181; 21 (fibre-structure of Cu and W-wires). (8) Ettisch, Polanyi and Weissenberg, *7*, **99**: 332; 21 (fibrous structure of hard-drawn metals). (9) Kirchner, *8*, **69**: 59; 22 (experiments on structure).

(10) Mark, Polanyi and Schmid, *96*, **12**: 58, 78, 111; 22 (drawing Zn crystals). (11) Niwa and Matûra, *338*, **122**: 1; 22 (cold rolling of sheet steel). (12) Ono, *470*, **2**: 261; 22 (inner structure of strained metals). (13) Ono, *470*, **2**: 241; 22 (inner structure of strained Cu-wire). (14) Polanyi, *218*, **10**: 411; 22 (crystal arrangement). (15) Polanyi, *9*, **28**: 16; 22 (fixing single crystals). (16) van Arkel, *208*, **3**: 76; 23 (uni-crystalline W). (17) Bain, *33*, **28**: 65; 23 (cored crystals and metallic compounds). (18) Czochralski, *95*, **15**: 60, 126; 23 (structure hypotheses). (19) Kakinuma, *219*, **5** 90; 23 (atomistic mechanism of metal rolling).

(20) Mark and Polanyi, *96*, **18**: 75; 23 (space-lattice, gliding directions and gliding planes in white Sn). (21) Mark, Polanyi and Schmid, *218*, **11**: 256; 23 (uni-crystalline Sn-wires). (22) Mark and Weissenberg, *96*, **16**: 314; 23 (rolled metal foils). (23) Mark and Weissenberg, *96*, **14**: 328; 23 (rolled metal foils). (24) Müller, *5*, **105**: 500; 24 (crystal axes in "single-crystal" Al-bars). (25) Polanyi, *96*, **17**: 42; 23 (structure changes through cold working). (26) Polanyi and Weissenberg, *97*, **4**: 199; 23 (worked metals). (27) Thomassen, *95*, **15**: 306; 23 (surface layer of worked metals). (28) Bragg, *58*, **113**: 639; 24 (metal film). (29) Research Staff of General Electric Co., *3*, **48**: 800; 24 (deformation of W single crystals).

(30) Glöcker and Kaupp, *95*, **16**: 377; 24 (recrystallization of Ag). (31) Gross, *95*, **16**: 18; 24. *47*, **31**: 385; 24 (deformed crystals and the process of work-hardening). (32) Kakinuma, *219*, **5**: 150; 24 (atomistic mechanism of metal rolling). (33) Lester, *471*, **5**: 455; 24 (crystal deformation in cold-worked steel). (34) Polanyi, *97*, **5**: 580; 24 (worked metals). (35) Schiebold, *95*, **16**: 417, 462; 24 (hardening phenomena in metals). (36) Wever, *96*, **28**: 69; 24 (cubically crystallizing metals after rolling). (37) Anderson and Norton, *80*, **71**: 720; 25 (evidence versus the amorphous-metal hypothesis). (38) van Arkel, *208*, **5**: 208; 25. *218*, **13**: 662; 25 (deformation of lattice of metals). (39) Clark, Brugmann and Heath, *45*, **17**: 1142; 25 (ultimate structures of commercial metals).

(40) Davey, *50*, **29**: 1211; 25 (plasticity of single crystals). (41) Elam, *115*, **120**: 368; 25 (orientation of crystals produced by heating strained Fe). (42) Fujiwara, *429*, **8A**: 339; 25 (arrangement of micro-crystals in Al-wire). (43) Glöcker, *96*, **31**: 386; 25 (deformation and recrystallization structures). (44) Glöcker, Kaupp and Widmann, *95*, **17**: 353; 25 (recrystallization of rolled plate Ag). (45) Leonhardt, *94*, **61**: 100; 25 (Laue diagrams of deformed crystals). (46) Lester and Abron, *471*, **6**:120, 200; 25 (Fe-crystals in steel under stress). (47) Mark, *94*, **61**: 75; 25 (growth and deformation structures). (48) Norton and Anderson, *2*, **25**: 582; 25 (cold-worked and burnished metals). (49) Ono, *470*, **3**: 195; 25 (Cu and Al under extension, compression and torsion).

(50) Ono, *470*, **3**: 267; 25 (α-Fe plastically strained in extension, compression and torsion). (51) Ono, *470*, **3**: 287; 25 (crystal rearrangement and the cause of strain-hardening). (52) Polanyi, *95*, **17**: 94; 25 (crystal deformation

and hardening). (53) Polanyi, *94*, **61:** 49; 25 (deformation of single crystals). (54) Polanyi and Schmid, *96*, **32:** 684; 25 (solidification and melting of Sn). (55) Sachs and Schiebold, *98*, **69:** 1557, 1601; 25 (volume compression of Al). (56) Sachs and Schiebold, *218*, **13:** 964; 25 (lattice lengths of deformed single crystals and crystal aggregates). (57) Seidl and Schiebold, *95*, **17:** 221, 320, 365; 25 (inhomogeneous Al-castings on cold rolling). (58) Tanaka, *429*, **8A:** 319; 25 (rolled Pt-plate). (59) Taylor and Elam, *5*, **108:** 28; 25 (plastic extension and fracture of Al-crystals).

(60) Carpenter, *440*, **28:** 543, 575; 26. **29:** 31, 26 (single crystals). (61) Elam, *5*, **112:** 289; 26 (tensile tests of large Au, Ag and Cu-crystals). (62) Frölich, Clark and Aborn, *Mass. Inst. Tech. Publications*, **61:** 239; 26. *78*, **49:** preprint; 26 (lead deposits). (63) Owen and Preston, *67*, **38:** 132; 26 (effect of rolling on crystal structure of Al). (64) Schiebold and Sachs, *94*, **63:** 34; 26 (growth of Al-crystals during recrystallization). (65) Smithells, Rooksby and Pitkin, *47*, **1926:** advance paper (deformation of W-crystals).

V. ORIENTATION OF CRYSTALS IN ELECTRODEPOSITED METALS

(1) Glöcker and Kaupp, *96*, **24:** 121; 24 (fibrous structure). (2) Clark and Frölich, *9*, **31:** 655; 25 (electrolytic Ni). (3) Bozorth, *2*, **26:** 390; 25 (orientation of crystals in electrodeposited metals).

VI. FIBROUS OR DEFORMED SUBSTANCES

(1) Friedrich, *63*, **14:** 317; 13 (X-ray interference in non-crystalline bodies). (2) Nishikawa and Ono, *219*, **7:** 131; 13 (transmission of X-rays through fibrous, lamellar and granular substances). (3) Nishikawa, *219*, **7:** 296; 14 (spectrum of X-rays obtained by lamellar or fibrous substances). (4) Becker, Herzog, Jancke and Polanyi, *96*, **5:** 61; 21 (arrangement of crystal elements). (5) Herzog, *218*, **12:** 955; 24 (fine structure of fibrous materials). (6) Rinne, *94*, **59:** 230; 24 (rearrangement and decomposition of crystal structures). (7) Rinne, *189*, No. **17:** 513; 24 (permanent structural deformation of graphite). (8) Schmid, *96*, **22:** 328; 24 (plastic deformation of crystals). (9) Rinne, *189*, **1925:** 225 (optical anomalies).

(10) Rinne, *218*, **13:** 690; 25 (paracrystalline and stressed substances). (11) Rinne, *94*, **61:** 389; 25 (flow of natural salts). (12) Sachs and Schiebold, *95*, **17:** 400; 25 (melting and recrystallization). (13) Herzog, *472*, **24:** 137; 26 (fibrous substances). (14) Levitskii, *96*, **35:** 850; 26 (bending of rock-salt in air and water). (15) Ranzi, *59*, **3,** No. **3:** 135; 26 (changes in reticular distances of rock-salt and calcite).

VII. CELLULOSE AND RELATED COMPOUNDS

(1) Herzog and Jancke, *96*, **3:** 196; 20 (cellulose). (2) Herzog, Jancke and Polanyi, *96*, **3:** 343; 20 (cellulose). (3) Herzog, *473*, **2:** 101; 21 (cellulose). (4) Herzog and Jancke, *92*, **34:** 385; 21 (cellulose). (5) Herzog, *472*, **21:** 388; 23 (deformation of cellulose). (6) Hess, Weltzien and Messmer, *13*, **435:** 1; 23 (cellulose). (7) Sponsler, *223*, **5:** 757; 23 (structural units of starch). (8) Gonell, *96*, **25:** 118; 24 (cellulose). (9) Katz, *63*, **25:** 659; 24 (X-ray spectroscopy and swelling).

(10) Katz, *63*, **25:** 321; 24 (swelling of substances giving fibrous diagram). (11) Katz, *63*, **25:** 659; 24 (X-ray methods and imbibition). (12) Katz and Mark, *64V*, **33:** 294; 24 (swelling). (13) Sponsler, *2*, **23:** 662; 24 (X-ray reflection from very thin crystals). (14) Vieweg, *25*, **57B:** 1917; 24 (aqueous and dilute alcoholic NaOH and cellulose). (15) Herzog, *473*, **6:** 39; 25 (constitution of cellulose). (16) Herzog, *472*, **23:** 121; 25 (significance of fine structure of cellulose fiber in purification process). (17) Katz, *473*, **6:** 37; 25 (celluloses of different degrees of polymerization). (18) Katz, *473*, **6:** 35; 25 (X-ray data and alkali adsorption of cellulose). (19) Katz and Mark, *9*, **31:** 105; 25 (X-ray diffraction patterns of cellulose hydrate and its reversion products).

(20) Katz and Mark, *7*, **115:** 385; 25 (changes in powder pattern of cellulose due to swelling). (21) Katz and Vieweg, *9*, **31:** 157; 25 (X-ray diffraction patterns and the alkali content during swelling of cellulose). (22) Herzog, *37*, **9:** 631; 26 (acetyl- and nitro-cellulose). (23) Herzog, *Pulp Paper Mag. Can.*, **24:** 699; 26 (colloidal characters of cellulose). (24) Herzog, *55*, **39:** 98; 26 (swelling of cellulose). (25) Herzog, *Pulp Paper Mag. Can.*, **24:** 694; 26. *Paper Trade J.*, **83,** No. **1:** 51; 26 (cellulose). (26) Herzog, *50*, **30:** 457; 26 (significance of structure of cellulose in chemical transformation). (27) Herzog and Gonell, *92*, **39:** 380; 26 (weighting of silk). (28) Katz, *9*, **32:** 269; 26 (inflation and mercerization of cellulose). (29) Ott, *37*, **9:** 378; 26 (crystalline character of acetyl-cellulose).

VIII. RUBBER AND RELATED COMPOUNDS

(1) Davey, *2*, **21:** 719; 23 (ZnO in vulcanized rubber). (2) Pummerer, Koch and Gross, *13*, **438:** 294; 24 (crystalline rubber and hydrorubber). (3) Hauser and Mark, *Kautschuk*, Dec., 1925 (elongated samples of rubber). (4) Katz, *55*, **36:** 300: 25. **37:** 19; 25. *218*, **30:** 410; 25 (changing of X-ray spectrum of rubber on stretching). (5) Katz, *136*, **49:** 353; 25 (rubber under different degrees of elongation). (6) Katz and Bing, *92*, **38:** 439; 25 (Is raw rubber partially crystallized?). (7) Katz and Bing, *92*, **38:** 545; 25 (rubbers containing inorganic ingredients). (8) Clark, *45*, **18:** 1131; 26 (rubber and allied materials). (9) Hauser, *456*, **40:** 2090; 26 (origin of interference in stretching of rubber).

(10) Hauser and Mark, *287*, **Ambronn-Festschrift:** 64: 26 (stretched rubber). (11) Hauser and Mark, *287*, **22:** 63; 26 (stretched rubber). (12) Ott, *218*, **14:** 320; 26 (size of rubber and gutta-percha molecules).

IX. CERAMIC MATERIALS AND PRODUCTS

(1) Hadding, *Lunds Universitets Årsskrift*, **14:** No. 23; 18. *Mineral. Abstr.*, **2:** 205 (feldspar). (2) Hadding, *Lunds Universitets Årsskrift*, **17:** No. 6; 20 (feldspar). (3) Kozu and Endö, *159*, **1 III:** 1; 21 (andularia and moonstone). (4) Bragg, Shearer and Mellor, *82*, **22:** 105; 23 (china clays). (5) Schwarz and Brenner, *25*, **56B:** 1433; 23 (synthetic aluminum silicate). (6) Rinne, *218*, **12:** 244; 24 (lead-pencil marks). (7) Schwarz, *105*, **8:** 298; 24. *103*, **32:** 538; 24 (formation of kaolin). (8) Shearer, *82*, **23:** 314; 24 (china clays). (9) Sielakov, *74E*, **21:** 527; 24 (clays).

(10) Hadding, *82*, **24:** 27; 25 (clays). (11) Research Staff of General Electric Co., *82*, **24:** 402; 25 (constitutional changes occurring in clays on heating). (12) Navias, *38*, **8:** 296; 25 (development of mullite in fired clays). (13) Navias and Davey, *38*, **8:** 640; 25 (mullite and sillimanite). (14) Norton, *38*, **8:** 401; 25 (natural and artificial sillimanite). (15) Norton, *38*, **8:** 636; 25 (cyanite and andalusite). (16) Rinne, *103*, **33:** 427, 459, 525; 25 (X-ray and ceramics). (17) Rinne, *94*, **61:** 113; 25 (calcined calcite, dolomite, kaolinite and mica). (18) Bowen and Wyckoff, *128*, **16:** 178; 26 (thermal dissociation of dumortierite). (19) Greig, *38*, **8:** 465; 25. *12*, **11:** 1; 26 (mullite from cyanite, andalusite and sillimanite).

(20) Mark and Rosbaud, *190B*, **54:** 127; 26 (Al_2SiO_5 and pseudobrookite). (21) Rosbaud, *9*, **32:** 317; 26 (aluminum silicate). (22) Wyckoff, Greig and Bowen, *12*, **11:** 459; 26 (mullite and sillimanite).

X. GLASS AND SILICA

(1) Kyropoulos, *93*, **99:** 197, 249; 17 (various kinds of silica). (2) Miller, *5*, **101:** 515; 22 (vitreous silica). (3) Washburn and Navias, *197*, **8:** 1; 22 (chalcedony and other forms of silica). (4) Selyakov and Strutinskii, *Mitt. wiss.-tech. Arbeiten in der Republik* (*Russ.*), **13:** 18; 24 (structure of glass). (5) Selyakov, Strutinskii and Krasnikov, *96*, **33:** 53; 25 (structure of glass). (6) Wyckoff and Morey, *105*, **9:** 256; 25 (soda-lime-silica glasses).

XI. X-RAY DATA APPLIED TO PROBLEMS OF CATALYSIS

(1) Clark, Asbury and Wick, *1*, **47:** 2661; 25 (structure of nickel catalysts). (2) Levi, *22*, **2:** 419; 25 (thorium oxide and the dehydration of alcohol). (3) Wyckoff and Crittenden, *1*, **47:** 2866; 25 (ammonia catalysts). (4) Levi and Haardt, *36*, **56:** 424; 26 (catalytic action considered as that of surfaces). (5) Levi and Haardt, *22*, **3:** 91; 26 (catalytic action of metals of the Pt group). (6) Levi and Haardt, *22*, **3:** 215; 26 (catalytic action of metals of the Pt group).

XII. AMORPHOUS AND COLLOIDAL MATERIALS

(1) Asahara, *210*, **1:** 23; 22. *209*, **1:** 35; 22 (graphite and amorphous C). (2) Haber, *25*, **55B:** 1717; 22 (amorphous precipitates and crystallized sols). (3) Kustner, *96*, **10:** 41; 22 (decomposition and rebuilding of gadolinites). (4) Mulligan, *50*, **26:** 247; 22 (dehydration of crystalline aluminum hydroxide). (5) Böhm and Niclassen, *93*, **132:** 1; 23 (amorphous precipitates and crystallized sols). (6) Fricke and Wever, *93*, **136:** 321; 24 (aging of precipitated metal hydroxides). (7) Rinne, *94*, **60:** 55; 24 (finely divided minerals, artificial products and dense rocks). (8) Baudisch and Welo, *141*, **64:** 753; 25 (aging of ferrous hydroxide and ferrous carbonate). (9) Böhm, *93*, **149:** 203; 25 (aluminum hydroxide and iron hydroxide).

(10) Böhm, *93*, **149:** 217; 25 (glowing of oxides of certain metals). (11) Herzog, *55*, **37:** 355; 25 (colloid systems). (12) Herzog and Gonell, *25*, **58B:** 2228; 25 (collagen). (13) Katz and Gerngross, *218*, **13:** 900; 25 (gelatin and collagen). (14) Levi, *216*, **7:** 410; 25 (new chemical studies). (15) Ruff, Schmidt and Olbrich, *93*, **148:** 313; 25 (amorphous C and graphite). (16) Welo and Baudisch, *141*, **65:** 215; 25 (catalytically active and inactive forms of Fe_2O_3). (17) Welo and Baudisch, *166*, **62:** 311; 25 (oxides of iron in new catalytic actions). (18) Gutbier, Hüttig and Dobling, *25*, **59B:** 1232; 26 (stannic oxide-water). (19) Herzog and Krüger, *218*, **14:** 599; 26 (dispersibility of organic colloids).

(20) Posnjak, *50*, **30:** 1073; 26 (stannic acids).

XIII. APPLICATION TO THE IDENTIFICATION OF COMPOUNDS

(1) Posnjak and Merwin, *1*, **44:** 1965; 22 (Fe_2O_3-SO_3-H_2O). (2) Schleede and Gruhl, *9*, **29:** 411; 23 (luminescent zinc silicate). (3) Kohlschütter and Scherrer, *37*, **7:** 337; 24 (polymorphism in lead oxide). (4) Levi and Quilico, *36*, **54:** 598; 24 (non-existence of Ag suboxide). (5) Shaxby, *34*, **179:** 1602; 24 (monochromatic X-rays in production of Laue diagrams and structure of mother-of-pearl). (6) Volmer, *13*, **440:** 200; 24 ($HClO_4.H_2O$ and NH_4ClO_4). (7) Jung, *93*, **142:** 73; 25 (dehydration products of gypsum). (8) Levi, *216*, **7:** 410; 25 (new chemical studies). (9) Levi and Tacchini, *36*, **55:** 28; 25 (non-existence of Ni suboxide).

(10) Linck and Jung, *93*, **147:** 288; 25 (black metallic P). (11) Shaxby, *3*, **49:** 1201; 25 (monochromatic X-rays in production of Laue diagrams and structure of mother-of-pearl). (12) Sosman and Posnjak, *128*, **15:** 329; 25 (ferromagnetic ferric oxide). (13) Ewles, *Proc. Leeds Phil. Lit. Soc.*, **1:** 6; 26 (luminescence of solids). (14) Frebold, *187*, **23:** 115; 26 (iron hydroxide ores).

PROPERTIES OF METALS AND ALLOYS

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INTRODUCTION

The very condensed form in which it has been necessary to present the metallurgical data in the tables, requires some explanation in regard to their use. The abbreviations and special symbols used are explained on p. 392 and some examples illustrating their interpretation in particular cases are given below.

A table of "Critical Values" of the mechanical properties of metals and alloys necessarily differs in certain important respects from the "Critical Values" given in other connections. The reason is that metallurgical products, particularly of the more complex sort, are subject to certain unavoidable variations even when produced under the best conditions. In regard to

INTRODUCTION

Etant donné la forme très condensée dans laquelle il a été nécessaire de présenter les données métallurgiques dans les tables, il est indispensable de donner quelques explications pour leur emploi. Les abréviations et les symboles spéciaux utilisés sont expliqués à la p. 392, et quelques exemples illustrant leur interprétation dans des cas particuliers sont donnés ci-dessous.

Une table de "valeurs critiques" des propriétés mécaniques des métaux et alliages diffère nécessairement sous certains rapports importants des "valeurs critiques" données pour d'autres sujets. La raison en est que les produits métallurgiques, et plus particulièrement ceux qui sont les plus complexes, sont sujets à certaines varia-

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EINLEITUNG

Die äusserst knappe Form in welcher die Metallurgie notwendigerweise in den Tafeln dargelegt ist, erfordert für ihren Gebrauch einige Erklärungen. Die vorkommenden Abkürzungen und besondere Symbole sind Seite 392 erklärt. Einige Beispiele zu ihrer Verständnis in besonderen Fällen sind weiter unten angegeben.

Eine Tafel der "Kritischen Werte" der mechanischen Eigenschaften von Metallen und Legierungen, weicht in gewissen wichtigen Beziehungen von den "Kritischen Werten" anderer Arten ab. Dies ruht daher dass metallurgische Produkte, besonders solche komplexerer Art, gewissen unvermeidlichen Eigenschaftsschwank-

INTRODUZIONE

La forma molto condensata in cui è stato necessario esporre i dati metallurgici richiede alcune spiegazioni circa l'uso delle tabelle. A pag. 392 sono spiegate le abbreviazioni e i simboli speciali adoperati, e più avanti sono riportati alcuni esempi illustranti la loro interpretazione in casi particolari.

Una tabella di "valori critici" delle proprietà meccaniche di metalli e leghe differisce necessariamente sotto alcuni punti di vista importanti dai "valori critici" di altre proprietà, e ciò per il fatto che i prodotti metallurgici, specie quelli più complessi, sono soggetti a variazioni inevitabili, anche se ottenuti nelle migliori condizioni. Per molti metalli e leghe i valori riportati many of the metals and alloys mentioned in the tables the origin of the data varies widely, some being derived from numerous tests on industrial products, while others represent the results of laboratory investigation. In making use of the tables, therefore, it is necessary to ascertain the nature of the data given. This can always be done by reference to the literature quoted. While laboratory results are generally accurately determined, it must be borne in mind that they may be either higher or lower than the figures to be anticipated from a corresponding industrial product. In some instances large-scale production makes it possible to secure better results than can be obtained in relatively small laboratory experiments, while in other cases the special conditions which can be used in laboratory work cannot readily be reproduced in industrial production.

If it is desired to form an opinion of the value of a given material for constructional purposes the nature of the material must be considered. In the case of castings, wide variations in mechanical properties occur as between different parts of the same casting, as between a large and small casting, and as between actual castings and test bars prepared either at the same time or otherwise. Even in a casting of given shape and material, variations in casting conditions, such as pouring temperature, rate of pouring and mold temperature, may cause considerable differences in mechanical properties. The figures quoted in the tables must therefore be regarded as indicating the values found for cast materials under conditions specified in the corresponding literature, and cannot be used, without further consideration, for the purpose of calculating the reliable strength of a particular casting. In wrought material, variations are likely to be much smaller than in cast. However, complete uniformity cannot be relied upon, particularly as between the products of different makers. In regard to some materials which are extensively produced industrially, the data given in the tables sometimes represent the values obtained from very numerous tests. In other cases the data may represent only isolated experiments. In compiling the tables, care has been taken to incorporate as far as possible only the most reliable data of both kinds.

Another cause of considerable variation in the mechanical properties of metals and alloys, in the wrought state, arises from the effect of mass. Material in large sections is in almost every case weaker than the same material produced in small sections. This is particularly marked where heat treatment of any kind has been given. Where the data in the tables include values corresponding to materials of different sections, it will obviously be desirable to attach the greatest importance to those figures relating to materials which have a cross section similar to that which it is proposed to use, or whose properties it is desired to ascertain. It should also be borne in mind that there is a steady improvement in foundry, rolling mill, forging and heat-treating practice, so that, as a rule, the more modern methods yield values superior to those of older materials.

In the use of the tables three possibilities will arise: (I) The properties of an alloy whose composition is known are desired. (II) The properties of some commercial alloy whose composition is not known are desired. (III) An alloy having certain properties is desired.

I. Composition of Alloy Known. Properties Desired

1. Turn to the Table of Contents (p. 358), and ascertain the section in which this type of alloy is treated.
2. Turn to the section at the page number given.
3. With the aid of the Table of Contents at the beginning of the section, ascertain the table containing the desired type of information and turn to it.
4. In each table (unless otherwise indicated) the alloys are arranged in the order of their "type formulae." The type formula

tions inévitables, même lorsqu'ils ont été fabriqués dans les meilleures conditions. L'origine des données se rapportant a plusieurs des métaux et alliages mentionnées dans les tables varie dans une large mesure; certaines données proviennent de nombreux essais sur des produits industriels alors que les autres représentent les résultats d'expériences de laboratoire. C'est pourquoi il est nécessaire pour l'emploi des tables de s'assurer de la nature des valeurs données. Ceci peut toujours être réalisé en se référant à la source bibliographique citée. Les résultats de laboratoire sont généralement déterminée avec précision; il ne faut pas cependant perdre de vue qu'ils peuvent être ou supérieurs ou inférieurs aux chiffres qu'on peut attendre d'un produit industriel correspondant. Dans certains cas une production sur une large échelle permet l'obtention de meilleurs résultats que ceux qui peuvent être obtenus dans des expériences effectuées dans le laboratoire, alors que dans d'autres cas, les conditions spéciales qui peuvent être utilisées dans le travail de laboratoire ne sont pas reproductibles facilement dans une production industrielle.

Si l'on désire se faire une opinion de la valeur d'une matière donnée et cela pour des buts de construction, il faut considérer la nature de la matière. Dans le cas des pièces fondues, il existe de grandes variations dans les propriétés mécaniques aussi bien entre les différentes parties d'une pièce donnée qu'entre une grande ou une petite pièce ou qu'entre une pièce donnée et des éprouvettes préparées au même moment ou plus tard. Même pour une pièce de dimension et d'une matière données, les variations dans les conditions de coulée, telle que la température de coulée, la vitesse de coulée et la température du moule, peuvent occasionner des différences considérables dans les propriétés mécaniques. Les chiffres cités dans les tables doivent donc être regardés comme indiquant les valeurs trouvées pour des matières coulées dans des conditions spécifiées dans la littérature correspondante, et ils ne peuvent être utilisés sans autres considérations, dans le but de calculer une valeur de résistance digne de confiance d'une pièce coulée particulière. Dans les matières travaillées, les variations sont ordinairement plus petites que dans les matières fondues. Cependant, on ne peut pas tabler sur une complète uniformité, surtout entre des produits de différents fabricants. En ce qui concerne certaines matières qui sont produites industriellement en grand, les valeurs données dans les tables représentent quelquefois les valeurs obtenues dans de très nombreux essais. Dans d'autres cas, les valeurs peuvent ne représenter que des expériences isolées. En établissant les tables, il a été pris soin de n'incorporer autant que possible que les valeurs des deux sortes les plus dignes de confiance.

Une autre cause, occasionnant une variation considérable dans les propriétés mécaniques des métaux et alliages à l'état travaillé, est produite par l'effet de la masse. Une matière de grande section est dans presque chaque cas plus faible que la même matière produite en petites sections. Ce fait est particulièrement marqué lorsqu'un traitement thermique quel qu'il soit a été effectué. Lorsque les données dans les tables comportent des valeurs correspondant à des matières de différentes sections, il sera évidemment préférable d'attacher la plus grande importance aux chiffres se rapportant aux matières ayant une section similaire à celle qu'on se propose d'utiliser, ou dont on désire connaître les propriétés. Il ne faut pas oublier non plus qu'il se produit une amélioration certaine dans les opérations de fonderie, de laminage, de forgeage et par les traitements thermiques de sorte qu'en règle générale, les méthodes les plus modernes conduisent à des valeurs supérieures à celles obtenues avec des matières fabriquées moins récemment.

Trois possibilités se présentent dans l'usage des tables: (I) On désire connaître les propriétés d'un alliage, dont la composition est connue. (II) On désire connaître les propriétés d'un alliage commercial dont la composition n'est pas connue. (III) On ungen unterworfen sind, selbst wenn die Herstellungsbedingungen die besten waren. Bezüglich der vielen in den Tabellen angeführten Metallen und Legierungen, sind die Quellen aus welchen die Daten entnommen worden sind, sehr verschieden. Einige Daten sind von vielen Materialsprüfungen an Industrieprodukten abgeleitet, andere wieder, stellen das Ergebnis von Laboratoriumsuntersuchungen dar. Beim Gebrauche der Tafeln ist daher die Feststellung der Natur der Daten notwendig, was immer an Hand der angegebenen Literatur geschehen kann. Während im allgemeinen die Laboratoriumsergebnisse genau sind, muss man bedenken, das die Zahlenwerte bald höher bald niedriger sein können als die, welche an einem Industrie-Produkt zu erwarten sind. In mancher Hinsicht gestattet die Herstellung im Grossen, ein besseres Ergebnis als es in dem verhältnismässig kleinem Masstab des Laboratoriums möglich ist. In anderen Fällen wieder können die Bedingungen im Laboratorium nicht leicht bei der industriellen Herstellung eingehalten werden.

Ist es wünschenswert, dass man sich ein Bild über die Zahlenwerte eines gegebenen Materials für Konstruktionszwecke macht, so ist es notwendig die Natur des Materials zu berücksichtigen. Beim Guss weichen die mechanischen Eigenschaften sehr weitgehend an verschiedenen Stellen desselben Gusstückes von einander ab. Unterschiede sind sowohl zwischen einem in grossen oder kleinem Gusstuck als auch zwischen dem Hauptguss und dem Probestück vorhanden, wenn beide zugleich oder auf andere Weise hergestellt wurden. Sogar beim Giessen einer gegebenen Form und gegebenen Material, zeigen sich bemerkenswerte Differenzen der mechanischen Eigenschaften, wenn die Bedingungen beim Gusse, wie Gusstemperatur, Gussgeschwindigkeit, die Temperatur der Form, u. s. w., verändert werden. Es gelten daher die in den Tafeln angegebenen Zahlenwerte für ein gegossen hergestelltes Material nur unter den Bedingungen, welche in der entsprechenden Literatur angegeben sind. Die Zahlenwerte können jedoch nicht ohne weiteres zu dem Zwecke benützt werden, um einen zuverlässlichen Eigenschaftswert eines bestimmten Gusses zu berechnen. In bearbeitetem Material sind die Unterschiede häufiger viel kleiner als im gegossenen. Auf eine vollkommene Gleichheit ist nie zu rechnen, ganz besonders bei Materialien verschiedenen Ursprunges. In Bezug auf gewisse Materialien, welche ausgedehnt industriell hergestellt werden, stellen die angegebenen Werte manchmal die Ergebnisse sehr zahlreicher Prüfungen dar. In manchen anderen Fällen beziehen sich die Daten nur auf einzelne Untersuchungen. Bei der Zusammenstellung der Tafeln wurden soweit als möglich sorgfältig nur die verlässlichsten Daten, beider Typen aufgenommen.

Ein anderer Grund zur Änderung der mechanischen Eigenschaften von Metall und Legierung im bearbeiteten Zustand, kommt vom Einfluss der Masse her. Ein Material in grossen Stücken ist fast in allen Fällen weicher, als wenn dasselbe in kleineren Stücken hergestellt wird. Dies ist besonders bei einer Wärmebehandlung irgend welcher Art hervortretend. Wo in den Tafeln Werte vorhanden sind die sich auf Material-Stücke verschiedener Grösse beziehen, so wird es natürlich wünschenswert sein die grösste Wichtigkeit den Zahlen beizulegen, die sich auf ein herausgearbeitetes Stück beziehen, welches gleich dem Stück ist, welches benützt werden soll, oder dem Stück dessen Eigenschaften man kennen lernen will.

Man bedenke, dass in den Giessereien, Walzwerken, bei der Schmiedung und Wärmebehandlung ständig Fortschritte zu verzeichnen sind, so dass in der Regel die modernere Methoden ein Material liefern, dessen Eigenschafts-Werte den nach älteren Methoden hergestellten überlegen sind.

Beim Gebrauch der Tabellen können drei Möglichkeiten vorliegen: (I) Man sucht Eigenschaften einer Legierung bekannter Zusammensetzung. (II) Man sucht Eigenschaften einer

provengono da fonti notevolmente diverse: alcuni sono ricavati da numerosi saggi su prodotti industriali, mentre altri sono dedotti da ricerche di laboratorio. Nel servirsi delle tabelle è perciò necessario tener conto della natura dei dati, cosa che può sempre farsi riferendosi alla letteratura citata. I risultati di prove di laboratorio sono in genere accurati, e perciò essi possono essere più bassi o più alti dei valori prevedibili per un prodotto industriale corrispondente. In alcuni casi la produzione su larga scala rende possibile migliori risultati di quelli ottenibili in piccole prove di laboratorio, mentre in altri casi le condizioni speciali che si possono realizzare in laboratorio non si possono facilmente riprodurre nell'industria.

Per farsi una idea di un dato materiale a scopi costruttivi, se ne deve prendere in considerazione la natura. Nel caso di getti, ad es., si hanno ampie oscillazioni nelle proprietà meccaniche tra le diverse parti di uno stesso getto, come pure tra un getto grande e uno piccolo ed anche tra getti e provini, sia che questi vengano preparati assieme al getto sia che vengano ottenuti diversamente. Anche in un getto di forma e materiale determinati, eventuali differenze nelle condizioni di colata, come temperatura e velocità di colata, e temperatura della forma, possono produrre differenze notevoli nelle proprietà meccaniche. Perciò i valori delle tabelle indicano le proprietà del materiale quando questo sia ottenuto nelle condizioni specificate nella letteratura corrispondente ed essi non possono servire per calcolare senz'altro la resistenza probabile di un particolare getto. Nei materiali lavorati le variazioni sono spesso molto più piccole che in quelli ottenuti di getto; tuttavia non si può fare affidamento sopra una completa uniformità specie se si tratta di prodotti che hanno provenienza diversa. Per certi materiali che sono prodotti largamente nell' industria, i valori delle tabelle sono alcune volte ricavati da numerosissimi saggi; in altri casi invece essi rappresentano soltanto esperienze isolate. Nel compilare le tabelle si è avuto cura di servirsi il più che possibile solo dei valori dei due tipi che più sono degni di fiducia.

Considerevoli differenze nelle proprietà meccaniche dei metalli o leghe allo stato lavorato possono essere prodotti da effetto di massa. Un materiale in sezioni grandi è quasi sempre più debole che in sezioni piccole, e questo è particolarmente evidente nei casi in cui si è ricorso ad un trattamento termico qualunque. Quando nelle tabelle sono riportati valori corrispondenti a sezioni differenti, bisogna evidentemente attribuire la massima importanza ai numeri che si riferiscono a materiali con sezione simile a quella che si ha in animo di usare o di cui si vogliono stabilire le proprietà. Deve pure tenersi presente che vi è un continuo miglioramento nella pratica di fonderia di laminatoio, di fucina, e dei trattamenti termici per modo che, di regola, i metodi più moderni danno valori superiori a quelli dei materiali più antichi.

Nel servirsi delle tabelle tre casi si possono presentare: (I) Si può desiderare di conoscere le proprietà di una lega di cui è nota la composizione. (II) Si può desiderare di conoscere le proprietà di una lega commerciale di cui non è nota la composizione. (III) Si può desiderare di conoscere una lega che abbia determinate proprietà.

I. La composizione della lega è nota e si desidera conoscerne le proprietà

1. Si consulta l'indice a p. 358 e si vede quale è il capitolo in cui si parla di questo tipo di leghe.
2. Si consulta il capitolo alla pagina indicata.
3. Dall'indice che si trova al principio del capitolo si ricava la tabella che contiene il tipo di informazione che si desidera.
4. In ogni tabella (tranne che non sia indicato diversamente) le leghe sono disposte nell'ordine delle loro formule tipo. La formula tipo di una lega è costituita da dei simboli chimici dei suoi costituenti essenziali scritti in ordine decrescente della proporzione

of an alloy consists of the chemical symbols of its essential constituents written in descending order of their amounts in the alloy except in the case of steels, where C is written last. (*N. B.*—An element once thought merely incidental or an impurity in an alloy may later be found to have an important effect on its properties; *cf.* the case of silicon in duralumin.) Thus Pb-Sb-Cu is the type formula of alloys whose largest constituent (by weight) is Pb, the next largest Sb, and the next Cu; while a vanadium steel has the type formula Fe-V-C, although C is generally present in larger amounts than V. The different alloys are arranged in alphabetical order according to their type formulae.

Under a given type formula the alloys are arranged in descending order of the amounts of the principal constituent in the alloy, where this is given by analysis, and, where it is not given, then in ascending order of amounts of the second largest constituent in the alloy. Under each composition the data follow approximately in order of the extent of treatment given the alloy. Thus the properties of castings (symbol = G) appear first, then those of hot-worked material, and finally those of cold-worked material. The properties of heat-treated material follow immediately after those of the material before heat treatment.

Example 1: It is desired to compare the mechanical properties of a sand-cast 10% aluminum bronze with those of the same alloy in which 3% of the Al is replaced by Fe. It is desired to ascertain the properties of the alloys at high temperatures. The first alloy, call it "A," has the type formula Cu-Al; the second, call it "B," has the type formula Cu-Al-Fe. Turning to the Table of Contents (p. 359), we find that the section containing the mechanical properties of Al bronzes, begins on p. 572. Turning here we find a Table of Contents for the section in which are listed 15 tables of properties of the type Cu-Al and 6 tables of properties of the type Cu-Al-Fe.

Let us first consider the Ultimate Tensile Strength (*UTS*) in kg/mm², % Elongation (*El*) and Brinell Hardness Number (*BHN*) of our alloy "A" in the sand-cast (G$_s$) condition. From the tables we find as follows:

t, °C / Table	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	500	
1	46–53		20		90–100		(13)
2	49.9		21.7				(3)
3	29.1	18.2	9.4	3.1			(2, 15)
4					76.7	<50	(12)
13	42.2		28.5		118		(26)
13	52.0		19.5		100		(7)

The values in Table 1 represent the average properties of alloy "A" and agree fairly well with those in the other tables excepting those in Table 3, which probably are for material cast under unsatisfactory conditions, a thing easily possible with aluminum bronze.

Considering alloy "B" in the same manner we have:

t, °C / Table	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	500	
17	52.4		38.0		80		(10)
20	(Contains 7.6% Al, 2% Fe)				125	70	(12)

Although fewer data are available, alloy "B" seems to be as strong as and more ductile than "A" at 20°C, while the presence of 2% Fe has increased the hardness of the alloy at 500°C. Hardness figures of (12), however, are inconsistent with those from other sources. On the basis of the tables then, alloy "B" is somewhat the better alloy.

The index (p. 370) shows whether any commercial alloys of the composition of "B" are included. Index numbers of aluminum bronzes are listed in one of the tables of Alloy Classes following

désire un alliage ayant certaines propriétés. Les trois cas seront considérés dans l'ordre indiqué.

I. Composition de l'alliage connue. Propriétés désirées

1. Consulter la table des matières p. 358 et s'informer de la section dans laquelle il est traité de ce type d'alliage.

2. Consulter cette section à la page indiquée.

3. Au moyen de la table des matières se trouvant au commencement de la section, s'informer qu'elle est la table contenant le type d'information désiré et s'y porter.

4. Dans chaque table (à moins d'une autre indication) les alliages sont arrangés dans l'ordre de leur "formule type." La formule type d'un alliage se compose des symboles chimiques de ses constituants essentiels écrits dans l'ordre descendant de leurs proportions dans l'alliage, excepté pour le cas des aciers, où C est écrit en dernier. (*N. B.* Il peut se trouver qu'un élément dont la présence peut être considérée accidentelle ou une impureté dans un alliage peuvent avoir un effet important sur ses propriétés: par ex. cas du silicium dans duralumin). Ainsi Pb-Sb-Cu est la formule type des alliages dont le constituant le plus important (en poids) est Pb, celui qui vient ensuite dans le même ordre d'idée est Sb, et finalement vient Cu; un acier au vanadium aura la formule type Fe-V-C, quoique C soit généralement présent en plus grande quantité que V. Les différents alliages sont arrangés dans l'ordre alphabétique en accord avec leurs formules types.

Sous une formule type donnée, les alliages sont arrangés, lorsque ce résultat est fourni par l'analyse, dans l'ordre descendant des proportions de leur constituant principal dans l'alliage; lorsque l'analyse n'a pas été effectué, dans l'ordre ascendant des proportions du deuxième constituant en importance de l'alliage. Sous chaque composition, les données suivent approximativement dans l'ordre de la succession des traitements subis par l'alliage. Ainsi les propriétés des pièces fondues (symbole = G), sont mentionnées en premier. Ensuite viennent les propriétés de la matière travaillée à chaud et finalement celles de la matière travaillée à froid. Les propriétés de la matière traitée thermiquement suivent immédiatement celles de la matière avant le traitement thermique.

Exemple 1: On désire comparer les propriétés mécaniques d'un bronze d'aluminium à 10% Al coulé en sable avec celles du même alliage dans lequel 3% de l'Al ont été remplacés par Fe. On désire connaître les propriétés des alliages à hautes températures. Le premier alliage, désignons-le par "A," a la formule type Cu-Al; le second, désignons-le par "B" a la formule type Cu-Al-Fe. Consultant la table des matières (p. 359) on trouve que la section contenant les propriétés mécaniques des bronzes d'Al commence à p. 572. À cette page nous trouvons une table des matières pour la section, dans laquelle sont disposées en liste 15 tables des propriétés du type d'alliage Cu-Al et 6 tables des propriétés du type d'alliage Cu-Al-Fe.

Considérons d'abord: la charge de rupture (*UTS*) en kg/mm², l'allongement en % (*El*) et le nombre de dureté Brinell (*BHN*) de notre alliage "A" dans la condition "coulé en sable" (G$_s$). Des tables, on trouve:

t, °C / Table	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	500	
1	46–53		20		90–100		(13)
2	49,9		21,7				(3)
3	29,1	18,2	9,4	3,1			(2, 15)
4					76,7	<50	(12)
13	42,2		28,5		118		(26)
13	52,0		19,5		100		(7)

Les valeurs dans la Table 1 représentent les propriétés moyennes de l'alliage "A;" elles s'accordent assez bien avec celles des autres

Legierung des Handels, unbekannter Zusammensetzung. (III) Man sucht eine Legierung von bestimmten Eigenschaften.

I. Die Zusammensetzung der Legierung ist bekannt. Eigenschaften gesucht

1. Man sehe im Inhaltsverzeichnis (S. 358) nach und stelle den Abschnitt fest in welchem diese Legierungstype behandelt wird.
2. Man schlage den Abschnitt an der gegebenen Seitenzahl auf.
3. Mit Hilfe des Inhaltsverzeichnisses am Anfang dieses Abschnittes, stelle man die Tafel fest, welche die gewünschte Type der Eigenschaften enthält und schlage diese Tafel dann auf.
4. In jeder Tafel (wenn nichts anderes angegeben ist) sind die Legierungen in der Reihenfolge ihrer "Typen-Formel" angeordnet. Diese "Typen-Formel" einer Legierung besteht in der Nebeneinandersetzung der chemischen Zeichen ihrer wesentlichen Bestandteile in absteigender Ordnung ihrer Prozentgehalte Eine Ausnahme ist bei den Stählen vorhanden, wo am Ende C steht. (*N. B.*—Ein Element, das zuweilen nur zufällig oder als Verunreinigung in den Legierungen vorhanden angesehen wurde, kann später als ein solches von besonderem Einfluss auf die Eigenschaft derselben erkannt werden, z. B. Si in Duralumin.) So ist Pb-Sb-Cu die Typenformel von Legierungen, in welchen Pb den höchsten Prozentgehalt darstellt, den nächst niedrigeren Sb, dann folgt Cu. Ein Vanadium-Stahl hat hingegen die Typenformel Fe-V-C, obwohl im allgemeinen C in grösserer Menge als V vorhanden ist. Die verschiedenen Legierungen sind in alphabetischer Reihenfolge ihrer Typenformeln angeordnet.

Unter einer gegebenen Typenformel sind die Legierungen in absteigender Ordnung des analytisch bekannten Hauptbestandteiles in der Legierung angeordnet. Ist dieser Gehalt nicht bekannt, so sind die Legierungen in aufsteigender Ordnung des Prozentgehaltes des zweiten grössten Bestandteiles angeordnet. Unter jeder Zusammensetzung folgen die Daten ungefähr nach der Zahl der verschiedenen Behandlungen, welchen die Legierung unterworfen wurde. So erscheinen die Eigenschaften des Gusses (Zeichen = G) zuerst, dann jene des heiss bearbeiteten und zum Schluss des kalt bearbeiteten Materials. Die Eigenschaften des wärmebehandelten Materials folgen unmittelbar nach denen des Materials vor der Wärmebehandlung.

Beispiel 1: Es sollen die mechanischen Eigenschaften einer in Sandform gegossenen 10% Aluminiumbronze mit einer gleichen Legierung verglichen werden, in welcher 3% des Aluminiumgehaltes durch Fe ersetzt sind. Die Kenntnis der Eigenschaften bei hoher Temperatur ist notwendig. Die erste Legierung, wir bezeichnen sie mit "A," hat die Typenformel Cu-Al, die zweite, "B" bezeichnet, hat die Typenformel Cu-Al-Fe. Aus dem Inhaltsverzeichnis (S. 359) finden wir, dass der Abschnitt, welcher die mechanischen Eigenschaften der Al-Bronzen enthält, auf S. 572 beginnt. Hier finden wir ein Inhaltsverzeichnis für diesen Abschnitt in welchem 15 Eigenschafts-Tafeln der Type Cu-Al und 6 Eigenschafts-Tafeln für die Type Cu-Al-Fe, vorhanden sind.

Wir wollen zuerst von der Legierung "A" (in *Sandform gegossen*) die Zugfestigkeit (*UTS*) in kg/mm^2, Prozent Dehnung (*El*) und die Brinell-Härtezahl (*BHN*) berücksichtigen. Aus den Tafeln finden wir:

t, °C / Tabelle	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	500	
1	46–53		20		90–100		(13)
2	49,9		21,7				(3)
3	29,1	18,2	9,4	3,1			(2, 15)
4					76,7	<50	(12)
13	42,2		28,5		118		(26)
13	52,0		19,5		100		(7)

in cui sono contenuti, eccetto nel caso degli acciai, dove C è scritto per ultimo. (*N. B.* Un elemento ritenuto solo accidentale oppure giudicato come impurezza può in seguito trovarsi che ha un effetto importante sulle proprietà di una lega: vedi, ad es. il caso del silicio nel duralluminio.) Così Pb-Sb-Cu è la formula tipo delle leghe nelle quali la proporzione maggiore in peso è di Pb, quella intermedia è di Sb e quella minore è di Cu; mentre un acciaio al vanadio ha la formula Fe-V-C, sebbene C, in genere, è presente in proporzione maggiore di V. Le diverse leghe sono disposte in ordine alfabetico secondo le loro formule tipo.

Sotto una certa formula tipo le leghe sono disposte in ordine decrescente della proporzione del costituente principale quando questa è nota. Se questa non è nota esse sono disposte nell' ordine crescente del contenuto del secondo componente più abbondante. Sotto ogni composizione i dati sono disposti approssimativamente nell'ordine della complessità del trattamento. Così le proprietà dei getti (simbolo = G) vengono per prime, poi quelle del materiale lavorato a caldo, e infine quelle del materiale lavorato a freddo. Le proprietà del materiale trattato a caldo seguono subito dopo quelle del materiale prima del trattamento a caldo.

Esempio 1: Si desideri confrontare le proprietà meccaniche di un bronzo d'alluminio al 10% colato in sabbia, con quelle della stessa lega nella quale 3% di alluminio è stato sostituito con ferro, e precisamente si desideri conoscere le proprietà della lega a temperature elevate. La prima lega, che indicheremo con "A," ha la formula tipo Cu-Al; la seconda, che indicheremo con "B," ha la formula tipo Cu-Al-Fe. Se si consulta l'indice (p. 359) si trova che il capitolo contenente le proprietà meccaniche dei bronzi di alluminio comincia a p. 572. Qui si trova un indice in cui sono riportate 15 tabelle di proprietà per il tipo Cu-Al e 6 tabelle di proprietà per il tipo Cu-Al-Fe.

Consideriamo dapprima il carico di rottura (*UTS*) in kg/mm^2, l'allungamento per cento (*El*) e il numero di durezza Brinell (*BHN*) della lega "A" colata in sabbia (G_s). Dalle tabelle si trova:

t, °C / Tabe a	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	500	
1	46–53		20		90–100		(13)
2	49,9		21,7				(3)
3	29,1	18,2	9,4	3,1			(2, 15)
4					76,7	—50	(12)
13	42,2		28,5		118		(26)
13	52,0		19,5		100		(7)

I valori della Tabella 1 rappresentano le proprietà medie della lega "A" e si accordano bene con quelli delle altre tabelle; si eccettuano solo i valori della Tabella 3, che probabilmente si riferiscono ad un materiale gettato in condizioni non soddisfacenti, cosa questa è facilmente possibile con i bronzi d'alluminio.

Se si considera le lega "B" allo stesso modo si ha:

t, °C / Tabella	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	300	
17	52,4		38,0		80		(10)
20	(7,6% Al, 2% Fe)				125	70	(12)

Sebbene si disponga di pochi dati, la lega "B" sembra sia resistente quanto la "A" e persino più duttile della "A" a 20°C, mentre la presenza del 2% di ferro ha accresciuto la durezza a 500°C. I numeri di durezza riportati nella (12) non si accordano però con quelli di altre fonti. In base alle tabelle tuttavia la lega "B" è un po' migliore.

Dall'indice (p. 370) si può sapere se nelle tabelle sono riportate leghe commerciali della composizione di "B." I numeri indici dei the Finding Index. Turning to these numbers in the Finding Index, we find No. 45, "Alcumite:" Cu; Al, 7.5; Fe, 5.5; Ni, Mn, No. 141, "Ampco bronze:" Cu; Al, 7–11; Fe, 1–5. If the alloys thus shown in the Finding Table are commercially available at the present time, reference to the firms producing them can no doubt be obtained from the advertising pages of metallurgical magazines or otherwise. It must, however, be borne in mind that other alloys, possibly of the type desired, are manufactured in various countries, without necessarily being known by a name which could be included in the Finding Index, while there are numerous manufacturers in every country having a well-developed metallurgical industry, who will be prepared to make up alloys to any desired specification, provided that patent rights do not interfere. In some instances, it may be noted that the properties of the materials as represented by data given in the corresponding table, can only be obtained by definitely stated methods of manufacture and treatment and these are, sometimes, available only at the hands of an individual manufacturing firm. Further, where alloys having trade names are given in the list, and if no definite data for these alloys as such are included, the inference that the alloy bearing the trade name will have the same properties as the alloy of similar composition listed in the detailed table, must be regarded as subject to the limitations just indicated.

Example 2: Given a Ni-Cr steel containing 3.5% Ni, 0.8% Cr and 0.25% C, to find the heat treatment giving the optimum combinations of tensile and notched-bar impact properties. From the Table of Contents, it is found that Ni-Cr steels are treated in the section beginning on p. 483. The first numbered table of this section is a table of compositions, in which No. 262 is found to correspond to the above composition. The table of contents at the beginning of the section (p. 483) shows that mechanical properties are given in Table 7, p. 510. Turning to this table, we locate alloy No. 262 (p. 511) and find that values of properties are given for 42 different conditions of this steel. Notched-bar impact test results are given under the following designations: IS_u (Izod machine using B. E. S. A. standard specimen), IS_v (Charpy machine using 45° V notch specimen), IS_x (Guillery machine, Mesnager notch). The energy absorbed in fracture is given in each case as there is no satisfactory basis for comparison of results as between the different types of specimen. The largest Izod values of No. 262 are for treatments h, j, k, and z, being respectively 8.85, 9.15, 9.0, and 9.0. Of these, "h" gives a material somewhat stronger and considerably more ductile than do the others. Meanings of symbols and abbreviations used in describing treatments are given in the table on p. 392. Treatment "h" reads as it stands "Same, Tp 650° Q_w." The "Same" refers to the previous treatment, *i.e.*, condition before tempering, which is N 820°. The whole treatment interpreted is: Normalized at 820° (*i.e.*, cooled in still air from 820°C), then tempered at 650°C and quenched in water. The other treatments which give high impact strengths, are: "1000° Q_o Tp 670°/120 Q_w" (*i.e.*, quenched in oil from 1000°C, tempered at 670° for 120 min, and quenched in water); "1000° Q_o Tp 650°/120 C_s 650° Q_w" (*i.e.*, quenched in oil from 1000°C, tempered at 650° for 120 min, cooled slowly, retempered at 650°C and quenched in water); and "850° Q_o Tp 675°/495 Q_w" (*i.e.*, quenched in oil from 850°C, tempered at 675° for 495 min, and quenched in water). These treatments give nearly as good properties, thus showing the necessity of a final water quench from 650–675°C. Consideration of some of the other treatments shows that cooling slowly from this temperature gives decidedly inferior notched-bar impact figures while not greatly affecting the tensile values. Quenching from lower temperatures gives better tensile properties, but inferior notched-bar impact figures. Inspection of values obtained on the other machines for these treatments and for others tables excepté celles de la Table 3, qui se rapportent probablement à un matériel fondu dans les conditions non satisfactoires, une circonstance qui est très possible avec le bronze d'aluminium.

Considérant l'alliage "B" de la même manière, nous avons:

t, °C / Table	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	300	
17	52,4		38,0		80		(10)
20	(7.6% Al, 2% Fe)				125	70	(12)

Quoiqu'il y ait peu de données disponibles, l'alliage "B" paraît être aussi résistant et plus ductible que "A" à 20°C, alors que la présence de 2 % de Fe a augmenté la dureté de l'alliage à 500°C. Les chiffres de dureté de (12) cependant, ne sont pas en accord avec ceux d'autres sources. On peut déduire sur la base des tables que l'alliage "B" est sensiblement le meilleur alliage.

L'index (p. 370) montre s'il y existe un alliage commercial de la composition de "B." Les nombres index des bronzes d'aluminium sont disposés en liste dans l'une des tables des alliages types qui se trouvent à la suite de l'index de recherche. En se reportant à ces nombres dans l'index de recherche, on trouve N° 45, "Alcumite:" Cu; Al, 7,5; Fe, 5,5; Ni; Mn, et N° 141, "Ampco bronze:" Cu; Al, 7–11; Fe, 1–5. Si les alliages ainsi mentionnés dans la table de recherche sont disponibles dans le commerce actuellement, on trouvera sans doute les références des firmes qui les produisent dans les annonces des magazines métallurgiques ou autre part. Il ne faut pas oublier cependant que d'autres alliages, qui peuvent être du type désiré sont fabriqués dans des pays divers, sans être nécessairement connus par un nom qui pourrait se trouver dans l'index de recherche; il existe en effet de nombreux fabricants dans chaque pays possédant une industrie métallurgique bien développée qui peuvent fabriquer des alliages suivant les spécifications variées, à condition que les droits de patente ne s'y opposent pas. Dans certains cas, il faut remarquer que les propriétés des matières ainsi qu'elles sont représentées par les valeurs données dans les tables correspondantes, ne peuvent être obtenues que par des méthodes de fabrication et des traitements établis d'une façon définie, qui quelquefois ne sont réalisés que chez un seul fabricant. Lorsqu'il s'agit d'alliages portant des noms commerciaux mentionnés dans la liste, il n'a pas été indiqué de données définies pour ces alliages considérés comme tels, et, déduire que les alliages portant un nom commercial ont les mêmes propriétés que l'alliage de composition similaire mentionné dans la table détaillée, doit être regardé comme étant sujet aux limitations indiquées ci-dessus.

Exemple 2: Etant donné un acier au Ni-Cr contenant 3,5% Ni, 0,8% Cr et 0,25% C, trouver le traitement thermique donnant la combinaison optimum relativement aux propriétés de traction et à l'essai de choc sur éprouvette entaillée. De la table des matières, on trouve que les aciers au Ni-Cr sont traités dans la section commençant à p. 483. La première table de cette section est une table de compositions, dans laquelle le N° 262 correspond à la composition donnée ci-dessus. La table des matières au commencement de la section (p. 483) montre que les propriétés mécaniques sont données dans la Table 7, p. 510; à cette table nous trouvons l'alliage N° 262 (p. 511) et constatons que les valeurs des propriétés sont données pour 42 différentes conditions de cet acier. Les résultats concernant l'essai de choc sur éprouvette entaillée sont donnés sous les désignations suivantes: IS_u (Machine d'Izod, utilisant des éprouvettes types B. E. S. A.), IS_v (Machine de Charpy utilisant une éprouvette avec entaille 45°V), IS_x (Machine de Guillery, éprouvette avec entaille Mesnager). L'énergie absorbée dans la rupture est donnée dans chaque cas, car il n'existe pas de base convenable pour la comparaison des résultats entre les différents types d'éprouvettes. Les valeurs Izod les plus fortes concernant le N° 262 sont obtenues avec les traitements

Der Wert in der Tabelle 1 stellt die Durchschnittseigenschaften der Legierung "A" dar, und stimmt ziemlich gut mit jenen in den anderen Tabellen überein. Ausgenommen jedoch die Werte der Tabelle 3, welche wahrscheinlich für ein Material gelten, das unter nicht befriedigenden Bedingungen gegossen worden ist. Bei Aluminiumbronzen ist ein solcher Fall sehr möglich. Nehmen wir die Legierung "B," so hat man in gleicher Weise:

Tabelle \ *t*, °C	*UTS*		*El*		*BHN*		Lit.
	20	500	20	500	20	500	
17	52,4		38,0		80		(10)
20	(7.6% Al, 2% Fe)				125	70	(12)

Obgleich weniger Daten vorliegen, scheint die Legierung "B" bezüglich der Zugfestigkeit ebenso gut wie "A," bezüglich der Duktilität bei 20° besser zu sein, während die Anwesenheit von 2% Fe die Härte bei 500°C erhöht. Die Härtezahlen von (12) aber stimmen mit denen aus anderen Quellen stammenden nicht überein. Auf Grund der Tafeln ist "B" eine etwas bessere Legierung als "A."

Der Index (S. 370) zeigt an, ob irgend eine Handelslegierung von der "B" Zusammensetzung gegeben ist. Die Indexzahlen der Aluminiumbronzen sind in einer der Tafeln für Legierungstypen eingetragen, die dem Nachschlage-Index folgen. Sehen wir diese Zahlen im Nachschlage-Index nach, so finden wir No. 45, "Alcumite:" Cu; Al, 7,5; Fe, 5,5; Ni, Mn; No. 141, "Ampco bronze:" Cu; Al, 7–11; Fe, 1–5. Sind diese Legierungen gegenwärtig handelsüblich, so kann vermutlich die Erzeugerfirma in dem Inseratenteil der Fachzeitschriften und auch sonst, gefunden werden. Es muss jedoch berücksichtigt werden, dass andere Legierungen, möglicherweise gerade von der gewünschten Type, in den verschiedenen Ländern erzeugt werden können, die vielleicht keinen Namen tragen, der in dem Nachschlage-Index angegeben werden konnte. Es gibt in jedem Lande mit einer gut entwickelten Metallindustrie, eine Anzahl von Fabriken die imstande sind, soweit nicht Patentrechte vorliegen, jede Legierung von besonderer Zusammensetzung herzustellen.

Es möge noch bemerkt werden, dass in mancher Beziehung, die in den entsprechenden Tabellen angegebenen Eigenschaften nur durch bestimmte Fabrikations-Methoden und Behandlungen erreicht werden können, die zuweilen nur den einzelnen Erzeugerfirmen zur Verfügung stehen. Ferner, wo in den Tabellen Legierungen mit Handelsmarken angegeben sind und keine definitive Werte für solche in den Tafeln angeführt sind, ist eine Schlussfolgerung, wie aus dem Vorhergegangenen folgt, dass eine Legierung mit Handelsmarke dieselben Eigenschaften habe als eine ähnlich zusammengesetzte Legierung die sich in der Tabelle vorfindet, sehr einzuschränken.

Beispiel 2: Gegeben ist ein Ni-Cr-Stahl mit 3,5% Ni, 0,8% Cr, und 0,25% C. Es ist die Wärmebehandlung zu finden, die ein Optimum an Zugfestigkeit und Schlagfestigkeit an einem gekerbten Probestück gibt. Aus dem Inhaltsverzeichnis findet man, dass Ni-Cr-Stähle in dem S. 483 beginnenden Abschnitt behandelt werden. Die erste Zahlentafel dieses Abschnittes gibt die Zusammensetzungen an worunter No. 262, der angegebenen Zusammensetzung entspricht. Das Inhaltsverzeichnis zu Beginn des Abschnittes (S. 483) gibt an, dass die mechanischen Eigenschaften in der Tafel 7, S. 510, zu finden sind. Hier findet man die Legierung No. 262 (S. 511) und sieht, dass die Eigenschaften für 42 verschiedene Behandlungen für diese Stahlsorte vorliegen. Die Schlagfestigkeit (Kerbeneinschnitt) ist unter der folgenden Bezeichnung angegeben: IS_u (Izod Machine, B. E. S. A. standard Probe), IS_v (Charpy-Machine, mit 45° V-Kerbe), IS_x (Guillery Machine, Kerbenformstück nach Mesnager). *Die beim Bruch absorbierte Energie* ist in jedem Falle angegeben, da keine befriedi-

bronzi di alluminio sono elencati in una delle tabelle dei tipi di leghe che seguono l'indice. Andando a cercare questi numeri nell'indice, si trova No. 45, "Alcumite:" Cu; Al, 7,5; Fe, 5,5; Ni; Mn; e No. 141, "Ampco Bronze:" Cu; Al, 7–11; Fe, 1–5. Se le leghe così indicate si trovano in commercio, si può sapere il nome delle ditte che le producono dalla réclame delle riviste metallurgiche o in qualche altro modo. Può darsi però che nei diversi paesi vengano fabbricate altre leghe, e che esse non siano conosciute con un nome che potrebbe essere incluso nell'indice. In ogni nazione con una industria metallurgica bene sviluppata, vi è un gran numero di produttori i quali sono in grado di fabbricare leghe con qualsiasi requisito purchè non esistano diritti di brevetti. Deve ancora osservarsi che le proprietà, quali sono rappresentate dai valori contenuti nelle tabelle, in alcuni casi possono solo ottenersi con processi di fabbricazione e trattamento ben definiti, e che questi talvolta sono a conoscenza esclusiva di una singola ditta fabbricante. Inoltre, quando nell'elenco sono contenute leghe con nomi commerciali, nessun valore definito è riportato per esse, e la deduzione che la lega con quel certo nome avrà le stesse proprietà di quella di composizione simile elencata nella tabella deve considerarsi sottoposta alle limitazioni sopraindicate.

Esempio 2: Dato un acciaio al Ni-Cr contenente 3,5% Ni, 0,8% Cr e 0,25% C, trovare qual'è il trattamento termico che dà l'optimum di carico di rottura e di resilienza. Nell'indice si trova che gli acciai al Ni-Cr sono trattati nel capitolo che comincia a p. 483. La prima tabella di questo dà le composizioni, e in essa si trova che il numero 262 corrisponde alla composizione di sopra. Dall'indice all'inizio del capitolo (p. 483) si ricava che le proprietà meccaniche sono esposte nella Tabella 7 (p. 510). Consultando questa si vede che a p. 511 sono riportati valori delle proprietà per 42 condizioni differenti dell'acciaio No. 262. I risultati delle prove di resilienza sono riportati sotto le seguenti designazioni: IS_u (macchina Izod con provino B.E.S.A.), IS_v (macchina Charpy con provino munito di intaglio V a 45°), IS_x (macchina Guillery con barretta Mesnager). L'energia assorbita nella rottura è data per ogni caso, giacchè non vi son elementi sufficienti per confrontare i risultati ottenuti con i diversi tipi di prove. I più grandi valori Izod del numero 262 sono per i trattamenti h, j, k, e z, e sono rispettivamente 8,85; 9,15; 9,0 e 9,0. Fra essi, "h" dà un materiale un po' più resistente e notevolmente più duttile che gli altri. I significati dei simboli e le abbreviazioni adoperate nel descrivere i trattamenti sono indicati nella tabella a p. 392. Il trattamento "h" è indicato con "Same, Tp 650° Q_w." Il "Same" (lo stesso) si riferisce al trattamento precedente, e cioè alla condizione prima del rinvenimento, che è N 820°. L'intero trattamento perciò è normalizzato a 820° (e cioè raffreddato in aria calma a partire da 820°C), quindi rinvenuto a 650° e temprato in acqua. Gli altri trattamenti che danno resilienza elevata sono "1000° Q_o Tp 670°/120 Q_w" (e cioè temprato in olio a partire da 1000°C, rinvenuto a 670° per 120 min, e temprato in acqua; "1000° Q_o Tp 650°/120 C_s 650° Q_w" (cioè temprato in olio a partire da 1000°C, rinvenuto a 650° per 120 min, raffreddato lentamente, rinvenuto di nuovo a 650°C e temprato in acqua; e "850° Q_o Tp 675°/495 Q_w" (cioè temprato in olio a partire da 850°C, rinvenuto a 675° per 495 min, e temprato in acqua). Questi trattamenti danno tutti quasi le stesse buone proprietà e mostrano così la necessità di una tempra finale in acqua a partire da 650–675°C. Se si considerano alcuni altri trattamenti, si vede che il raffreddamento lento a partire da questa temperatura dà valori di resilienza decisamente inferiori, anche se non influenza molto i valori del carico di rottura. La tempra a partire da temperature più basse dà proprietà tensorie migliori, ma valori di resilienza più bassi. L'esame dei valori ottenuti per questi trattamenti e per altri per i quali non sono dati valori Izod, mostra che il trattamento "h" dà l'optimum dei valori desiderati.

for which no Izod values are given, show that treatment "h" gives the optimum desired values.

II. Name of Alloy Is Known, Its Composition and Properties Are Desired

Refer to the Finding Index, p. 370. The first column of this index contains the Index Numbers by which commercial alloys are identified when their properties occur in the tables. The second column contains 1510 trade names of alloys included in the following classes:

(*a*) Trade mark names of patented alloys, as "Alpax."

(*b*) Trade mark names of alloys no longer protected by patent (*cf.* Duralumin in France, where name "Aldal" is used for an alloy of approximately the same composition, the name Duralumin being protected).

(*c*) Names of inventor or manufacturer given to alloys, the names or compositions not necessarily being protected, as Babbitt metal.

(*d*) Names generally applied to certain types of alloys, as Cartridge Brass.

(*e*) Names of types of alloys including a wide range of compositions, as Chrome Nickel steel. In this case, particular alloys of this type may be found from Tables of Alloy Classes, p. 388.

(*f*) Designations of standard or tentative standard alloys, and certain government-specification alloys. These will be found under the alloy type as: Brass ingots, A. S. T. M. Spec. B30–22 or Government Bronze, Spec. G.

No distinction is made in the Finding Index among the first four classes, except that in some cases it has been necessary to identify an alloy, known usually by a number, by adding the manufacturer's name, as in the case of alloy No. 193 of the Driver Harris Co. This is listed under Ferronickel, but cross-reference is given to this and similar alloys under "Numbered Alloys." In other cases the manufacturer is not mentioned.

In class (*d*) no attempt has been made to include all alloys to which usage has given a name, as Spring Steel, Dynamo Sheets, etc., although such alloys are useful for the purpose indicated.

With regard to class (*f*) it should be mentioned that specifications may be drawn up regardless of existing patents and, of course, in ignorance of pending ones.

The names of alloys are arranged alphabetically regardless of type, excepting in the case of: (1) Alloys known by a manufacturer's number. (2) Specification alloys known by number or letter. (3) Alloys, the first part of whose name is descriptive of condition (*e.g.*, hard solder), where there are several such included in one type. Such alloys are listed under the name of the type and where commonly used, cross-references are also given under first part of name.

The third column of the Finding Index gives the compositions of the alloys. In stating the composition, the elements together with their weights % are given in descending order of amounts in the alloy. Where the % of the first, *i.e.*, largest constituent, is not given, it has not been determined by analysis. Where the amounts of the last constituents are not given, they are only incidental or impurities. Where no percentages are given, the information has not been available.

Where the composition of an alloy varies over a range of values, the limits have been stated, as Index No. 915, MS steel: Fe; Cr, 0.8–1.1; Mo, 0.3–0.4; Mn, 0.6–0.9; C, 0.4–0.6.

The fourth column of the Finding Index contains the page numbers where values of properties of the alloy may be found; the page numbers where the values of properties of a similar alloy may be found are indicated by italic type.

The electrical, magnetic and optical properties of metals and alloys will be found in a succeeding volume of I. C. T.; no page reference to such data can therefore be given in the Finding Index.

h, j, k et z, et sont respectivement 8,85, 9,15, 9,0 et 9,0. Parmi ceux-ci, "h" donne une matière un peu plus résistante et considérablement plus ductile que les autres. La signification des symboles et les abréviations utilisées pour spécifier les traitements sont données dans la table à la p. 392. Le traitement "h" représente "Same, Tp 650° Q_w," "Same" (c'est-à-dire le même) se rapporte au traitement antérieur, c'est-à-dire, à la condition avant le revenu, qui est N 820°. L'interprétation de tout le traitement est la suivante: Normalisé à 820° (c'est à dire refroidi dans l'air calme à partir de 820°C), ensuite revenu à 650° puis trempé à l'eau. Les autres traitements qui donnent une grande résistance au choc sont: "1000° Q_o Tp 670°/120 Q_w" (c'est à dire, trempé à l'huile à partir de 1000°C, revenu à 670° pendant 120 minutes, refroidi doucement, de nouveau revenu à 650°C et trempé à l'eau); et "850° Q_o Tp 675°/495 Q_w" (c'est-à-dire trempé à l'huile à partir de 850°C, revenu à 675°C pendant 495 min. et trempé à l'eau). Ces traitements donnent tous à peu près d'aussi bonnes propriétés montrant ainsi la nécessité d'une trempe à l'eau finale à partir de 650–675°C. L'examen de quelques autres traitements montre que le refroidissement lent à partir de cette température donne décidément des chiffres inférieurs à l'essai de choc sur éprouvette entaillée tout en n'affectant pas beaucoup les valeurs de traction. Une trempe à partir de températures plus basses donne des meilleures propriétés à la traction, mais des chiffres inférieurs à l'essai de choc sur éprouvette entaillée. L'examen des valeurs obtenues sur les autres machines pour ces traitements et pour d'autres pour lesquels il n'a pas été donné de valeurs Izod montre que le traitement "h" donne l'optimum désiré.

II. Le nom de l'alliage est connu; on désire connaître sa composition et ses propriétés

Consulter l'index de recherche, p. 370. La première colonne de cet index contient les nombres index au moyen desquels les alliages commerciaux sont identifiés lorsque leurs propriétés sont mentionnées dans les tables. La deuxième colonne contient 1510 noms commerciaux des alliages compris dans les classes suivantes:

(*a*) Noms commerciaux d'alliages brevetés, comme "Alpax."

(*b*) Noms commerciaux d'alliages dont le brevet est expiré; (par exemple: Duralumin en France, où le nom "Aldal" est utilisé pour un alliage ayant approximativement la même composition, le nom Duralumin étant déposé).

(*c*) Noms de l'inventeur ou du fabricant donnés aux alliages, les noms ou les compositions n'étant pas nécessairement déposés, comme métal "Babbitt."

(*d*) Noms généralement employés pour désigner certains types d'alliages, comme "Cartridge brass," laiton pour cartouches.

(*e*) Noms de types d'alliages comportant un large intervalle de composition, comme acier en chrome nickel. Dans ce cas on peut trouver des alliages particuliers de ce type dans les "Tables of Alloy Classes," p. 388.

(*f*) Désignation d'alliages standards ou alliages standards tentatifs et certains alliages suivant spécifications gouvernementales. Ceux-ci seront trouvés sous le type d'alliage comme par exemple: Brass ingots (laiton en lingots), A. S. T. M. Spec. B30–22 ou Bronze du Gouvernement, Spec. G.

Il n'a pas été fait de distinction dans l'index de recherche pour les quatre premières classes, excepté dans quelques cas où il a été nécessaire pour identifier un alliage connu ordinairement par un nombre, d'ajouter le nom du fabricant comme dans le cas de l'alliage N° 193 de la Driver Harris Co. Celui-ci est inscrit sous ferronickel, mais il y a une référence pour cet alliage et pour les alliages similaires sous "Numbered Alloys." Dans d'autres cas le fabricant n'est pas mentionné.

Dans la classe (*d*) on n'a pas cherché à inclure tous les alliages auxquels l'usage a donné un nom, tels que acier à ressorts, tôles gende Basis zum Vergleich der Ergebnisse bei verschiedenen Typen der Proben vorhanden sind. Der höchste Izod-Wert für No. 262 ergibt sich für die Behandlung h, j, k und z, und beträgt der Reihe nach 8,85, 9,15, 9,0 und 9,0. Von diesen gibt "h" ein Material höherer Zugfestigkeit und ein deutlich duktileres Material als die anderen. Erklärungen der Zeichen und die Behandlung betreffenden Abkürzungen sind in der Tabelle S. 392 angegeben. Die Behandlung "h" ist durch "Same, Tp 650° Q_w" in den Tafeln ausgedrückt. "Same" zeigt vorhergegangene Behandlung an, d. h. Zustand vor der Anlassung, welche "N 820°" ist. Die ganze Behandlung ist angezeigt: Normalisiert bei 820° (d. h. gekühlt in ruhender Luft von 820° herunter), dann bei 650°C angelassen und in Wasser abgeschreckt. Die anderen Behandlungen, welche eine sehr grosse Schlagfestigkeit geben, sind: 1000° Q_o Tp 670°/120 Q_w (d. h. bei 1000° in Öl abgeschreckt bei 670°, 120 Minuten lang angelassen und in Wasser abgeschreckt); "1000° Q_o Tp 650°/120 C_s 650° Q_w" (bei 1000° in Öl abgeschreckt, für 120 Minuten lang bei 650° angelassen, langsam gekühlt, nochmals bei 650° angelassen und in Wasser abgeschreckt); ferner "850° Q_o Tp 675°/495 Q_w" (d. h. bei 850° in Öl abgeschreckt, 495 Minuten lang bei 675° angelassen, und in Wasser abgeschreckt). Diese Behandlungen geben ungefähr gleich gute Eigenschaften und zeigen die Notwendigkeit einer am Schlusse vorgenommen Wasserabschreckung von 650–675°. Die Betrachtung einiger anderer Behandlungen zeigt, dass eine langsame Kühlung von dieser Temperatur herunter entschieden niedrigere Werte für die Schlagfestigkeit gibt, während die Zugfestigkeit und Duktilität nicht stark beeinflusst wird. Abschreckung bei tieferen Temperaturen gibt bessere Zugfestigkeit und Duktilität, aber niedrigere Werte für die Schlagfestigkeit. Eine Durchsicht der Werte die mit anderen Maschinen erhalten werden, zeigt für diese Behandlungen und andere, für welche keine Izod-Werte gegeben sind, dass die "h" Behandlung das Optimum der gewünschten Eigenschaft gibt.

II. Der Name der Legierung ist bekannt, es sind ihre Zusammensetzung und Eigenschaften zu ermitteln

Siehe im Nachschlage-Index S. 370 nach. Die erste Kolonne in diesem enthält die Index-Zahl, durch welche Handelslegierungen bezeichnet sind, wenn ihre Eigenschaften in den Tabellen vorkommen. Die zweite Kolonne enthält 1510 Handelsnamen von Legierungen die in folgende Klassen eingeteilt sind.

(*a*) Handelsmarken patentierter Legierungen, wie z. B. "Alpax."

(*b*) Handelsmarken von Legierungen, nicht mehr unter Patentschutz stehend (*vgl.* Duralumin in Frankreich, wo der Name "Aldal" für eine Legierung von ungefähr derselben Zusammensetzung benützt wird, da der Name Duralumin geschützt ist).

(*c*) Die Legierung trägt den Namen des Erfinders oder des Erzeugers. Der Name selbst braucht nicht notwendig geschützt zu sein; z. B. Babbitt-Metall.

(*d*) Namen die im allgemeinen gewissen Legierungstypen gegeben werden; z. B. "Cartridge brass," Patronen-Messing.

(*e*) Namen von Legierungen deren Zusammensetzung in weitem Ausmasse varieren kann, z. B. Chrom-Nickel Stahl. In solchem Fall, die besondere Legierung dieser Type in "Tables of Alloy Classes," S. 388 zu finden ist.

(*f*) Als Standards bestimmte Legierungen oder solche als Prüfungs-Standard geltende, ferner gewisse staatlich vorgeschriebene Legierungen. Diese werden unter folgenden Legierungstypen gefunden: Brass ingots, A. S. T. M. Spec. B30–22 Government Bronze, Spec. G.

Es ist in den ersten vier Klassen kein Unterschied im Nachschlage-Index gemacht, ausgenommen, dass es in manchen Fällen notwendig war eine, sonst nur durch eine Zahl bekannte Legierung durch Hinzufügung des Namens des Fabrikants näher zu bezeichnen, z. B. bei der Legierung No. 193 der Driver

II. Si suppone noto il nome della lega e si desidera conoscerne la composizione e le proprieta

Si consulti l'indice di ricerca a pag. 370. La prima colonna contiene i numeri indici con cui sono indicate le leghe commerciali, e la seconda 1510 nomi commerciali di leghe suddivisi nelle classi seguenti:

(*a*) Nomi commerciali di leghe brevettate, come "Alpax."

(*b*) Nomi commerciali di leghe non più protette da brevetti (ad es. in Francia si usa il nome "Aldal" per una lega che ha approssimativamente la stessa composizione del duralluminio, essendo il nome duralluminio protetto da brevetto).

(*c*) Nomi di inventori o fabbricanti dati alle leghe. I nomi o le composizioni non sempre sono protette da brevetti, come ad es. nel caso del metallo "Babbitt."

(*d*) Nomi generalmente applicati a certi tipi di leghe, come ad es. "Cartridge brass," ottone per cartucce.

(*e*) Nomi di tipi di leghe che possono avere composizioni oscillanti entro limiti larghi, come ad es. acciai al cromo-nichel. In questi casi, si possono trovare leghe particolari di detto tipo nelle "Tables of Alloy Classes," p. 388.

(*f*) Indicazioni di leghe standard, o tentativi standard, e di certe leghe con le caratteristiche richieste da amministrazioni governative. Queste si troveranno riportate sotto i tipi di leghe come: Brass ingots (lingotti di ottone), A. S. T. M. Spec. B30–22, oppure bronzo secondo le prescrizioni governative, Spec. 9.

Nessuna distinzione è fatta nell'indice tra le prime quattro classi eccetto che in alcuni casi è stato necessario aggiungere, al numero che ordinariamente contradistingue una lega, il nome del fabbricante, come nel caso della lega N° 193 della Driver Harris Co. Questa è elencata tra i ferro-nichel, ma sotto "Numbered Alloys" vi è un rapporto a questa ed a leghe simili al N°. 193. In altri caso non è fatta menzione del fabbricante.

Nella classe (*d*) non si è tentato di comprendervi tutte le leghe alle quali l'uso ha dato un nome, come acciaio per molle, lamierini per dinamo, ecc., sebbene dette leghe siano utili per gli scopi indicati.

Riguardo alla classe (*f*) deve ricordarsi che determinate caratteristiche possono ottenerdi indipendentemente dal brevetti esistenti e, naturalmente, nell'ignoranza di eventuali in corso.

I nomi delle leghe sono disposti per ordine alfabetico senza tener conto del loro tipo tranne il caso di: (1) Leghe indicate con il numero di un fabbricante. (2) Leghe speciali note con un numero o una lettera. (3) Leghe di cui la prima parte del nome ne descrive la natura (per es. "hard solder," saldatura forte) quando ve ne sono parecchie comprese in uno stesso tipo. Tali leghe sono elencate sotto il nome del tipo, e, quando esse sono comunemente adoperate, si trovano riportate indicazioni anche sotto la prima parte del nome.

La terza colonna dell'indice dà le composizioni delle leghe. Nell'indicare la composizione, gli elementi e le rispettive percentuali sono date in ordine decrescente del contenuto nella lega. Quando il percento del primo costituente, e cioè quello più abbondante, non è indicato, significa che esso non è stato determinato con l'analisi. Quando le proporzioni degli ultimi componenti non sono indicate, essi sono soltanto costituenti accidentali o impurezze. Se le percentuali non sono riportate, significa che non si è potuto avere l'informazione relativa.

Quando la composizione di una lega può assumere tutta una serie di valori, sono stati indicati i limiti entro i quali i valori possono oscillare, come per es. per Index No. 915, MS steel: Fe; Cr, 0,8–1,1; Mo, 0,3–0, 4; Mn, 0,6–0,9; C, 0,4–0,6.

Nella quarta colonna dell'indice sono indicate le pagine dove si possono trovare valori delle proprietà della lega (in caratteri romani) oppure dove si possono trovare i valori delle proprietà di una lega simile (in corsivo).

No data on resistance to corrosion are included in these tables. In the opinion of the most competent experts on the subject, it is not possible to give quantitative data for the corrosion resistance of metals and alloys. No page references can therefore be given in regard even to certain alloys which are chiefly valued on account of their resistance to corrosion. These, however, are listed in the tables of alloy types.

The sources of information for the Finding Index have been as follows: William Campbell's List of Names of Alloys, prepared for Committee B-2 of the A. S. T. M.; names and compositions given by the co-operating experts; and current metallurgical and technological literature.

III. It Is Desired to Find an Alloy Having Certain Desired Properties

For this purpose consult the Table of Properties on p. 610, directions being given there.

de dynamo, etc., quoique de tels alliages soient utiles pour le but indiqué.

En ce qui concerne la classe (*f*), il faut mentionner que des spécifications peuvent être rédigées sans tenir compte des patentes existantes et naturellement aussi dans l'ignorance des brevets demandés.

Les noms des alliages sont disposés dans l'ordre alphabétique sans tenir compte de leur type, excepté dans les cas suivants: (1) Alliages connus par un numéro de fabrique. (2) Certains alliages connus par un nombre ou une lettre. (3) Alliages dont la première partie de leurs noms est descriptive de la condition (par ex. "hard solder," soudure dure) et où il existe plusieurs variétés incluses dans un type. De tels alliages sont inscrits sous le nom du type et lorsqu'ils sont d'un usage commun, sont aussi mentionnés dans l'index par la première partie de leur nom.

La troisième colonne de l'index de recherche donne les compositions des alliages. En établissant la composition, on a inscrit les éléments avec leurs poids en % successivement dans l'ordre des proportions décroissantes dans l'alliage. Lorsque le pourcent du premier, c'est-à-dire le constituant principal, n'est pas donné, c'est qu'il n'a pas été déterminé par l'analyse. Lorsque les proportions des derniers constituants ne sont pas mentionnés, ceux-ci ne sont qu'accessoires ou bien sont des impuretés. Lorsqu'aucun pourcentage n'est donné, c'est que l'information n'a pas été disponible.

Lorsque la composition d'un alliage varie suivant un intervalle de valeurs, les limites ont été fixées: par ex. Index No. 915, MS steel: Fe; Cr, 0,8–1,1; Mo, 0,3–0,4; Mn, 0,6–0,9; C, 0,4–0,6.

La quatrième colonne de l'index de recherche contient en caractères romains les numéros des pages où l'on peut trouver les propriétés de l'alliage, ou en italique les numéros des pages, où l'on peut trouver les valeurs des propriétés d'un alliage similaire.

On trouvera les propriétés électriques, magnétiques et optiques des métaux et alliages dans un volume suivant des T. C. I.; on ne peut donc donner aucune page de référence pour de telles données dans l'index de recherche.

On ne trouvera dans ces tables aucune donnée relative à la résistance à la corrosion. D'après l'opinion des experts les plus compétents sur ce sujet, il n'est pas possible de donner des valeurs quantitatives pour la résistance à la corrosion des métaux et alliages. On ne peut donc donner aucune référence en ce qui concerne même certains alliages dont la valeur est surtout due à leur résistance à la corrosion. Ceux-ci, cependant sont mentionnés dans les tables des types d'alliages.

Les sources d'information pour l'index de recherche ont été les suivantes: List of Names of Alloys établie par William Campbell préparée pour le Comité B-2 de l'A. S. T. M.; noms et compositions données par les experts coopérants; et la littérature métallurgique et technologique courante.

III. On désire trouver un alliage ayant certaines propriétés désirées

Pour cela, consulter la Table des Propriétés à la p. 610, où les instructions sont données.

Harris Co. Sie ist unter Ferronickel mit einem entsprechenden Hinweis angeführt, der dieser und ähnlichen Legierungen unter "Numbered Alloys" beigefügt wird.

Zu (*d*). Es ist nicht die Absicht gewesen, alle solche Legierungen hier zu vereinigen denen der Gebrauch besondere Namen, wie Feder-Stahl, Dynamo-Lamellen, u. s. w., beigelegt hat, obgleich diese Legierungen für die angezeigte Verwendung nützlich sind.

Hinsichtlich (*f*) wäre zu bemerken, dass die Vorschriften ohne Rücksicht auf vorhandene und in Unkenntnis angemeldeter Patente, niedergeschrieben werden können.

Die Namen der Legierungen sind in alphabetischer Reihenfolge ohne Rücksicht auf die Type angeordnet. Ausgenommen: (1) Die Legierung hat die Nummer eines Erzeugers. (2) Besondere Legierungen die durch eine Zahl oder Buchstaben kenntlich gemacht sind. (3) Legierungen in deren Namen der erste Teil ihre Natur beschreibt (z. B. "hard solder," hart Lot). Es sind dann mehrere in einer Type vereinigt. Solche Legierungen sind unter dem Namen der Type angeführt unter welcher sie gewöhnlich gebraucht werden. Unter dem ersten Teil der Namen sind Hinweisdaten gegeben.

Die dritte Kolonne des Nachschlage-Index enthält die Zusammensetzung der Legierungen. Die Elemente, welche die Zusammensetzung ausdrücken sind zusammen mit ihrem Prozentgehalt absteigend nach diesem, angeordnet. Ist der Prozentgehalt des Hauptbestandteiles nicht angegeben, so ist er analytisch nicht bestimmt. Sind die Mengen des letzten Bestandteiles nicht angegeben, so ist dieser nur zufällig vorhanden oder nur Verunreinigung. Fehlen der Prozentzahlen bedeutet, dass keine diesbezügliche Angaben erreichbar waren.

Ändert sich die Zusammensetzung einer Legierung innerhalb einer Grenze, so werden nur die Grenzwerte angegeben, z. B. Index No. 915, MS steel: Fe; Cr, 0,8–1,1; Mo, 0,3–0,4; Mn, 0,6–0,9; C, 0,4–0,6.

Die vierte Kolonne des Nachschlage-Index enthält die Seitenzahlen, wo die Werte für die Eigenschaften gefunden werden können. Die Eigenschaften ähnlicher Legierungen sind auf den kursiv gedruckten Seitenzahlen zu finden.

Die elektrischen, magnetischen und optischen Eigenschaften der Metalle und Legierungen sind Gegenstand späterer Bände der I. C. T. Aus diesem Grunde sind keine diesbezügliche Hinweise im Nachschlage-Index angegeben.

In den Tafeln finden sich keine Angaben über Korrosion. Nach der Meinung massgebender Fachleute ist es nicht möglich quantitative Angaben über den Widerstand gegen Korrosion zu machen. Es sind daher diesbezüglich keine Angaben vorhanden, selbst in Hinblick auf gewisse Legierungen die gerade wegen ihres Widerstandes gegen Korrosion besonders geschätzt werden. Sie sind aber unter den Legierungstypen zu finden.

Für den Nachschlage-Index sind folgende Quellen massgebend gewesen: William Campbell's List of Names of Alloys, prepared for Committee B-2 of the A. S. T. M.; Namen und Zusammensetzung wie sie von den Mitarbeitern (Experten) angegeben worden sind; die vorhandene metallurgische und technologische Literatur.

III. Es ist eine Legierung mit gewünschten Eigenschaften aufzufinden

Zu diesem Zwecke benütze man die S. 610 vorhandenen Eigenschaftstafeln, wo weitere Richtlinien gegeben sind.

Le proprietà elettriche, magnetiche e ottiche dei metalli e delle leghe si troveranno in un volume successivo delle I. C. T.; non è possibile perciò fare richiami a questi valori nell'indice.

Dati sulla resistenza alla corrosione non sono inclusi nelle tabelle, giacchè, secondo i maggiori conoscitori dell'argomento, non è possibile indicare con dati quantitativi la resistenza alla corrosione. Valori numerici non sono perciò riportati neppure per certe leghe che sono sopratutto apprezzate per la loro resistenza alla corrosione. Esse tuttavia sono elencate nelle tabelle dei tipi di leghe.

Le fonti per la compilazione dell'indice sono state: William Campbell's List of Names of Alloys, preparato per il Comitato B-2 della A. S. T. M.; nomi e composizioni fornite dai collaboratori; la letteratura tecnologica e metallurgica corrente.

III. Si desideri trovare una lega che abbia certe proprietà

A questo scopo si consulti la tabella delle proprietà a p. 610 dove si troveranno indicazioni in proposito.

DEFINITIONS

1. Proportional Limit.—Stress at which the deformation ceases to be proportional to the load as determined by strainometer (extensometer for tension, compressometer for compression, and deflectometer for transverse tests, value being read from plotted results).

2. Elastic Limit.—In tensile and compressive tests: The stress at which the initial permanent elongation or shortening of the gage length occurs, as shown by an instrument of high precision (determined from set readings with extensometer or compressometer). In transverse tests: The extreme fiber stress at which the initial appreciable permanent deflection occurs as determined with deflectometer.

Tests are rarely made to determine the elastic limit, since such tests involve repeated application and release of load, and require considerable time. For practical purposes the elastic limit may be regarded as equal to the proportional limit.

3. Yield Point.—Stress at which marked increase in deformation of specimen occurs without increase in load as determined usually by drop of beam or with dividers for tensile, compressive, or transverse tests.

4. Tensile, Compressive, or Shearing Strength (Ultimate).—Maximum stress to which the test specimen is subjected by slowly increased load until rupture, divided by the original cross-sectional area of the test specimen.

5. Modulus of Rupture.—Maximum stress in the extreme fiber of a specimen tested to rupture, as computed by the empirical application of the flexural formula to stresses above the transverse proportional limit. For simple rectangular test piece with concentrated center load, it equals

$$\frac{1.5 \times \text{load} \times \text{span}}{\text{area} \times \text{depth}}$$

6. Torsional Strength (or **Modulus of Rupture in Torsion**).—Maximum stress in the extreme fiber of a specimen tested to rupture as computed by the empirical application of the torsional formula to stresses above the torsional proportional limit. For a round specimen it is

$$S = \frac{5.1 \times \text{twisting moment}}{\text{diameter}^3}$$

In ductile materials the stress at rupture may be considered uniformly distributed over the cross-sectional area and the above formula assumes the form

$$S = \frac{3.82 \times \text{twisting moment}}{\text{diameter}^3}$$

7. Elongation.—The percentage of elongation is found by dividing 100 × the increase of length after rupture by the original gage length. The percentage of elongation depends on the gage length. The elongation indicates the ductility of the material.

8. Reduction of Area.—The percentage of reduction is found as the ratio of 100 × the difference between the original and broken area of cross section to the original area. Reduction of area indicates generally the ductility of material.

9. Poisson's Ratio.—The ratio of lateral contraction per unit of diameter to longitudinal extension per unit of length of a bar under terminal tension within the elastic limit of material.

DEFINITIONS

1. Limite de proportionnalité.—C'est la tension pour laquelle la déformation cesse d'être proportionnelle à la charge, cette tension étant déterminée à l'aide d'un appareil approprié: extensomètre pour la traction, compressomètre pour la compression, et déflectomètre pour les essais de flexion, la valeur de cette tension étant déduite d'une courbe tracée par points.

2. Limite d'élasticité.—Pour les essais de traction et de compression: c'est la plus petite tension pour laquelle la déformation permanente de la longueur entre repères devient appréciable au moyen d'un instrument de haute précision (cette tension étant déterminée au moyen des lectures effectuées à l'aide de l'extensomètre ou du compressomètre). Pour les essais de flexion: c'est la plus petite tension de la fibre extrême, pour laquelle la déformation permanente devient appréciable au moyen du déflectomètre.

Comme la détermination de la limite d'élasticité implique une succession de mises en charge et de décharges de l'éprouvette, et demande un temps considérable, ces essais sont rarement effectués. Dans la pratique on peut considérer la limite d'élasticité comme étant égale à la limite de proportionnalité.

3. Limite d'étirage.—C'est la tension pour laquelle se produit une augmentation importante de la déformation de l'éprouvette sans augmentation de la charge, cette détermination étant faite ordinairement par la chute de l'aiguille ou au compas pour les essais de traction, compression et flexion. (Limite élastique apparente.)

4. Résistance à la traction, à la compression; Résistance au cisaillement.—C'est l'effort maximum auquel l'éprouvette est soumise, par l'augmentation lente et progressive de la charge, jusqu'à rupture, divisé par la section transversale initiale de l'éprouvette.

5. Module de rupture.—C'est la tension maximum de la fibre extrême d'une éprouvette essayée jusqu'à rupture, ainsi qu'elle est calculée par l'application empirique de la formule de flexion, à une tension supérieure à la limite de proportionnalité de la flexion. Pour une éprouvette simple de section rectangulaire, avec une charge concentrée au milieu de la portée, elle est égale à:

$$1{,}5 \times \text{charge} \times \text{portée}/\text{section} \times \text{hauteur de la pièce}$$

6. Résistance à la torsion (**ou module de rupture à la torsion**).—C'est la tension maximum de la fibre extrême d'une éprouvette essayée jusqu'à rupture, ainsi qu'elle est calculée par l'application empirique de la formule de torsion à une tension supérieure à la limite de proportionnalité de la torsion. Pour une éprouvette de section circulaire, elle est égale à:

$$S = 5{,}1 \times \text{moment de torsion}/\text{diamètre}^3$$

Pour les matières ductiles, la tension lors de la rupture peut être considérée comme étant répartie uniformément dans la section transversale et la formule ci-dessus prend la forme:

$$S = 3{,}82 \times \text{moment de torsion}/\text{diamètre}^3$$

7. Allongement.—Le pourcentage d'allongement est obtenu en multipliant par 100 le rapport de l'augmentation de la longueur après rupture à la longueur initiale entre repères. Le pourcentage d'allongement dépend de la longueur entre repères. L'allongement donne une mesure de la ductilité de la matière.

8. Striction.—Le pourcentage de striction est le rapport multiplié par 100 de la différence entre la section initiale et la section de rupture à la section initiale. La striction donne généralement une mesure de la ductilité de la matière.

9. Coefficient de Poisson.—C'est le rapport de la contraction transversale (par unité de diamètre) à la dilatation longitudinale

DEFINITIONEN

1. Proportionalitäts-Grenze.—Spannung, bei der die Formänderung aufhört proportional zur Belastung zu verlaufen; sie wird bestimmt durch ein Formänderungsmessinstrument (Dehnungsmesser für Zug, Zusammendrückungsmesser für Druck und Durchbiegungsmesser für Biegeversuche, der Punkt wird aus dem Diagramm ermittelt).

2. Elastizitäts-Grenze.—Bei Zug- und Druckversuchen: Diejenige Spannung bei der die erste bleibende Dehnung oder Verkürzung der Messlänge eintritt, bestimmt durch ein Messinstrument von hoher Präzision (bestimmt aus den Restablesungen am Dehnungs- oder Zusammendrückungsmesser). Bei Biegeversuchen: Die Spannung der äusseren Faser bei der die erste bemerkbar bleibende Durchbiegung eintritt, bestimmt mit dem Durchbiegungsmesser.

Versuche zur Bestimmung der Elastizitäts-Grenze werden selten ausgeführt, da solche Versuche wiederholte Belastung und Entlastung erforderlich machen und beträchtliche Zeit beanspruchen. Für praktische Zwecke kann die Elastizitäts-Grenze als gleichbedeutend mit der Proportionalitäts-Grenze angesehen werden.

3. Streck-Grenze.—Spannung, bei der ein deutliches Anwachsen der Formänderung der Probe eintritt, ohne dass die Belastung steigt, gewöhnlich bestimmt durch Absinken des Lastanzeigers oder an den Formänderungsmasstäben für Zug-, Druck- oder Biegeversuch.

4. Zug-, Druck- oder Scherfestigkeit (Höchstlast).—Grösste Spannung, der die Probe unterworfen ist, bei langsamer Steigerung der Belastung bis zum Bruch, dividiert durch den ursprünglichen Probenquerschnitt.

5. Biegespannung (oder Bruchmodul).—Grösste Spannung in der äusseren Faser einer bis zum Bruch geprüften Probe in der Annahme, dass die empirische Biegeformel für Spannungen oberhalb der Proportionalitäts-Grenze angewendet werden kann. Für Proben mit einfachem rechteckigen Querschnitt und zentrischer Belastung gilt

$$1{,}5 \times \text{Last} \times \text{Stützweite}/\text{Querschnitt} \times \text{Höhe}$$

6. Torsions-Festigkeit (oder Bruchmodul für Torsion).—Grösste Spannung in der äusseren Faser der Probe beim Bruch, unter der Annahme, dass die Torsionsformel auch für Spannungen oberhalb der Proportionalitätsgrenze gilt. Für eine zylindrische Probe ist diese Torsions-Festigkeit

$$S = 5{,}1 \times \text{Drehmoment}/\text{Durchmesser}^3$$

Bei sehr formänderungsfähigen Materialien kann diese Bruchspannung als gleichmässig über den ganzen Querschnitt verteilt angesehen werden, und die obige Formel geht über in die Formel:

$$S = 3{,}82 \times \text{Drehmoment}/\text{Durchmesser}^3$$

7. Bruchdehnung.—Die prozentuale Dehnung wird gefunden, indem man die Längenzunahme nach dem Bruch durch die ursprüngliche Messlänge dividiert und mit 100 multipliziert. Die Bruchdehnung hängt von der Messlänge ab. Die Bruchdehnung ist ein Masstab für die Formänderungsfähigkeit des Materials.

8. Querschnittsverminderung.—Die prozentuale Querschnittsverminderung wird gefunden als das Verhältnis des Unterschiedes zwischen ursprünglichem und Bruchquerschnitt zu dem ursprünglichem Querschnitt multipliziert mit 100. Die Querschnittsverminderung zeigt allgemein die Formänderungsfähigkeit des Materials an.

9. Poisson'sche Konstante.—Das Verhältnis der Querkontraktion eines Stabes bezogen auf die Einheit des Durchmessers zur Längsdehnung, bezogen auf die Einheit der Länge eines

DEFINIZIONI

1. Limite di proporzionalità.—È quel valore della forza applicata dopo il quale le deformazioni cessano di essere proporzionali alla forza stessa. Le deformazioni sono misurate da apposito apparato (estensometro per le prove di trazione, compressometro per le prove di compressione, e deflettometro o flessimetro per le prove alla flessione). I valori vengono desunti da grafici.

2. Limite elastico.—Nelle prove di trazione e compressione. È quel valore della forza al quale corrisponde l'inizio dell'allungamento o del raccorciamento permanente. La deformazione permanente è messa in evidenza da un istrumento di alta precisione, e determinata mediante una serie di letture all'estensometro o compressometro.

Nelle prove di flessione. Quel valore della forza che si ha nella fibra estrema quando si manifesta una deflessione permanente apprezzabile determinata con il flessimetro.

Le prove per determinare il limite di elasticità si eseguono raramente, perchè richiedono ripetute applicazioni ed annullamenti della forza applicata, e quindi molto tempo. Per scopi pratici, si può considerare il limite di elasticità come coincidente con il valore del limite di proporzionalità.

3. Punto di snervamento.—È quel valore della forza in corrispondenza del quale si ha un aumento marcato nella deformazione del provino senza che il carico aumenti. Esso viene determinato osservando il momento in cui l'apparato registratore della forza applicata al provino cade rapidamente, oppure a mezzo di misurazione sul provino calibrato alle prove di trazione, compressione e flessione.

4. Carico di rottura alla trazione, compressione e taglio.—È il valore massimo dello sforzo al quale il provino è soggetto alla rottura, quando lo sforzo viene accresciuto lentamente. Questo valore viene riferito all'area della sezione trasversale primitiva del provino.

5. Modulo di rottura.—Massimo sforzo che si verifica nelle fibre maggiormente sollecitate di un provino che venga provato a flessione fino a rottura. Esso è calcolato con l'applicazione empirica della formula di sollecitazione per flessione, anche quando lo sforzo supera il limite di proporzionalità per sollecitazione della flessione stessa. Per pezzi di forma rettangolare semplice con carico concentrato nel centro, è eguale a:

$$\frac{1{,}5 \times \text{carico} \times \text{distanza tra gli appoggi}}{\text{area} \times \text{spessore}}$$

6. Sforzo di torsione (oppure modulo di rottura alla torsione).—Massimo sforzo che si verifica nelle fibre più sollecitate di un provino provato fino alla rottura, calcolato applicando empiricamente (anche al di sopra del limite di proporzionalità per torsione) la formula che dà la sollecitazione per torsione. Per un provino a sezione rotonda, la formula è:

$$S = \frac{5{,}1 \times \text{momento torcente}}{\text{diametro}^3}$$

Nei materiali duttili lo sforzo di rottura può essere considerato uniformemente distribuito sull'area della sezione trasversale, e la formula (2) diventa:

$$S = \frac{3{,}82 \times \text{momento torcente}}{\text{diametro}^3}$$

7. Allungamento.—L'allungamento percentuale è calcolato dividendo l'aumento di lunghezza dopo rottura per la lunghezza originale calibrata. L'allungamento percentuale dipende dalla lunghezza calibrata, cioè dalla lunghezza alla quale è riferito l'allungamento stesso. Questo allungamento indica la duttilità dei materiali.

10. Modulus of Elasticity (*(a)* **in Tension or** *(b)* **in Compression).**—Ratio of stress within the proportional limit to the corresponding strain as determined with a precise extensometer. Accurate determinations of the modulus of elasticity are made with a gage length at least 8 in. (203.2 mm) in length.

11. Modulus of Elasticity in Shear.—Ratio of stress within the proportional limit to the corresponding angular strain (in radians). The following theoretical relation exists between the modulus of elasticity in shear and the modulus of elasticity:

$$G = \frac{E}{2(1 + \lambda)}$$

where G is the modulus of elasticity in shear, E modulus of elasticity, and λ Poisson's ratio.

It is difficult to make a direct experimental determination of G on account of the presence of other stresses. It is usually determined by the torsion of a round bar.

12. Brinell Hardness Number.—Ratio of load, on a sphere used to indent the material to be tested, to the area of the spherical indentation produced. The standard sphere used is a 10 mm diameter hardened steel ball. The loads are (*a*) 3000 kg (6615 lb.) and (*b*) 500 kg (1102 lb.), and the time of application of load is 30 sec. Values shown in the tables are based on spherical areas computed from measurements of the diameters of the spherical indentations, by the following formula:

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D\left(\frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}\right)}$$

P being load in kg, h being depth of indentation, D being diameter of ball and d being diameter of indentation, all lengths being expressed in millimeters. Brinell hardness values have a certain relation to tensile strength, and hardness determinations may be used to determine tensile strengths approximately by employing the proper conversion factor for the material under consideration.

13. Shore Scleroscope Hardness.—Height of rebound of a diamond-pointed hammer falling on the object from a fixed, stated height through a tube under the acceleration due to its own weight. On very soft materials a "magnifier" hammer is used in place of the commonly used "universal" hammer, and values may be converted to the corresponding "universal" value by multiplying the reading by $4/7$.

14. Erichsen Value.—The test is conducted by supporting the sheet on a circular ring and deforming it at the center of the ring by a spherical-pointed tool. The depth of impression (or cup), in millimeters, required to obtain fracture is the Erichsen value.

15. Bend Test.—(*a*) Angle through which the material can be bent without fracture; or (*b*) the number of bendings around a predetermined diameter; or (*c*) a minimum diameter around which the test piece can be bent through a stated angle.

16. Impact Resistance.—(Bibliography on Impact Testing, Whittemore, *Proc. A. S. T. M.*, 1922.) Indicates the shock-resisting qualities of material. Is of particular value in ascertaining the influence of heat treatment. Impact value depends on the form of the specimen and type of apparatus, both of which must be stated.

(par unité de longueur) d'une barre soumise à une tension inférieure à la limite d'élasticité de la matière.

10. Module d'élasticité (*a*) **de traction,** (*b*) **de compression.**—C'est le rapport de la tension (celle-ci étant inférieure à la limite de proportionnalité) à la dilatation correspondante, cette détermination étant faite au moyen d'un extensomètre de précision. Les déterminations précises du module d'élasticité se font sur une longueur entre repères d'au moins 203,2 mm.

11. Module d'élasticité de glissement.—C'est le rapport de la tension (celle-ci étant inférieure à la limite de proportionnalité) au glissement correspondant (en radians). Il existe entre le module d'élasticité de glissement et le module d'élasticité la relation théorique suivante:

$$G = \frac{E}{2(1 + \lambda)}$$

ou G est le module d'élasticité de glissement, E le module d'élasticité et λ le coefficient de Poisson.

Il est difficile de faire une détermination expérimentale directe de G par le fait de la présence d'autres tensions. G est ordinairement déterminé par la torsion d'une barre de section circulaire.

12. Nombre de dureté Brinell.—C'est le rapport de la charge appliquée sur une bille qui pénètre dans la matière à essayer, à la surface de l'empreinte sphérique produite. La bille type utilisée est une sphère en acier trempé de 10 mm de diamètre. Les charges sont de (*a*) 3000 kg et (*b*) 500 kg et la durée d'application de la charge est de 30 secondes. Les valeurs données dans les tables sont basées sur les surfaces des calottes sphériques calculées d'après les diamètres mesurés des empreintes sphériques produites, par la formule suivante:

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D\left(\frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}\right)}$$

P est la charge en kg, h la profondeur de l'empreinte, D le diamètre de la bille et d le diamètre de l'empreinte, toutes les longueurs étant exprimées en millimètres.

Il y a une certaine relation entre les nombres de dureté Brinell et la résistance de rupture, et des déterminations de dureté peuvent être employées pour déterminer approximativement la résistance de rupture en employant le facteur de conversion relatif à la matière considérée.

13. Dureté au scléroscope de Shore.—C'est la hauteur de rebondissement d'un petit marteau à pointe de diamant tombant sous l'effet de son propre poids sur l'object d'une hauteur fixe définie, en se déplaçant dans un tube. Lorsqu'il s'agit de matières très tendres, on utilise un marteau amplificateur à la place du marteau "universel" généralement employé, et les valeurs peuvent être converties en valeurs "universelles" correspondantes en multipliant la lecture par $4/7$.

14. Nombre d'Erichsen.—On effectue l'essai en supportant la tôle sur une bague circulaire et en la déformant au centre de la bague par un outil à pointe sphérique. Le nombre d'Erichsen est la profondeur de l'empreinte exprimée en millimètres, nécessaire pour produire la rupture.

15. Essai de pliage.—(*a*) C'est l'angle sous lequel la matière peut être pliée sans rupture; ou (*b*) le nombre de pliages successifs autour d'une barre de diamètre prédeterminé; ou (*c*) le diamètre minimum du cylindre autour duquel l'éprouvette peut être pliée sous un angle défini.

16. Résistance au choc.—(Bibliographie concernant l'essai de choc, Whittemore, *Proc. A. S. T. M.*, 1922.) Elle donne une mesure des qualités de résistance de la matière au choc. Elle est d'une importance particulière pour se rendre compte de l'influence d'un traitement thermique. Les valeurs obtenues aux essais de choc dépendent de la forme de l'éprouvette et du type d'appareil employé; ces deux éléments doivent être définis.

Stabes bei bestimmten Zugspannungen innerhalb der Elastizitätsgrenze des betreffenden Materials.

10. Elastizitäts-Modul (*a*) **für Zug oder** (*b*) **für Druck.**—Das Verhältnis der Spannung innerhalb der Proportionalitätsgrenze zur entsprechenden Formänderung, ermittelt durch einen präzisen Dehnungsmesser. Genaue Bestimmungen Elastizitätsmoduls werden ausgeführt mit einer Mindestmesslänge von 203,2 mm.

11. Elastizitäts-Modul bei Scherbeanspruchung.—Verhältnis der Spannung innerhalb der Proportionalitätsgrenze zu der entsprechenden Winkeländerung (in radians). Die folgende theoretische Beziehung besteht zwischen dem Elastizitätsmodul bei Scherbeanspruchung und den Elastizitätsmodul bei Zugbeanspruchung $G = E/2\ (1 + \lambda)$, worin G der Elastizitätsmodul für Scherbeanspruchung, E der Elastizitätsmodul für Zugbeanspruchung und λ die Poisson'sche Konstante ist. Es ist schwer, den Gleitmodul G direkt experimentell zu bestimmen wegen des Vorhandenseins von Nebenspannungen. Gewöhnlich wird er bestimmt durch einen Drehversuch mit einem Rundstab.

12. Brinell Härtezahl.—Das Verhältnis der Last, mit der eine Kugel in das zu prüfende Material eingedrückt wird, zur Fläche des erzeugten Kugeleindruckes. Die gebräuchliche Normalkugel ist eine gehärtete Stahlkugel von 10 mm Durchmesser. Die Kugelbelastungen sind (*a*) 3000 kg (6615 engl. Pfund) und (*b*) 500 kg (1102 engl. Pfund). Die Zeitdauer der Belastung beträgt 30 Sekunden. Die in den Tabellen angegebenen Werte für die Härtezahl werden aus Messungen der Durchmesser der erzeugten Kugeleindrücke unter Verwendung folgender Formel gewonnen:

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D\left(\frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}\right)}$$

Darin bedeuten P die Kugelbelastung in kg, h die Eindrucktiefe in mm, D den Kugeldurchmesser in mm und d den Durchmesser des Eindrucks in mm. Die Brinell-Härtezahlen haben eine gewisse Beziehung zur Zugfestigkeit, Härtebestimmungen können deshalb angewandt werden, um angenähert die Zerreissfestigkeiten zu bestimmen, unter Anwendung eigenen Koeffizienten eines für jedes Material.

13. Shore Skleroskope-Härte.—Die Höhe des Rückpralls eines mit Diamantspitze versehenen Fallhammers, der aus einer bestimmten festgelegten Höhe durch eine Röhre unter Beschleunigung durch sein Eigengewicht auf die Probe fällt. Bei sehr weichen Materialien wird ein Spezialhammer angewandt an Stelle des gewöhnlich benutzten "Universalhammers;" die mit diesem Spezialhammer erzielten Werte können auf den Universalhammer bezogen werden durch Multiplikation der Ablesungen mit $4/7$.

14. Erichsen-Wert.—Der Versuch wird ausgeführt, indem ein Blech am Rande kreisförmig eingespannt und in der Mitte durch einen kugelförmigen Stempel eingedrückt wird. Die Tiefe des Eindrucks (oder der Beule) in mm, die erforderlich ist um Bruch hervorzurufen, ist der Erichsen-Wert.

15. Biegeprobe.—(*a*) Winkel, um den das Material gebogen werden kann ohne zu brechen; oder (*b*) die Zahl der Biegungen um einen bestimmten Durchmesser: oder (*c*) der kleinste Durchmesser, um den die Probe um einen bestimmten Winkel gebogen werden kann.

16. Schlag- oder Stossfestigkeit.—(Bibliography on Impact Testing, Whittemore, *Proc. A. S. T. M.*, 1922.) Gibt die Eigenschaften eines Materials an, Stossbeanspruchungen zu widerstehen und ist von besonderem Wert zur Feststellung des Einflusses von Wärmebehandlung. Der gefundene Schlagfestigkeitswert hängt von der Form der Probe und der Art des Apparates ab, beides muss also festgelegt werden.

17. Widerstand gegen Ermüdung.—Widerstand eines Materials gegen wiederholte, zwischen zwei bestimmten Spannungsgrenzen

8. Riduzione di area.—Percentuale di riduzione di area calcolata come rapporto della differenza tra l'area del provino prima e dopo la rottura (nel punto dove è avvenuta la rottura) e l'area originale. La riduzione di area indica generalmente la duttilità dei materiali.

9. Rapporto di Poisson.—Il rapporto della contrazione laterale per unità di diametro e l'allungamento longitudinale, riferito alla unità di allungamento di una barra sottoposta, nei suoi estremi, a sollecitazioni di tensione entro i limiti di elasticità del materiale.

10. Modulo di elasticità (*a*) **alla trazione,** (*b*) **alla compressione.**—Il rapporto del valore dello sforzo entro i limiti di proporzionalità e le corrispondenti deformazioni determinate con un estensometro molto preciso. Determinazioni accurate del modulo di elasticità sono fatte sopra una lunghezza calibrata del provino di almeno mm 203,2.

11. Modulo di elasticità al taglio.—Rapporto del valore dello sforzo entro i limiti proporzionali corrispondenti alle deformazioni angolari espresse in radianti. La relazione teorica che esiste tra il modulo di elasticità al taglio e il modulo di elasticità è:

$$G = \frac{E}{2(1 + \lambda)}$$

dove G è il modulo di elasticità al taglio, E quello di allungamento e λ il rapporto di Poisson.

È molto difficile eseguire un esperimento per misurare direttamente il valore di G, a causa della presenza di altri sforzi. Generalmente viene determinato eseguendo una prova di torsione sopra una barra rotonda.

12. Numero di durezza Brinell.—Rapporto tra il carico applicato sopra una sfera che penetra nel materiale sottoposto alla prova e l'area della impronta prodotta.

La sfera tipo è del diametro di mm 10 ed è di acciaio temprato. I carichi applicati sono: (*a*) kg 3000: (*b*) kg 500. Il tempo di applicazione del carico è di 30 secondi.

I valori riportati nelle tabelle si riferiscono alla misura dell'area fatta in base al diametro dell'impronta sferica.

$$H_B = \frac{P}{\pi h D} = \frac{P}{\pi D\left(\frac{D}{2} - \sqrt{\frac{D^2}{4} - \frac{d^2}{4}}\right)}$$

dove P è il carico in kg, h la profondità dell'impronta, D il diametro della sfera adoperata e d il diametro della impronta. La durezza Brinell ha una certa relazione col carico di trazione, e le determinazioni della durezza possono servire a determinare appunto i carichi di trazione, in via approssimativa, mediante un fattore di conversione caratteristico per il materiale in esame.

13. Durezza allo scleroscopio di Shore.—Altezza del rimbalzo di un martello munito di una punta di diamante che cade sull'oggetto da una altezza nota e determinata, percorrendo un tubo sotto l'accelerazione dovuta al proprio peso. Per materiali molto teneri si usa un martello "moltiplicatore" invece del martello comune chiamato "universale," ed i valori possono essere convertiti in corrispondenti valori del martello universale moltiplicando la lettura per $4/7$.

14. Valori di Erichsen.—La prova si fa appoggiando il foglio di lamiera contro un anello e deformandolo nel centro a mezzo di un utensile pure sferico. La profondità dell'impressione in mm, che si ha per ottenere la frattura, è il valore di Erichsen.

15. Prove di piegamento.—(*a*) Angolo di cui il materiale può essere piegato senza fratturarsi, oppure: (*b*) numero di piegature attorno ad un predeterminato diametro, oppure: (*c*) diametro minimo attorno al quale il provino può essere piegato percorrendo un determinato angolo.

16. Resistenza all'urto.—(Bibliography on Impact Testing, Whittemore, *Proc. A. S. T. M.*, 1922.) Indica la resistenza del materiale all'urto, ed ha particolare valore per accertare l'influenza dei trattamenti termici. Il valore all'urto dipende dalla forma del provino e dal tipo della macchina, ed entrambi questi elementi devono essere specificati.

17. Fatigue Resistance.—Resistance of material to a load varying continuously and cyclically between two fixed stress values.

Numerical values of Fatigue Resistance for the case of zero mean stress (Reversed Stresses) may be given as follows:

17a. Fatigue Strength.—The numerical values of upper and lower limits of stress cycle which cause failure after a definite number of repetitions.

17b. Endurance Limit.—The value of the upper (or lower) limit of stress cycle which is just insufficient to cause failure after a stated number of repetitions have been endured.

17c. True Endurance Limit.—The limiting value of the endurance limit, *i.e.*, the upper limit of a cycle of stress which can be applied an indefinitely great number of times without causing failure. The true endurance limit can never, of course, be determined experimentally. For many materials, however, it is found that if values of fatigue strength are plotted against the number of cycles N to fracture (logarithmically or semi-logarithmically) the resulting curve tends to become parallel to the N axis, affording strong evidence of the existence of a "true endurance limit."

Numerical values of fatigue resistance for cycles of stress whose mean stress is *not* zero may be given by stating the upper and lower limits of the stress cycles corresponding to 17*a* above, or by stating the value of the mean stress and the range (or semi-range) of the cycle. Consequently, corresponding to the above we shall have:

17d. Fatigue Strength Range.

17e. Endurance Range.

17f. True Endurance Range.

18. Ductility.—The *ductility* is the elongation of the test specimen measured after rupture on a distance distributed symmetrically on both sides of the place of rupture, and should be specified in % of the original length of the distance.

19. Acetyl Value.—Defined as g KOH (56.1) to neutralize the acetic acid from 1000 g acetylated oil (**1, 2, 7**). It gives hydroxy-acids + alcohols + oxidized fatty acids + unknown acids + mono- and di-glycerides + rancidity (**7**).

20. Iodine Value.—Per cent I_2 or its equivalent of other halogen absorbed (**3, 6, 12, 13**). Heat of bromination is proportional to I-value for most non-oxidized oils and fats (**4, 8**).

21. Saponification Value.—Mg KOH for complete saponification of 1 g of the oil, fat or wax. The corresponding mean equivalent weight of the substance is the "saponification equivalent." (**5**) gives a method for cold saponification.

22. Hehner Value.—Per cent insoluble fatty acids + unsaponifiables.

23. Polenske Value.—Proportion of insoluble volatile fatty acids (in terms of cm^3 of 0.1N KOH per 5 g of fat) obtained by Polenske's method of distillation (**10**).

24. Acid Value.—Mg KOH required to neutralize the free fatty acids in 1 g of oil or fat. The free fatty acids are also often expressed as a percentage of the principal fatty acid in the fat. Except in the case of the waxes, this value is not a constant, but varies with the degree of hydrolysis of the fat.

25. Reichert-Meissl Value.—Soluble volatile fatty acids in terms of 0.1N KOH per 5 g fat, under Meissl's test conditions (**9, 11, 14**).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Benedikt and Ulzer, *57*, **8**: 41; 87. (2) Grün, *Oel-Fett Industrie*, **1**: 339, 364; 19. (3) Hanus, *279*, **4**: 913; 01. (4) Hehner and Mitchell, *173*, **20**: 146; 95. (5) Henriques, *92*, **8**: 721; 95. **9**: 221; 96. (6) Hübl, *112*, **253**: 281; 84. (7) Lewkowitch, *173*, **24**: 319; 99. (8) Marden, *45*, **8**: 121; 16. (9) Meissl, *112*, **233**: 229; 79.

(10) Polenske, *279*, **7**: 273; 04. (11) Reichert, *91*, **18**: 68; 79. (12) Waller, *136*, **19**: 1831; 95. (13) Wijs, *25*, **31**: 750; 98. (14) Wollner, *173*, **12**: 203; 87. *352*, **16**: 609; 87.

17. Résistance à la fatigue.—Résistance des matériaux soumis à une sollicitation variant d'une façon continue et périodique entre deux valeurs fixes.

Les valeurs numériques de la résistance à la fatigue pour le cas d'un effort moyen nul (efforts alternatifs) peuvent être données comme suit:

17a. Résistance à la fatigue.—Ce sont les valeurs numériques des limites supérieures et inférieures du cycle de tension qui produisent la rupture après un nombre défini de répétitions de l'effort.

17b. Limite d'endurance.—C'est la valeur de la limite supérieure (ou inférieure) du cycle de tension qui est juste insuffisante pour produire la rupture après un nombre défini de répétitions de l'effort.

17c. Limite d'endurance vraie.—C'est la valeur limite de la limite d'endurance, c'est-à-dire la limite supérieure d'un cycle de tension, qui peut être appliqué un nombre indéfini de fois sans produire la rupture. La limite d'endurance vraie ne peut naturellement jamais être déterminée expérimentalement.

Cependant, pour plusieurs matériaux, on a constaté que si l'on représente graphiquement les valeurs de la résistance à la fatigue en fonction du nombre de cycles N jusqu'à rupture (logarithmiquement ou semi-logarithmiquement), la courbe qui en résulte tend à devenir parallèle à l'axe des N, mettant ainsi bien en évidence l'existence d'une "limite d'endurance vraie."

Les valeurs numériques de la résistance à la fatigue pour des cycles de tension dont la valeur moyenne *n'est pas* zéro, peuvent être obtenues en fixant la limite supérieure et la limite inférieure des cycles de tension correspondant à 17*a* ci-dessus, ou en fixant la valeur de la tension moyenne et l'amplitude (ou demi amplitude) du cycle. Par conséquent, correspondant à ce que nous avons ci-dessus, nous aurons:

17d. Amplitude de la résistance à la fatigue.

17e. Amplitude d'endurance.

17f. Amplitude d'endurance vraie.

18. Ductilité.—*La ductilité* est l'allongement d'une éprouvette essayée, mesuré après rupture sur une distance répartie symétriquement de part et d'autre de la section de rupture. Elle doit être exprimée en % de la longueur initiale entre repères.

19. Indice d'acétyle.—Il est défini par le nombre de g de KOH (56,1) nécessaires pour neutraliser l'acide acétique de 1000 g d'huile acétylée (**1, 2, 7**). Il donne les hydroxyacides + alcools + les acides gras oxydés + acides inconnus + mono et diglycérides + rancidité.

20. Indice d'iode.—Pourcentage de I_2 ou son équivalent d'un autre halogène absorbé (**3, 6, 12, 13**). La chaleur de bromuration est proportionnelle á l'indice d'iode pour la plupart des huiles et graisses non oxydées (**4, 8**).

21. Indice de saponification.—Mg KOH pour la saponification complète de 1 g d'huile, graisse ou cire. Le poids équivalent moyen correspondant à la substance est "l'équivalent de saponification." (**5**) donne une méthode pour la saponification à froid.

22. Indice de Hehner.—Pourcent d'acides gras insolubles + insaponifiables.

23. Indice de Polenske.—Proportion d'acides gras volatils insolubles (exprimés en cm^3 de 0,1N KOH pour 5 g de graisse) obtenue par la méthode de distillation de Polenske (**10**).

24. Indice d'acide.—Mg KOH nécessaires pour neutraliser les acides libres contenus dans 1 g d'huile ou de graisse. On exprime aussi souvent les acides gras libres en pourcent des acides gras principaux contenus dans la graisse. Excepté dans le cas des cires, cette valeur n'est pas une constante, mais elle varie avec le degré d'hydrolyse de la graisse.

25. Indice de Reichert-Meissl.—Acides gras volatils, solubles exprimés en 0.1N KOH pour 5 g de graisse, suivant les conditions de l'essai de Meissl (**9, 11, 14**).

schwingenden Beanspruchungen. Zahlenmässige Werte für den Ermüdungswiderstand können für den Fall, dass der Spannungsmittelwert Null ist (vollkommene Umkehrung der Spannung nach Richtung und Grösse) folgendermassen ausgedrückt werden:

17a. Ermüdungsfestigkeit.—Die zahlenmässigen Werte der oberen und unteren Grenzen des Spannungswechsels, welche nach einer bestimmten Anzahl von Wiederholungen Bruch hervorrufen.

17b. Dauerbruchgrenze.—Der Wert der oberen (od. unteren) Grenze des Spannungswechsels, welcher gerade noch nicht ausreicht, um den Bruch nach einer bestimmten Zahl von der Probe erlittener Lastwechsel hervorzurufen.

17c. Wahre Dauerbruchgrenze.—Der Grenzwert der Ermüdungsgrenze, d.h., die obere Grenze eines Spannungswechsels, welcher unbegrenzt häufig—ohne Bruch zu verursachen—angewandt werden kann. Die wahre Dauerbruchgrenze kann selbstverständlich niemals experimentell bestimmt werden. Sie ist jedoch für viele Materialien festgestellt, sobald man die Werte der Ermüdungsfestigkeit in Abhängigkeit von der Zahl der Spannungswechsel N, die zum Bruch führen, logarithmisch (oder für die eine Achse logarithmisch) aufgetragen, darstellt, die sich ergebende Kurve parallel zur N-Achse zu verlaufen strebt und damit einen sicheren Anhalt für das Vorhandensein einer "wahren Dauerbruchgrenze" bietet. Zahlenmässige Werte des Widerstandes gegen Ermüdung für Lastwechselfolgen, deren Spannungsmittelwerte nicht Null sind, können wiedergegeben werden durch Angabe der oberen und unteren Grenzen des Spannungswechsels, entsprechend 17*a* oder durch Angabe des Spannungsmittelwertes und der ganzen (oder halben) Amplitude. Entsprechend obigem, kann man demnach setzen:

17d. Ermüdungsfestigkeit für bestimmte Spannungswechsel.

17e. Dauerbruchfestigkeit für bestimmte Spannungswechsel.

17f. Wahre Dauerbruchfestigkeit für bestimmte Spannungswechsel.

18. Formänderungsfähigkeit.—Die Formänderungsfähigkeit ist die Verlängerung des Probestabes, gemessen nach dem Bruch auf eine Länge, die symmetrisch zu beiden Seiten der Bruchstelle verteilt ist. Sie ist in Prozenten der ursprünglichen Messlänge anzugeben.

19. Acetyl-Zahl.—Gibt die Gramme KOH (56,1) an, die für die Neutralisation der Essigsäure in 1000 g des acetylierten Öles notwendig sind (1, 2, 7). Damit sind bestimmt: Oxysäuren + Alkohole + oxydierte Fettsäuren + unbekannte Säuren + Mono und Diglyceride + Ranzigkeit (7).

20. Jod-Zahl.—Ist durch Prozente Jod bestimmt(Äquivalent den anderen absorbierbaren Halogenen) (3, 6, 12, 13). Die Bromierungs-Wärme ist proportional der Jod-Zahl bei den meisten nicht oxydierten Fetten (4, 8).

21. Verseifungs-Zahl.—Gibt die mg KOH an die für die vollständige Verseifung von 1 g Fett, Öl, Wachs notwendig sind. Das entsprechende mittlere Äquivalent-Gewicht der Substanz ist das "Verseifungs-Äquivalent." (5) gibt eine Methode für die Verseifung in der Kälte.

22. Hehner'sche-Zahl.—Ist Prozente unlösliche Fettsäuren + Unverseifbares.

23. Polenske-Zahl.—Gibt die Anzahl cm^3 0.1N KOH an die nötig sind, um die flüchtigen unlöslichen Fettsäuren für 5 g Fett zu neutralisieren, die entsprechend der Destillationsmethode nach Polenske (10) erhalten werden.

24. Säure-Zahl.—Ist die Anzahl mg KOH die für die Neutralisation der freien Fettsäuren von 1 g Öl oder Fett notwendig sind. Die freien Fettsäuren werden öfters in Prozenten der Hauptfettsäure im Fett angegeben. Mit Ausnahme bei den Wachsarten ist diese Zahl nicht konstant und ändert sich mit dem Grade der Hydrolyse des Fettes.

25. Reichert-Meissl'sche-Zahl.—Lösliche flüchtige Fettsäuren ausgedrückt in cm^3 0.1N KOH für 5 g Fett, bestimmt nach dem Vorgange von Meissl (9, 11, 14).

17. Resistenza alla fatica.—Resistenza del materiale sottoposto a sforzi varianti in modo continuo e ciclico tra due valori fissi.

Valori numerici della resistenza alla fatica nel caso di uno sforzo medio eguale a zero (sforzi invertiti) possono essere indicati nella maniera seguente:

17a. Resistenza alla fatica.—I valori numerici dei limiti superiore ed inferiore delle sollecitazioni cicliche che producono rottura dopo un numero definito dei ripetizioni.

17b. Limite di durata.—Valore superiore (o inferiore) della massima sollecitazione ciclica insufficiente a produrre la rottura dopo essere stata applicata un determinato numero di volte.

17c. Limite vero (o pratico) di durata.—Valore limite del limite di durata, cioè valore superiore della massima sollecitazione ciclica che può essere applicata un gran numero di volte senza produrre rottura. Naturalmente, il vero limite di durata non può mai essere determinato sperimentalmente. Tuttavia, per molti materiali si è trovato che, se si riportano in un diagramma i valori della sollecitazione in funzione del numero di cicli N che producono la frattura (logaritmicamente o semilogaritmicamente) la curva risultante tende a divenire parallela all'asse N mostrando all' evidenza che esiste un "vero limite di durata."

Valori numerici di resistenza alla fatica per sollecitazioni cicliche nelle quali i valori medi delle sollecitazioni sono diversi a zero possono essere dati stabilendo i limiti superiore ed inferiore dei cicli delle sollecitazioni corrispondenti a 17*a*, oppure stabilendo il valore della sollecitazione media e l'intervallo (o semintervallo) del ciclo. Di conseguenza, d'accordo con quanto sopra si avrà:

17d. Ampiezza delle oscillazioni tra i valori delle sollecitazioni cicliche alla fatica.

17e. Ampiezza od oscillazioni di durata.

17f. Ampiezza od oscillazioni pratiche di durata.

18. Duttilità.—La duttilità è l'allungamento del provino, e viene misurata dopo la rottura sopra una lunghezza distribuita simmetricamente da entrambe le parti del punto di rottura. Essa è specificata in percento della lunghezza originale primitiva.

19. Numero di acetile.—Indica i grammi di KOH (56,1) necessari per neutralizzare l'acido acetico in 1000 g di olio acetilato (1, 2, 7). Esso è in relazione: con gli ossiacidi + gli alcooli + gli acidi grassi ossidati + acidi sconosciuti + mono e digliceridi, + la rancidità (7).

20. Numero di iodio.—Percento di I_2 (o suo equivalente di altri alogeni) fissato (3, 6, 12, 13). Il calore di bromurazione è proporzionale al numero di iodio per la maggior parte degli olii e grassi non ossidati (4, 8).

21. Numero di saponificazione.—Mg di KOH necessari per la completa saponificazione di 1 g di olio, grasso o cera. Il corrispondente peso equivalente medio della sostanza è "l'equivalente di saponificazione." (5) dà un metodo di saponificazione a freddo.

22. Numero di Hehner.—Percento di acidi grassi isolubili + sostanze insaponificabili.

23. Numero di Polenske.—Quantità di acidi grassi volatili insolubili (riferito in cm^3 di KOH 0.1N per 5 g di grasso) ottenuta col metodo di distillazione di Polenske (10).

24. Numero di acidità.—Mg di KOH richiesti per neutralizzare gli acidi grassi liberi di 1 g di olio o grasso. Gli acidi grassi liberi sono spesso riferiti come percentuale dell'acido principale contenuto nel grasso. All'infuori del caso delle cere questo numero non è una costante, ma varia col grado di idrolisi del grasso.

25. Numero di Reichert-Meissl.—Acidi grassi volatili solubili, espressi in cm^3 di KOH 0.1N per 5 g di grasso, ottenuti nelle condizioni di procedimento Meissl (9, 11, 14).

LITERATURE REFERENCES

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In all literature references cited in International Critical Tables the name of the journal or publication is indicated by means of a *Key Number* corresponding to the list given below. The numbers which follow this key number in a literature citation are, in the order named: (1) the volume, (2) the page, and (3) the last two figures of the year. Thus *64V*, **31**: 253; 22, indicates Verslag Koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, page 253, 1922. Series numbers are not given. Key Numbers referring to books and other non-serial publications are preceded by the letter *B*, and the volume number is given in Roman numerals. Thus, *B10*, **IV**: 191; 18 indicates Doelter, Handbuch der Mineralchemie, page 191 of Vol. 4 of the 1918 edition. The Key Number *O* is used to indicate "private communication from."

DAS LITERATURVERZEICHNIS

In allen Literaturstellen, die in I. C. T. verzeichnet sind, ist der Name der Zeitschrift oder der Publikation mit Hilfe einer *Schlüsselnummer*, entsprechend der unten folgenden Liste, angegeben. Die Zahlen, welche diesen Schlüsselnummern bei einem Literaturzitat folgen, bedeuten der Reihe nach: (1) der Band, (2) die Seite und (3), die letzten zwei Zahlen des Jahrganges. So bedeutet z. B. *64V*, **31**: 253; 22, Verslag Koninklijke Akademie van Wetenschappen te Amsterdam, Band 31, Seite 253, 1922. Serien-Nummern werden nicht angegeben. Der Schlüsselzahl wird ein *B* vorausgesetzt, wenn sie Bücher, oder eine andre nicht periodische Veröffentlichung bezeichnet. Die Bandnummer wird durch römische Ziffern angegeben. Es bedeutet z. B. also *B10*, **IV**: 191; 18, Doelter, Handbuch der Mineralchemie, Seite 191, des 4 Bandes, der Auflage des Jahres 1918. Die Schlüsselzahl *O* wird gebraucht, um anzuzeigen, dass es eine "private Mitteilung" ist.

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INDICAZIONI BIBLIOGRAFICHE

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311. France-Belgique. (Revue de l'ingénieur et index technique *merged with this in 1922.*)
312. Mitteilungen aus dem Materialprüfungsamt und dem Kaiser-Wilhelm-Institut für Metallforschung zu Berlin-Dahlem. (Mitteilungen aus dem königlichen technischen Versuchsanstalten zu Berlin, 1883–1903; *in 1904 became* Mitteilungen aus dem königlichen Materialprüfungsamt zu Gross-Lichterfelde West; *later becoming* Mitteilungen aus dem königlichen Materialprüfungsamt zu Berlin-Lichterfelde West; *name changed in 1919 to* Mitteilungen aus dem Materialprüfungsamt zu Berlin-Lichterfelde West; *name changed in 1920 to* Mitteilungen aus dem Materialprüfungsamt zu Berlin-Dahlem; *present name dates from 1923.*)
313. U. S. Bureau of Mines, Reports of Investigations.
314. Tonindustrie-Zeitung.
315. Memorial des poudres. (*Formerly* Memorial des poudres et salpetres.)
317. Chemische Industrie. (*Combined with* No. 92 *in 1921; separated again in 1923.*)
324. Canadian Chemistry and Metallurgy.
325. Proceedings of the Royal Institution of Great Britain.
329. Mining and Metallurgy. (Transactions of the American Brass Founders' Association, 1908–11; Transactions of the American Institute of Metals, 1912–16; Journal of the American Institute of Metals, 1917–18; *discontinued in 1918 and incorporated with* Bulletin of the American Institute of Mining Engineers; *with* No. 148, *1919, this Bulletin became* Bulletin of the American Institute of Mining and Metallurgical Engineers; *with* No. 154, *1919, name changed again to* Mining and Metallurgy.)
338. Researches of the Electro-technical Laboratory, Tokyo.
340. Philippine Agriculturist.
341. Journal of Agricultural Research.
342. Annales de chimie analytique et de chimie appliquée et revue de chimie analytique réunies.
343. Zeitschrift für öffentliche Chemie. (*Suspended at* end of 1922.)
344. Apotheker Zeitung.
345. Bulletin des sciences pharmacologiques.
346. Malayan Agricultural Journal. (*Formerly* Bulletin of the Department of Agriculture, Federated Malay States.)
347. Pharmaceutical Journal and Pharmacist.
348. Cotton Oil Press.
349. Seifensieder-Zeitung und Rundschau über die Harz-, Fett- und Ölindustrie mit dem Bleiblatt: Der chem.-techn. Fabrikant.
350. Les matières grasses.
351. Journal of State Medicine, London.
352. Milchwirtschaftliche Zentralblatt. (*Name changed in 1912 from* Milch-Zeitung.)
353. Academia Caesarea Leopoldino Carolina Germanica naturae curiosorum.
354. National Physical Laboratory, Collected Researches and Reports, London.
355. The Engineer, London.
356. Journal of the Royal Society of Arts.
357. Anales de la associación química Argentina. (*Name changed Jan., 1921 from* Anales de la sociedad química Argentina.)
358. Journal of the Institution of Petroleum Technologists and Record of Transactions.
359. Petroleum Age. (Petroleum; *name changed to* Petroleum Magazine, *and then back to* Petroleum; *in Sept., 1921 combined with* Petroleum Age *to form* Petroleum Age including Petroleum; *name changed back to* Petroleum Age, *Dec., 1925.*)
360. National Petroleum News.
361. Petroleum, Zeitschrift für die gesamten Interessen der Mineralöl-Industrie und des Mineralöl-Handels. (*Formerly* Petroleum, Zeitschrift für die gesamten Interessen der Petroleum-Industrie und des Petroleum-Handels.)
362. Chemické Listy pro vedu a prumysl.
363. Petroleum Review. (*Replaced by* No. 364.)
364. Petroleum Times. *See* No. 363.
365. Bureau of Standards, Circulars.
366. Feuerungstechnik.
367. Oesterreichische Chemiker-Zeitung.
368. Proceedings of the Institution of Automobile Engineers, London.
369. Gornyi zhurnal.
370. Memoirs of the American Academy of Arts and Sciences, Boston.
371. University Geological Survey of Kansas, Reports.
372. Verein zur Beforderung des Gewerbefleisses, Verhandlungen.
373. Chemisch-technisches Repertorium. (*Supplement to* No. 136.)
374. Oil and Colourman's Journal.
375. Polytechnisches Centralblatt.
376. Automotive Industries.
377. Bulletin de la section scientifique de l'académie Roumaine.
378. Chimie et industrie.
379. Journal of the Japanese Ceramic Society.
380. Gesundheits-Ingenieur.
381. Automobile Engineer and Internal Combustion Engineering. (Automobile Engineer, London, *1910 to Oct., 1912;* Internal Combustion Engineering, *Oct., 1912 to Jan., 1914; present name since Jan., 1914.*)
382. Refrigerating Engineering. (Transactions of the American Society of Refrigerating Engineers, 1905–13; American Society of Refrigerating Engineers Journal; *present name dates from July, 1922.*)

383. Revue générale du froid et des industries frigorifiques.
384. Le génie civil, Paris.
385. Journal of the American Society of Heating and Ventilating Engineers.
386. Canada Department of Mines.
387. Mineral Industry.
388. Översigt av Förhandlingar kongl. Svenska Vetenkaps-Akademien.
389. South African Journal of Industries. (*United with the* Official Labour Gazette of the Union of South Africa *in 1925 to form the* South African Journal of Industries and Labour Gazette.)
390. Indian Forest Bulletin.
391. Indian Forester.
392. Indian Forest Pamphlet.
393. American Society for Testing Materials Standards.
394. Fuel in Science and Practice.
395. Engineering and Mining Journal-Press. (*Formed in April, 1922 by the combining of* Engineering and Mining Journal *with* Mining and Scientific Press; *name changed July, 1926 to* Engineering and Mining Journal.)
396. Gas Journal. (*Formerly* Journal of Gas Lighting and Water Supply.)
397. Gas- und Wasserfach. (*Name changed Jan., 1922 from* Journal für Gasbeleuchtung und verwandte Beleuchtungsarten sowie für Wasserversorgung.)
398. Memoirs and Proceedings of the Manchester Literary and Philosophical Society.
399. Colliery Guardian and Journal of the Coal and Iron Trades.
400. Beama.
401. Revue de l'industrie minérale. (Bulletin de la société de l'industrie minérale; *name changed Jan., 1921 to* Revue de la société de l'industrie minérale; *name changed to* Revue de l'industrie minérale.)
402. Technique moderne.
403. Proceedings of the Institution of Mechanical Engineers.
404. Engineering News-Record. (*Formed by the combining of* Engineering News *with* Engineering Record.)
405. Glückauf, Berg- und Hüttenmännische Zeitschrift.
407. Jornal de Sciencias Matematicas, Physicas e Naturaes, Lisbon.
408. Journal de mathématiques pures et appliquées (Paris). (*Continues* Annales de mathématiques pures et appliquées; *present name dates from 1836.*)
409. Bayerisches Industrie- und Gewerbe-Blatt. (Kunst- und Gewerbe-Blatt, 1815–68; *present name dates from 1869.*)
410. Edinburgh Philosophical Journal, 1819–26; Edinburgh New Philosophical Journal, 1826–64; Quarterly Journal of Science, 1864–70; Quarterly Journal of Science and Annals of Mining, Metallurgy, Engineering, Industrial Arts, Manufactures and Technology, 1871–79; Monthly Journal of Science and Annals of Astronomy, Biology, Geology, Industrial Arts, Manufactures and Technology, 1879–85.
411. Proceedings of the North East Coast Institute of Engineers and Shipbuilders.
412. Horseless Age. (*Merged into* Motor Age *in 1918.*)
413. Journal of the Royal Aeronautical Society. (Annual Report of the Royal Aeronautical Society, 1866–96; *superseded by* Aeronautical Journal; *later* Journal of the Royal Aeronautical Society.)
414. Mitteilungen über Forschungsarbeiten auf den Gebiete des Ingenieurwesens hrsg. vom Vereine deutscher Ingenieure.
415. Journal of the Textile Industry.
416. Brennstoff-Chemie.
417. Iron and Steel Institute Carnegie Scholarship Memoirs.
418. Pottery Gazette and Glass Trade Review.
419. Ohio Journal of Science. (*Name changed Nov., 1915 from* Ohio Naturalist.)
420. Bulletin de la société d'encouragement pour l'industrie nationale.
421. Journal of West Scotland Iron and Steel Institute.
422. American Machinist.
423. Transactions of the American Foundrymen's Association. (Journal of the American Foundrymen's Association, 1896–1904.)
424. Oesterreichische Zeitschrift für Berg- und Hüttenwesen. (*Merged into* Montanistische Rundschau.)
425. Deutsche Mechaniker-Zeitung. (Beiblatt zur Zeitschrift für Instrumentenkunde.)
427. Physikalische Berichte. (Beiblätter zu den Annalen der Physik und Chemie; Beiblätter *united with* Fortschritte der Physik *and* Halbmonatliches Literaturverzeichnis *to form* Physikalische Berichte.)
428. Repertorium für Experimental-Physik für physikalische Technik für mathematische und astronomische Instrumentenkunde. (*Before 1867 was* Repertorium für physikalische Technik für mathematische und astronomische Instrumentenkunde; *also known as* Carl's Repertorium.)
429. Memoirs of the College of Science, Kyoto Imperial University. (*Before 1914 was part of* Memoirs of the College of Science and Engineering, Kyoto Imperial University.)
430. Iron Age.
431. Revue de la société russe de métallurgie.
433. Annual Report of the Royal Mint, London.
434. Scientific Transactions of the Royal Dublin Society.
435. Proceedings of the Institution of British Foundrymen.
436. Reports of the Research Department, Royal Arsenal, Woolwich.
437. Japanese Journal of Physics.
438. Transactions of the American Society of Mechanical Engineers.
439. Mémoires et compte rendu des travaux de la société ingénieurs civils de France.
440. Metal Industry and the Iron Foundry (London).
441. India Rubber Journal.
442. Annals of Botany.
443. Archief voor Rubbercultuur in Nederlandsch-Indië.
445. Zeitschrift des Vereins der deutschen Zucker-Industrie. (*Before 1898 was* Zeitschrift des Vereins für die Rubenzuckerindustrie.)
446. Zeitschrift für die Zuckerindustrie der Cechoslovakischen Republik. (*Formerly* Zeitschrift für die Zuckerindustrie in Böhmen.)
447. India Rubber World.
449. Caoutchouc et gutta percha.
450. Transactions of the Institution of the Rubber Industry.
456. Gummi-Zeitung.
459. Electrical Review and Industrial Engineer. (*Formerly* Electrical Review and Western Electrician.)
460. Deutsche Zuckerindustrie, Wochenblatt für Landwirtschaft, Fabrikation und Handel.
468. Kongliga Svenska Vetenskaps-Akademien, Handlingar.
469. Bulletin of the Institute of Physical and Chemical Research (Tokyo).
470. Memoirs of the College of Engineering, Kyushu Imperial University.
471. Army Ordnance.
472. Papier-Fabrikant (Tech.-Wiss. Teil).
473. Cellulosechemie.

B3. Landolt-Börnstein, Physikalisch-chemische Tabellen. 5th ed. Berlin, Springer, 1923.

B4. Singer, Die Keramik im Dienste von Industrie und Volkswirtschaft. Braunschweig, Vieweg, 1923.

B5. Rieke and Gary, Die Prüfung von Porzellan, 1922. Reprinted from *104*, **3**: 5; 22.

B6. Gilchrist and Klinefelter, High Voltage Porcelain Insulators. Westinghouse Electric and Manufacturing Company, Special Pub. 1690, 1925.

B7. Peek, Dielectric Phenomena in High Voltage Engineering. New York, McGraw-Hill Book Company, Inc., 1915.

B8. Rziha and Seidener, Starkstromtechnik. Taschenbuch für Elektrotechniker. 5th ed. Berlin, Ernst, 1922.

B10. Doelter, Handbuch der Mineralchemie. Leipzig, Steinkopff, 1912–

B12. Friese, Das Porzellan als Isolier- und Konstruktions-Material in der Elektrotechnik. Klosterlausnitz, 1904.

B26. Hirschwald, Handbuch der bautechnischen Gesteinprüfung. Berlin, Borntraeger, 1912.

B27. Hermann, Gesteine für Architektür und Sculptur. Berlin, Borntraeger, 1914.

B28. Johnson, Comparison of Experiments on American and Foreign Building Stones. New Haven, Hamlen. Reprinted from *American Journal of Science and Arts*, **11**: 1; 51.

B29. Merrill, Stones for Building and Decoration. 3rd ed. New York, Wiley, 1903.

B30. Popplewell and Carrington, Properties of Engineering Materials. London, Methuen, 1923.

B31. Schweizerische Geotechnische Kommission, Die naturlichen Bausteine und Dachschiefer der Schweiz. Berne, 1915.

B32. U. S. Ordnance Department, Tests of Metals and Other Materials. Washington, Government Printing Office, 1894.

B33. U. S. Geological Survey, The Stone Industry in 1903. Washington, Government Printing Office, 1903.

B61. Ullmann, Encyclopädie der techn. Chemie. Wien, Urban and Schwarzenberg, 1914–23.

B68. Abraham, Asphalt and Allied Substances, Their Occurrence, Mode of Production, Uses in the Arts and Methods of Testing. New York, Van Nostrand, 1920.

B71. Mellor, Treatise on Inorganic and Theoretical Chemistry. London, Longmans, 1922– .

B72. Bunsen, Gasometrische Methoden. 2nd ed. Braunschweig, 1877.

B73. Berthelot, Thermochimie. Paris, Gauthier-Villars, 1897.

B74. Rieke, Das Porzellan. Hannover, 1910.

B75. Société d'encouragement pour l'industrie nationale, Contribution à l'étude des argiles et da la céramique. Paris, Chapuy, 1906.

B76. Winkelmann, Handbuch der Physik. Leipzig, Barth, 1905–8.

B77. Marks, Mechanical Engineers' Handbook. 2nd ed. New York, McGraw-Hill Book Company, Inc., 1914.

B79. de Vries, Estate Rubber. Batavia, Drukkerijen Ruycrok, 1920.

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INTERNATIONAL CRITICAL TABLES

P-V-T RELATIONS FOR ONE-PHASE SYSTEMS (DENSITY, SPECIFIC GRAVITY, THERMAL EXPANSION AND COMPRESSIBILITY)

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* *See also* Vol. I, p. 102.

† This chapter covers only data showing the variation of density or volume with temperature. For additional density data at single temperatures, *see* Vol. I, p. 98–314 and 338–347.

* *Voir aussi* Vol. I, p. 102.

† Ce chapitre ne comprend que les données indiquant la variation de la densité ou du volume avec la température. Pour d'autres données de densité à une seule température, *voir* Vol. I, p. 98–314 et 338–347.

* *Siehe auch* Bd. I, S. 102.

† Dieser Abschnitt enthält nur Angaben über die Änderung der Dichte oder des Volumens mit der Temperatur. Weitere Angaben über Dichten bei einzelnen Temperaturen, *siehe* Bd. I, S. 98–314 und 338–347.

* *Vedi anche* Vol. I, p. 102.

† Questo capitolo contiene solo notizie sulla variazione della densità e del volume in funzione della temperatura. Per ulteriori notizie sulle densità a singole temperature, *vedi* Vol. I, p. 98–314 e 338–347.

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‡ *See also* **Vol. I**, p. 98–314 and 338–347.

‡ *Voir aussi* Vol. I, p. 98–314 et 338–347.

‡ *Siehe auch* **Bd. I**, S. 98–314 und 338–347.

‡ *Vedi anche* **Vol. I**, p. 98–314 e 338–347.

P-V-T RELATIONS IN THE GASEOUS STATE FOR SUBSTANCES WHICH ARE GASES AT 0° AND 1 ATMOSPHERE

S. F. Pickering

PART I. STANDARD DENSITY

$$1 + \lambda = \frac{p_0 v_0(0°,\ 0_{\text{atm.}})}{p_1 v_1(0°,\ 1\text{A}_n)}. \quad v_0 = \frac{M(1 + \lambda)}{d_s}$$

Formula	Formula weight, M	d_s, gl^{-1} 0°, 1A$_n$	Lit.	$1 + \lambda$	Lit.	v_0
𝔄-Table.—Elements and Atmospheric Air						
A	39.91	1.7832	(55, 71, 112, 124)	1.0009_0	(54, 55, 100)	22.401
Cl_2	70.916	3.214	(61)			
F_2	38.000	1.696	(78)			
H_2	2.0154	0.08988	(42, 92, 93, 131)	0.9993_9	(44, 49, 51, 54, 99, 138)	22.410
He	4.00	0.1785	(16, 42, 50, 131, 140)	0.99954	(49, 54, 55, 97)	22.398
Kr	82.9	3.70_8	(91, 139)			
N_2 (chem.)	28.016	1.2505_7	(37, 82, 87, 88, 146)	1.00047	(49, 52, 54, 74, 125, 146)	22.413
N_2 (atm.)		1.2568	(107)			
Ne	20.2	0.900_2	(139)	0.999_6	(53, 54, 101)	22.430
O_2	32.00	1.4290_4	(15, 22, 34, 37, 58, 60, 69, 84, 89, 90, 92, 94, 114, 122, 134, 145, 153)	1.0009_4	(10, 44, 52, 59, 67, 74, 145)	22.413_7
Rn	222	9.73	(38)			
Xe	130.2	5.85_1	(91, 139)			
Air		1.2929	(34, 35, 41, 46, 68, 86, 107, 114, 136)	1.0006_1	(54, 55)	
𝔅-Table.—Chemical Compounds						
Standard arrangement (*v.* p. viii)						
Cl_2O	86.916	3.89	(33)			
HCl	36.4657	1.6392	(24, 122)	1.0074	(123)	22.411
HBr	80.9237	3.6445	(80, 120)	1.0092_9	(80, 120)	22.411
HI	127.9397	5.789_1	(30, 148)	1.015	(148)	22.432
SO_2	64.065	2.9269	(40, 122)	1.024_0	(11, 59)	22.414
H_2S	34.0804	1.539	(12)	1.010	(74)	22.369
H_2Se	81.2154	3.670	(23)	1.01_2	(23)	22.391
H_2Te	129.5154	4.49*	(32)			
NO	30.008	1.3402	(37, 45, 122)	1.0011	(5, 9, 59, 123)	22.420
N_2O	44.016	1.977_8	(47, 77, 116)	1.0074	(9, 39, 117)	22.420
NH_3	17.0311	0.7710	(48, 75, 110, 122, 154)	1.015_1	(74)	22.423
NOCl	65.466	2.992	(143)			
PH_3	34.0471	1.529_4	(132)			
PF_5	126.024	5.81	(76)			
POF_3	104.024	4.8	(77)			
AsH_3	77.9831	3.48	(31)			
SbH_3	124.7931	5.30†	(127)			
CO	28.000	1.250_4	(77, 115)	1.0005	(123)	22.404
CO_2	44.000	1.9769	(27, 48, 68, 115, 119)	1.0070_6	(44)	22.414
CH_4	16.0308	0.716_8	(13, 64)	1.0024	(64)	22.418
C_2H_2	26.0154	1.173	(126, 150)	1.010	(57, 150)	22.400
C_2H_4	28.0308	1.260_4	(4)	1.0078_0	(9, 44)	22.413
C_2H_6	30.0462	1.3566	(13, 126)			
C_3H_8	44.0616	2.020	(135)			
iso-C_4H_{10}	58.077	2.673	(106)			
$(CH_3)_2O$	46.0462	2.1098	(6, 11)	1.0254	(7, 9)	22.379
CH_3F	34.0231	1.545_2	(85)	1.018_1	(83)	22.416
CH_3Cl	50.4811	2.3076	(8, 11, 144)	1.0244	(8, 11, 14, 144)	22.410
iso-C_4H_9F	92.5273	2.58‡	(79)			
COS	60.065	2.72	(133)			
CH_3NH_2	31.0465	1.396	(95)			
$(CH_3)_2NH$	45.0619	1.966§	(95)			
$(CH_3)_3N$	59.0773	2.580§	(95)			
SiH_4	32.0908	1.44	(128)			
Si_2H_6	62.1662	2.85	(128)			
SiF_4	104.06	4.68_4	(36)			
SiH_3Cl	66.5411	3.03	(129)			
$SiH_3(CH_3)$	46.1062	2.08	(129)			
$SiH_2(CH_3)_2$	60.1216	2.73	(129)			
$SiH_2Cl(CH_3)$	80.5565	3.64	(129)			
$SiHCl_2(CH_3)$	115.0068	5.3	(129)			
GeH_4	76.4108	3.420	(26)			
$(CH_3)_3B$	55.8893	2.52	(130)			

* 3°/air 3°. † 15°, 754 mm. ‡ 21°/air 21°. § 17°.

PART II. THERMAL EXPANSION AND COMPRESSIBILITY

$\alpha_{0,t} = \dfrac{v - v_0}{t v_0}$, the coefficient of expansion at constant pressure, p_0, between 0° and t, °C

$\beta_{0,t} = \dfrac{p - p_0}{t p_0}$, the coefficient at constant volume, v_0, between 0° and t, °C

𝔄-Table.—Elementary Substances and Atmospheric Air

A, Argon

p, m Hg	100α (53, 55)					
	0 to 50°C	0 to 100°C	0 to 150°C	0 to 200°C	0 to 300°C	0 to 400°C
0					0.3660	0.3660
1	0.3678	0.3676	0.3675	0.3673	0.3672	0.3671
5					0.3716	0.3711
10	0.3826	0.3804	0.3793	0.3780	0.3772	0.3761
15					0.3826	0.3811
20	0.4004	0.3955	0.3930	0.3903	0.3881	0.3860
25					0.3934	0.3908
30	0.4176	0.4104	0.4064	0.4026	0.3986	0.3955
35					0.4038	0.4001
40	0.4348	0.4251	0.4195	0.4146	0.4089	0.4047
45					0.4138	0.4091
50	0.4507	0.4390	0.4321	0.4259	0.4187	0.4135
55					0.4235	0.4177
60	0.4662	0.4525	0.4442	0.4369	0.4282	0.4218
65					0.4327	0.4259
70	0.4813	0.4656	0.4556	0.4473	0.4371	0.4298
75	0.4886	0.4720	0.4610	0.4524	0.4415	0.4336
80					0.4456	0.4372

$\frac{1}{v}$	100β (53, 55)					
	0 to 50°C	0 to 100°C	0 to 150°C	0 to 200°C	0 to 300°C	0 to 400°C
0					0.3660	0.3660
1	0.3676	0.3675	0.3675	0.3674	0.3674	0.3674
5					0.3728	0.3727
10	0.3801	0.3794	0.3796	0.3790	0.3796	0.3794
15					0.3863	0.3860

A, Argon.—(*Continued*)

$\frac{1}{v}$	100β (53, 55) 0 to 50°C	0 to 100°C	0 to 150°C	0 to 200°C	0 to 300°C	0 to 400°C
20	0.3957	0.3940	0.3937	0.3930	0.3931	0.3926
25					0.3998	0.3991
30	0.4109	0.4085	0.4081	0.4070	0.4066	0.4055
35					0.4112	
40	0.4255	0.4228	0.4224	0.4209	0.4158	
50	0.4397	0.4371	0.4360			
60	0.4539					
65	0.4609					

100β = 0.3671, 0 to 20°, p at 0° = 0.76 m (100).

p, kg/cm²	$v_{3000} - v_p$, cm³/g	p, kg/cm²	$v_{3000} - v_p$, cm³/g	p, kg/cm²	$v_{3000} - v_p$, cm³/g	Lit.
2 000	−0.083	6 000	0.112	11 000	0.190	(19, 20)
2 500	−0.034	7 000	0.134	12 000	0.201	
3 000	0.000	8 000	0.152	13 000	0.209	
4 000	+0.049	9 000	0.167	14 000	0.217	
5 000	0.085	10 000	0.180	15 000	0.224	

p in atm.; v = 1.0000 at 0°C and 1 atm.; range, 0 to 100 atm. (53, 54, 55)

−100°C $pv = 0.6346 - 0.0_{2}2872p - 0.0_{4}1021p^2 - 0.0_{9}130p^4$
− 50°C $pv = 0.8178 - 0.0_{2}1687p + 0.0_{6}79p^2 + 0.0_{9}100p^4$
0°C $pv = 1.0010 - 0.0_{3}986p + 0.0_{5}237p^2$
+ 50°C $pv = 1.1842 - 0.0_{3}492p + 0.0_{5}179p^2$
100°C $pv = 1.3674 - 0.0_{3}192p + 0.0_{5}161p^2$
150°C $pv = 1.5506 + 0.0_{4}52p + 0.0_{5}124p^2$
200°C $pv = 1.7338 + 0.0_{3}208p + 0.0_{5}112p^2$
300°C $pv = 2.1002 + 0.0_{3}501p + 0.0_{6}46p^2$
400°C $pv = 2.4666 + 0.0_{3}683p$

Leiden Temperature Scale (v. Vol. I, p. 54)

v = 1.0000 at 0°C and 1 atm. (100)

p, atm.	pv	p, atm.	pv	p, atm.	pv	p, atm.	pv
+20.39°C		+18.39°C		0.00°C		−57.72°C	
21.783	1.0627	37.264	1.0526	20.576	0.9856	17.872	0.7602
27.320	1.0606	49.586	1.0471	26.070	0.9808	25.228	0.7465
34.487	1.0582	62.489	1.0405	31.572	0.9774	35.127	0.7300
37.673	1.0535			36.743	0.9725	46.209	0.7115
49.604	1.0483			49.871	0.9620	62.079	0.6845
61.741	1.0420			62.230	0.9526		
−87.05°C		−102.51°C		−109.88°C		−113.80°C	
16.178	0.6432	14.864	0.5813	14.443	0.5504	31.001	0.4622
21.651	0.6282	19.790	0.5642	18.653	0.5359	38.005	0.4276
33.296	0.5965	32.394	0.5205	31.515	0.4838	42.682	0.4001
41.094	0.5752	40.976	0.4878	39.166	0.4493	47.655	0.3689
51.533	0.5446	45.088	0.4706	43.718	0.4254	51.752	0.3389
61.830	0.5159	51.398	0.4435	49.515	0.3944	52.188	0.3358
		56.882	0.4194	54.250	0.3658	55.763	0.3062
		62.239	0.3939	59.616	0.3297	55.991	0.3030
						58.898	0.2765
−115.86°C		−115.86°C		−116.62°C		−116.62°C	
31.323	0.4478	53.204	0.2957	13.863	0.5235	46.496	0.3478
37.788	0.4138	57.493	0.2442	17.697	0.5065	50.259	0.3147
41.908	0.3880	61.626	0.1929	30.681	0.4470	50.447	0.3119
46.648	0.3547			37.250	0.4113	54.922	0.2615
50.324	0.3244			41.943	0.3806	60.669	0.1831
−119.20°C		−119.20°C		−120.24°C		−120.24°C	
13.766	0.5123	43.006	0.3441	30.809	0.4242	47.705	0.2877
17.378	0.4970	47.272	0.3023	33.776	0.4078	50.351	0.2438
30.303	0.4299	51.679	0.2321	37.836	0.3812	52.253	0.1864
34.052	0.4090	53.044	0.1929	41.668	0.3516	53.191	0.1569
37.641	0.3887	54.244	0.1610	44.510	0.3265		
37.923	0.3836						
−121.21°C		−130.38°C		−139.62°C		−149.60°C	
13.754	0.5033	12.773	0.4662	11.986	0.4262	11.150	0.3820
17.225	0.4882	15.664	0.4511	14.586	0.4100	12.788	0.3691
30.122	0.4215	22.861	0.4096				
34.070	0.3981	25.519	0.3918				
37.465	0.3734	28.878	0.3711				
45.282	0.3040						
47.094	0.2769						
49.865	0.2130						
50.885	0.1525						

H_2, Hydrogen

p, kg/cm²	$(v_{3000} - v_p)$ cm³/g		$\frac{(pv)_{t,p}}{(pv)_{0,1}}$* (19, 20)	
	30°C	65°C	30°C	65°C
2 000	−2.25		2.43	
3 000	0.00	0.00	3.04	3.18
4 000	1.12	1.14	3.66	3.84
5 000	1.84	1.88	4.30	4.47
6 000	2.35	2.44	4.85	5.08
7 000	2.77	2.88	5.40	5.66
8 000	3.09	3.21	5.95	6.23
9 000	3.38	3.46	6.47	6.82
10 000	3.63	3.68	6.97	7.38
11 000	3.86	3.88	7.45	7.93
12 000	4.09	4.04	7.89	8.47
13 000	4.32	4.21	8.28	9.00

* Assuming v_{3000} = 11.64 and 12.17 cm³/g at 30 and 65° respectively (Amagat).

p in atm.; v = 1.0000 at 0°C and 1 atm.; range 0 to 100 atm.* (51, 53, 54, 138, 147)

−207.9°C $pv = 0.2388 - 0.0_{2}1077p + 0.0_{5}242p^2 + 0.0_{6}2704p^3 - 0.0_{8}1785p^5$
−183°C $pv = 0.3299_5 - 0.0_{3}247p + 0.0_{5}381p^2$
−150°C $pv = 0.4506_5 + 0.0_{3}132p + 0.0_{5}200p^2$
−100°C $pv = 0.6336 + 0.0_{3}408p + 0.0_{6}90p^2$
− 50°C $pv = 0.8165 + 0.0_{3}540p + 0.0_{6}50p^2$
0°C $pv = 0.99938 + 0.0_{3}624p + 0.0_{6}20p^2$
+ 20°C $pv = 1.0726 + 0.0_{3}645p + 0.0_{6}12p^2$
50°C $pv = 1.1824 + 0.0_{3}676p$
100°C $pv = 1.3653 + 0.0_{3}695p$
200°C $pv = 1.7310 + 0.0_{3}701p$

* At 0 and 20° (138) covers a range from 0 to 200 atm.

Leiden Temperature Scale

v = 1.0000 at 0°C and 1 atm. (105)

p, atm.	pv	p, atm.	pv
−103.57°C		−139.89°C	
38.414	0.6376	29.800	0.4954
45.000	0.6402	35.132	0.4976
51.489	0.6433	40.172	0.4991

p, atm.	pv	p, atm.	pv
−182.74°C		−203.97°C	
20.159	0.3274	16.970	0.2425
22.995	0.3272	19.335	0.2412
23.010	0.3273	21.764	0.2400
26.255	0.3271		
26.281	0.3271		
29.530	0.3270		

Leiden Temperature Scale

H_2, Hydrogen.—(*Continued*)

v = 1.0000 at 0°C and 1 atm. (105).—(*Continued*)

p, atm.	*pv*	*p*, atm.	*pv*
−212.73°C		−217.32°C	
14.571	0.2074	13.288	0.1889
16.539	0.2057	15.052	0.1871
18.443	0.2039	16.812	0.1851
		13.199	0.1890
		14.875	0.1872
		16.558	0.1853
−225.37°C		−231.38°C	
10.898	0.1566	9.472	0.1315
12.424	0.1541	10.291	0.1296
13.685	0.1520	11.402	0.1268
−236.28°C		−238.29°C	
8.298	0.1106	8.083	0.1007
8.663	0.1093	8.310	0.0998
9.496	0.1065	8.715	0.0981
−239.90°C		−241.88°C	
7.512	0.0940	6.821	0.0858
7.843	0.0924	6.820	0.0858
8.155	0.0910	7.117	0.0840

p, atm.	*pv*
−243.88°C	
6.191	0.0767
6.192	0.0767
6.392	0.0752
6.604	0.0735
6.619	0.0734

pv = 1.0000 at 0°C and 1 atm. (29)

p, atm.	*pv*	*p*, atm.	*pv*
−217.33°C		−225.36°C	
34.24	0.1695	28.75	0.1280
36.98	0.1677	33.38	0.1231
40.21	0.1659	36.83	0.1205
44.09	0.1645	38.13	0.1198
48.33	0.1637	39.51	0.1192

pv = 1.0000 at 0°C and 1 atm. (29).—(*Continued*)

p, atm.	*pv*	*p*, atm.	*pv*
−217.33°C		−225.36°C	
53.52	0.1635	43.47	0.1185
56.52	0.1642	48.68	0.1191
		55.85	0.1225
−231.40°C		−236.31°C	
23.44	0.0952	17.91	0.0668
26.40	0.0889	18.62	0.0632
27.43	0.0872	21.89	0.0525
28.54	0.0856	22.45	0.0524
30.28	0.0837	23.00	0.0518
31.11	0.0831	24.11	0.0517
32.29	0.0826	24.83	0.0519
33.38	0.0821	25.98	0.0524
34.64	0.0821	28.12	0.0540
35 79	0.0824	29.65	0.0554
36.18	0.0823	30.00	0.0559
39.42	0.0838	34.77	0.0607
42.37	0.0858	40.64	0.0675
48.60	0.0911		
−238.29°C		−239.91°C	
15.39	0.0542	13.62	0.0288
17.60	0.0401	13.77	0.0286
18.00	0.0391	14.05	0.0286
18.95	0.0390	14.25	0.0286
20.07	0.0395	14.45	0.0286
20.90	0.0402	14.78	0.0288
22.79	0.0420	15.59	0.0294
23.05	0.0421	17.67	0.0317
25.87	0.0453	20.94	0.0357
29.79	0.0499	23.43	0.0388
38.08	0.0598	24.08	0.0396
43.47	0.0665	25.86	0.0419
45.50	0.0690	28.76	0.0455
−239.92°C		29.25	0.0462
12.96	0.0434	31.62	0.0491
13.01	0.0408	33.05	0.0509
13.03	0.0397	38.38	0.0576
		47.94	0.0693
		51.46	0.0735

Virial Coefficients of Hydrogen

$pv = A + B/v$; Leiden temperature scale; $v = 1.00000$ at 0°C and 1 atm. (1)

T, °K	A	B
90.23	0.33019	−0.000120
69.86	0.25562	−0.000194
20.55	0.07518	−0.000470
20.53	0.07516	−0.000474
18.16	0.06647	−0.000505
16.65	0.06094	−0.000527
15.64	0.05725	−0.000553
14.50	0.05306	−0.000581
18.22	0.06666	−0.000506

Values of *pv*

Each individual value in this table has been experimentally determined (151, 152, 156)

p, atm.	*pv*					
	0°	50°	99.85°	198.9°	299.1°	399.3°
1	**1.0000**					
50	1.0330	1.2182	1.4026	1.7684		
100	1.0639	1.2521	1.4359	1.8030	2.1700	2.5141
200	1.1336	1.3272	1.5105	1.8804	2.2502	2.6054
300	1.2045	1.3986	1.5836	1.9556	2.3240	2.6800
400	1.2775	1.4720	1.6563	2.0295	2.3977	2.7625
600	1.4226	1.6160	1.7999	2.1726	2.5394	
800	1.5665	1.7582	1.9415	2.3157	2.6762	
1000	1.7107	1.9006	2.0839	2.4568	2.8125	

p, atm.	*pv* (3)		
	0°C	15.4°C	47.3°C
1	**1.0000**		
500	1.3565		
1000	1.7260	1.7780	1.8930
1100	1.8007	1.8535	1.9635
1200	1.8690	1.9248	2.0334
1300	1.9383	1.9929	2.1027
1400	2.0048	2.0608	2.1714
1500	2.0700	2.1270	2.2395
1600	2.1352	2.1920	2.3072
1700	2.2006	2.2542	2.3732
1800	2.2644	2.3184	2.4372
1900	2.3275	2.3835	2.5004
2000	2.3890	2.4450	2.5614
2100	2.4496	2.5074	2.6229
2200	2.5102	2.5707	2.6840
2300	2.5714	2.6323	2.7473
2400	2.6340	2.6940	2.8092
2500	2.6950	2.7525	2.8700
2600	2.7547	2.8145	2.9289
2700	2.8134	2.8701	2.9889
2800	2.8686	2.9260	3.0464
2900		2.9812	3.1059
3000		3.0375	

p_0, atm.	100α (142)				
	0 to +100°C	0 to +20°C	0 to −77°C	0 to −104°C	0 to −147°C
1	0.3661				
5	0.3665	0.3655	0.3658	0.3661	0.3666
10	0.3646	0.3647	0.3652	0.3656	0.3667
15	0.3637	0.3639	0.3646	0.3652	0.3668
20	0.3629	0.3631	0.3640	0.3648	0.3669
25	0.3620	0.3623	0.3635	0.3644	0.3670
30	0.3611	0.3615	0.3629	0.3640	0.3670
35	0.3602	0.3608	0.3623	0.3635	0.3669
40	0.3594	0.3601	0.3618	0.3631	0.3668
45	0.3585	0.3593	0.3613	0.3626	0.3666
50	0.3576	0.3586	0.3608	0.3621	0.3663
55	0.3567	0.3578	0.3602	0.3616	0.3659
60	0.3558	0.3571	0.3596	0.3611	0.3654

H_2, Hydrogen.—(*Continued*)

p_0, atm.	100α (142)			
	0 to −183°C	0 to −190°C	0 to −205°C	0 to −212°C
1				
5	0.3674	0.3678	0.3685	0.3691
10	0.3680	0.3685	0.3701	0.3711
15	0.3688	0.3696	0.3717	0.3732
20	0.3697	0.3707	0.3734	0.3754
25	0.3704	0.3716	0.3751	0.3774
30	0.3710	0.3724	0.3766	0.3792
35	0.3715	0.3731	0.3779	0.3808
40	0.3721	0.3738	0.3789	0.3821
45	0.3724	0.3742	0.3796	0.3830
50	0.3727	0.3746	0.3802	0.3835
55	0.3728	0.3748	0.3806	0.3838
60	0.3728	0.3749	0.3808	0.3841

p_0,* atm.	100α (3)			100β (3)		
	0 to 15.4°C	0 to 99.2°C	99.2 to 200.2°C	0 to 15.4°C	0 to 47.3°C	0 to 99.2°C
100	0.360			0.357		0.373
200	0.345	0.332	0.242			0.383
300	0.323	0.314	0.231			0.383
400	0.300	0.295	0.221			0.380
500	0.278	0.278	0.214			0.379
600	0.260	0.261	0.204			0.376
700	0.244	0.249	0.196			0.371
800	0.231	0.237	0.189			
900	0.220	0.226	0.182			
1000	0.210	0.218		0.357	0.347	
1200	0.190			0.346	0.335	
1500	0.176			0.342	0.334	
1800	0.161			0.321	0.318	
2000	0.153			0.321	0.317	
2400	0.141			0.319	0.305	
2500	0.138					
2800	0.131			0.325		
3000	0.128					

* p_0 = constant pressure for α and initial pressure for β.

p, m Hg	100α (49)	100β (49)
	$t = 0°C$	$t = 0°C$
ca. 1	$0.3660_4 - 0.00012p$	$0.3660_4 + 0.00017p$

p, respectively p_0 = 1 atm. (70)

100α		100β	
0°C	0 to 100°C	0°C	0 to 100°C
0.3660	0.3661	0.3662	0.3663

p, m Hg	100α (51, 53)		
	0 to 50°C	0 to 100°C	0 to 200°C
0	0.3662	0.3662	0.3660
1	0.3660	0.3660	0.3658
5	0.3654	0.3651	0.3648
10	0.3645	0.3641	0.3635
15	0.3636	0.3630	0.3623
20	0.3626	0.3619	0.3610
25	0.3616	0.3608	0.3597
30	0.3606	0.3596	0.3584
35	0.3596	0.3585	0.3572
40	0.3585	0.3573	0.3559
45	0.3574	0.3561	0.3546
50	0.3563	0.3550	0.3532
55	0.3551	0.3538	0.3520
60	0.3539	0.3525	0.3506
65	0.3526	0.3513	0.3493
70	0.3513	0.3501	0.3480
75	0.3500	0.3488	0.3467
76	0.3498	0.3486	
80			0.3453

$\frac{1}{v}$	100β (51, 53)		
	0 to 50°C	0 to 100°C	0 to 200°C
0	0.3662	0.3662	0.3660
1	0.3663	0.3663	0.3661
5	0.3670	0.3668	0.3665
10	0.3678	0.3674	0.3669
15	0.3685	0.3680	0.3673
20	0.3692	0.3686	0.3677
25	0.3698	0.3691	0.3681
30	0.3704	0.3696	0.3684
35	0.3709	0.3701	0.3688
40	0.3714	0.3705	0.3691
45	0.3719	0.3710	0.3694
50	0.3723	0.3714	
55	0.3726		
60	0.3729		

He, Helium (19, 20)

p, kg/cm²	$v_{3000} - v_p$, cm³/g at 65°C	$v_{95°} - v_{30°}$, cm³/g	$v_{65°}$, cm³/g*	$\frac{(pv)_{t,\,p}}{(pv)_{0,\,1}}$, 65°*
3 000	0.00	0.613	5.54	2.88
4 000	0.77	0.598	4.77	3.29
5 000	1.23	0.589	4.31	3.72
6 000	1.54	0.584	4.00	4.15
7 000	1.77	0.581	3.77	4.56
8 000	1.96	0.579	3.59	4.96
9 000	2.10	0.578	3.44	5.34
10 000	2.22	0.576	3.32	5.73
11 000	2.33	0.575	3.21	6.09
12 000	2.41	0.574	3.13	6.49
13 000	2.48	0.572	3.06	6.88
14 000	2.55	0.571	2.99	7.25
15 000	2.60	0.570	2.94	7.61

* Based on the value of v_{3000} obtained by extrapolation from an unpublished equation of Keyes (63.5).

p in atm.; v = 1.0000 at 0°C and 1 atm.; range, 0 to 105 atm. (52, 53, 54, 147)

−258.0°C $pv = 0.0555_8 - 0.0_3797p + 0.0_45437p^2 - 0.0_67513p^3 + 0.0_83796p^4$
−252.8°C $pv = 0.0746_0 - 0.0_31642p + 0.0_41853p^2 - 0.0_61105p^3$
−208.0°C $pv = 0.2384_7 + 0.0_35508p + 0.0_5238p^2 - 0.0_7141p^3$
−183.0°C $pv = 0.3299_2 + 0.0_36229p + 0.0_6735p^2$
−150°C $pv = 0.4507 + 0.0_3509p + 0.0_6259p^2$
−100°C $pv = 0.6336 + 0.0_3531p + 0.0_6165p^2$
− 50°C $pv = 0.8165_5 + 0.0_3532p + 0.0_794p^2$
0°C $pv = 0.9994_5 + 0.0_3529p$
+ 50°C $pv = 1.1824_5 + 0.0_3524p$
100°C $pv = 1.3654 + 0.0_3508p$
200°C $pv = 1.7312 + 0.0_3494p$
300°C $pv = 2.0970 + 0.0_3468p$
400°C $pv = 2.4628_5 + 0.0_3452p$

He, Helium.—(*Continued*)

Leiden Temperature Scale

$pv = 1.0000$ at 0°C and 1 atm. (109)

p, atm.	pv	p, atm.	pv	p, atm.	pv	p, atm.	pv
−205.31°C		−212.06°C		−217.41°C		−252.65°C	
43.987	0.2690	40.113	0.2421	36.351	0.2202	12.411	0.0748
47.605	0.2707	42.770	0.2433	38.669	0.2213	13.196	0.0749
50.301	0.2721	42.749	0.2432	41.026	0.2224	13.903	0.0750
		45.220	0.2444				

p, atm.	pv
−258.33°C	
8.614	0.0513
9.168	0.0511
9.728	0.0510

Leiden Temperature Scale

$pv = 1.0000$ at 0°C and 1 atm. (18)

p atm.	pv	p, atm.	pv
−37.40°C		−70.32°C	
24.46	0.8758	22.82	0.7541
26.87	0.8774	24.89	0.7556
26.88	0.8770	28.77	0.7584
30.24	0.8791	28.78	0.7584
31.35	0.8796	33.92	0.7609
37.43	0.8842	35.29	0.7629
37.44	0.8834	41.13	0.7645
37.55	0.8834	43.39	0.7667
46.55	0.8874	56.27	0.7731
−103.64°C		−142.01°C	
21.34	0.6321	20.54	0.4911
21.54	0.6320	24.58	0.4932
24.12	0.6337	24.88	0.4932
27.66	0.6362	24.88	0.4933
27.69	0.6360	28.20	0.4954
32.40	0.6388	28.76	0.4957
32.62	0.6388	28.77	0.4958
35.31	0.6403	34.06	0.4988
39.52	0.6422	41.52	0.5027
49.96	0.6479	53.06	0.5088
−183.32°C		−201.51°C	
20.61	0.3391	20.10	0.2716
23.21	0.3407	29.69	0.2769
23.22	0.3407		
26.54	0.3426		
30.97	0.3451		
37.02	0.3482		
−225.01°C		−235.91°C	
43.44	0.1952	36.68	0.1498
43.47	0.1951	40.32	0.1515
48.58	0.1976	50.34	0.1562
55.06	0.2008	50.35	0.1561
		55.16	0.1585
−249.87°C		−252.63°C	
25.27	0.0896	22.53	0.0773
26.93	0.0902	23.84	0.0777
26.95	0.0902	25.31	0.0782
28.84	0.0909	26.97	0.0788
31.12	0.0918	28.26	0.0792
32.84	0.0925		

p, atm.	pv	p, atm.	pv
−256.04°C		−258.78°C	
18.74	0.0617	15.43	0.0490
19.61	0.0619	16.01	0.0491
20.63	0.0622	16.65	0.0492
21.70	0.0625	17.30	0.0493
22.50	0.0627	17.78	0.0494

$v = 1.0000$ at 0°C and 1 atm. (97)

p, atm.	pv	p, atm.	pv
−103.57°C		−182.75°C	
20.580	0.6314	13.751	0.3379
24.100	0.6330	16.019	0.3390
29.185	0.6360	18.189	0.3402
33.383	0.6384		

−103.57°

$$pv = 0.6203 + \frac{0.0_3337}{v}.$$

−182.75°

$$pv = 0.3306 + \frac{0.0_3176}{v}.$$

$v = 1.0000$ at 0°C and 1 atm. (98)

p, atm.	pv	p, atm.	pv
−268.88°C		−269.37°C	
0.2709	0.0145	0.1550	0.0129
0.3551	0.0140	0.1616	0.0129
0.3800	0.0140	0.2493	0.0125
0.6624	0.0127	0.2748	0.0123
0.9928	0.0107	0.2757	0.0123
		0.4322	0.0115
		0.5703	0.0107
−269.69°C		−270.52°C	
0.2323	0.0113	0.0308	0.0091
0.2608	0.0110	0.0486	0.0087
0.3531	0.0104	0.0649	0.0086

Virial Coefficients of Helium

$pv = A + B/v$; Leiden temperature scale; $v = 1.00000$ at 0°C and 1 atm. (1)

T, °K	A	B
69.86	0.25572	+0.000100
20.55	0.07520	−0.000004
20.53	0.07516	−0.000009
20.51	0.07508	−0.000009
18.22	0.06669	−0.000024
16.65	0.06096	−0.000024

p, m Hg	100α (52, 53)				
	0 to 50°C	0 to 100°C	0 to 200°C	0 to 300°C	0 to 400°C
0	0.3660	0.3660	0.3660	0.3660	0.3660
1*	0.3658	0.3658	0.3658	0.3658	0.3658
10	0.3635	0.3634	0.3633	0.3632	0.3633
20	0.3609	0.3608	0.3606	0.3605	0.3605
30	0.3584	0.3582	0.3579	0.3578	0.3578
40	0.3558	0.3556	0.3552	0.3551	0.3551
50	0.3532	0.3529	0.3526	0.3524	0.3525
60	0.3506	0.3503	0.3501	0.3498	0.3499
70	0.3481	0.3477	0.3475	0.3473	0.3474
80	0.3455	0.3450	0.3450	0.3447	0.3448

* At *ca.* $p = 1$ m Hg, $100\alpha = 0.3660_4 - 0.00019p$ (49).

$\frac{1}{v}$	100β (52, 53)				
	0 to 50°C	0 to 100°C	0 to 200°C	0 to 300°C	0 to 400°C
0	0.3661	0.3661	0.3661	0.3660	0.3660
1*	0.3661	0.3661	0.3660	0.3660	0.3660
10	0.3660	0.3658	0.3656	0.3655	0.3654
20	0.3658	0.3656	0.3652	0.3649	0.3648
30	0.3656	0.3653	0.3648	0.3643	0.3641
40	0.3655	0.3650	0.3645	0.3638	
50	0.3653	0.3648	0.3640		
60	0.3652	0.3645			

* At *ca.* $p = 1$ m Hg, $100\beta = 0.3660_4 - 0.00004p$ (49).

Kr, Krypton

$v = 1.000$ at 0°C and 1 atm. (113)

p, atm.	pv	p, atm.	pv
11.2°C		237.3°C	
25.88	1.012	50.93	1.882
27.91	1.008	54.82	1.880
30.31	1.000	59.36	1.874
33.15	0.993	65.12	1.868
36.60	0.980	71.20	1.862
40.89	0.968	79.25	1.859
46.29	0.953	89.53	1.856
49.58	0.940	104.09	1.877
53.72	0.937		
57.81	0.918		
63.07	0.901		
69.46	0.884		
72.10	0.863		
87.39	0.841		
101.74	0.821		

N_2, Nitrogen; *v.* p. 17

Ne, Neon

p in atm.; v = 1.0000 at 0°C and 1 atm.; range, 0 to 95 atm. (53, 54, 147)

−207.9°C	$pv = 0.2388{\scriptstyle 5} - 0.0_21231p + 0.0_5177p^2 + 0.0_9894p^3$
−182.5°C	$pv = 0.3318 - 0.0_3365p + 0.0_5225p^2$
−150°C	$pv = 0.4507{\scriptstyle 5} + 0.0_54p + 0.0_5136p^2$
−100°C	$pv = 0.6337 + 0.0_3288p + 0.0_650p^2$
− 50°C	$pv = 0.8166 + 0.0_3407p + 0.0_635p^2$
0°C	$pv = 0.9995 + 0.0_3530p$
+100°C	$pv = 1.3653 + 0.0_3584p$
200°C	$pv = 1.7312 + 0.0_3609p$
300°C	$pv = 2.0970 + 0.0_3631p$
400°C	$pv = 2.4629 + 0.0_3607p$

Leiden Temperature Scale

v = 1.0000 at 0°C and 1 atm. (28, 101)

p, atm.	pv	p, atm.	pv
+20.00°C		0.00°C	
22.804	1.0835	22.064	1.0089
25.015	1.0852	23.555	1.0103
26.575	1.0863	25.867	1.0121
29.090	1.0872	28.468	1.0135
32.572	1.0897	30.790	1.0147
34.887	1.0902	39.753	1.0168
35.423	1.0917	44.892	1.0196
37.812	1.0928	59.777	1.0265
39.168	1.0928	66.104	1.0307
44.762	1.0955	74.059	1.0359
54.149	1.1003	79.108	1.0392
59.717	1.1026	84.662	1.0408
65.021	1.1059		
77.360	1.1131		
82.545	1.1160		
88.239	1.1186		
93.298	1.1220		
−103.01°C		−141.22°C	
35.558	0.6304	33.840	0.4846
36.697	0.6302	37.707	0.4852
40.610	0.6324	38.581	0.4853
42.107	0.6329	43.319	0.4869
55.136	0.6369	49.881	0.4875
58.583	0.6384	51.916	0.4878
78.110	0.6481	66.471	0.4927
		78.558	0.4970
−182.60°C		−200.08°C	
32.067	0.3210	26.214	0.2494
32.988	0.3208	28.402	0.2483
36.438	0.3205	31.417	0.2469
36.880	0.3205	34.268	0.2451
41.371	0.3196	34.285	0.2451
42.533	0.3194	39.843	0.2425
49.943	0.3189	39.891	0.2423
50.514	0.3186	46.517	0.2394
63.320	0.3179	46.529	0.2392
		47.951	0.2388
		61.657	0.2338
		67.456	0.2317
		73.850	0.2302
		79.923	0.2293
−208.10°C		−213.08°C	
24.071	0.2151	23.086	0.1925
28.844	0.2114	24.810	0.1911
31.948	0.2088	26.673	0.1893
37.856	0.2041	29.365	0.1862
41.798	0.2010	32.441	0.1829
58.472	0.1897	37.418	0.1776
64.451	0.1867	53.896	0.1611
69.692	0.1844	59.769	0.1565
74.532	0.1822	66.271	0.1522
79.228	0.1804	72.858	0.1503
		79.698	0.1491

p, atm.	pv
−217.52°C	
21.349	0.1730
22.997	0.1707
24.686	0.1683
26.848	0.1652
30.042	0.1607
32.795	0.1564
49.930	0.1393
53.528	0.1353
59.618	0.1301
64.975	0.1269
71.649	0.1253
79.417	0.1256

O_2, Oxygen

p, atm.	pv (3)				p, atm.	pv (3)	
	0°C	15.65°C	99.50°C	199.50°C		0°C	15.6°C
1	**1.0000**				1	**1.0000**	
100	0.9265	1.0045	1.3750		500	1.1570	
200	0.9140	0.9945	1.4000	1.8190	1000	1.7360	1.8000
300	0.9625	1.0420	1.4530	1.8850	1200	1.9620	2.0268
400	1.0515	1.1250	1.5320	1.9610	1400	2.1798	2.2470
500	1.1560	1.2270	1.6220	2.0500	1600	2.3960	2.4640
600	1.2690	1.3370	1.7200	2.1420	1800	2.6073	2.6793
700	1.3855	1.4515	1.8270	2.2415	2000	2.8160	2.8880
800	1.5030	1.5660	1.9340	2.3430	2200	3.0217	3.0932
900	1.6200	1.6820	2.0415	2.4465	2400	3.2244	3.2976
1000	1.7355	1.7980	2.1510		2600	3.4229	3.4996
					2800	3.6176	3.6946
					3000		3.8880

p in atm.; v = 1.0000 at 0°C and 1 atm.; range, 0 to 100 atm. (52, 67)

0°C	$pv = 1.0010 - 0.0_3994p + 0.0_5219p^2$
20°C	$pv = 1.0742{\scriptstyle 5} - 0.0_3753p + 0.0_5150p^2$
50°C	$pv = 1.1842 - 0.0_3491p + 0.0_5170p^2$
100°C	$pv = 1.3674 - 0.0_3160p + 0.0_5137p^2$
0°C	$pv = 1.0010 - \frac{0.0_3958}{v} + \frac{0.0_5206}{v^2}$
20°C	$pv = 1.0742{\scriptstyle 5} - \frac{0.0_3804}{v} + \frac{0.0_5206}{v^2}$

Leiden Temperature Scale

pv = 1.0000 at 0°C and 1 atm. (96)

p, atm.	pv	p, atm.	pv
−40.01°C		−80.00°C	
5.755	0.8462	6.445	0.6926
7.385	0.8432	7.300	0.6902
8.559	0.8416	7.918	0.6892
9.382	0.8403		
−102.49°C		−109.99°C	
4.759	0.6105	5.594	0.5788
5.783	0.6076	6.218	0.5767
6.507	0.6051	6.684	0.5745
7.029	0.6037		
−113.94°C		−116.01°C	
5.470	0.5642	4.506	0.5594
6.092	0.5613	5.422	0.5557
6.501	0.5597	6.008	0.5534
		6.486	0.5512

p, atm.	pv	p, atm.	pv
−116.03°C		−117.01°C	
3.841	0.5616	4.493	0.5555
4.533	0.5596	5.385	0.5517
		5.965	0.5496
		6.389	0.5478
−118.58°C		−124.95°C	
3.799	0.5520	2.882	0.5316
5.910	0.5433	3.715	0.5276
6.254	0.5421	5.160	0.5213
		5.688	0.5190
		6.013	0.5171
−135.29°C		−145.39°C	
3.550	0.4878	3.375	0.4492
4.838	0.4816	5.007	0.4387
5.599	0.4773		

p, atm.	pv
−152.56°C	
3.251	0.4213
4.636	0.4117
4.854	0.4102

v = 1.0000 at 0°C and 1 atm. (137); Leiden temperature scale

p, atm.	pv	p, atm.	pv	p, atm.	pv
0°C		15.6°C		20°C	
36.20	0.9685	34.10	1.0322	35.61	1.0499
38.77	0.9661	44.19	1.0252	40.49	1.0467
46.90	0.9590	56.70	1.0168	46.10	1.0427
47.15	0.9589			51.38	1.0392
54.74	0.9528			57.04	1.0358
				62.43	1.0329

Leiden Temperature Scale
v = 1.0000 at 0°C and 1 atm. (104)

p, atm.	pv	p, atm.	pv
−40.05°C		−80.03°C	
21.142	0.8218	21.010	0.6550
28.034	0.8112	27.295	0.6388
34.794	0.7992	33.475	0.6221
41.818	0.7898	34.178	0.6213
49.255	0.7806	39.240	0.6086
55.425	0.7713	43.247	0.5976
61.030	0.7642	44.613	0.5949
		50.430	0.5772
		61.880	0.5464
−102.46°C		−109.97°C	
20.118	0.5594	20.010	0.5244
26.932	0.5344	25.330	0.5022
31.601	0.5155	29.977	0.4804
37.564	0.4910	35.427	0.4544
42.513	0.4710	38.979	0.4346
48.720	0.4420	45.687	0.3989
54.588	0.4127	51.130	0.3618
60.474	0.3811	56.200	0.3220
		56.655	0.3174
		60.867	0.2770
−113.97°C		−116.01°C	
20.149	0.5044	22.300	0.4835
24.462	0.4847	27.849	0.4560
28.893	0.4624	32.648	0.4297
33.731	0.4370	37.468	0.4012

p, atm.	pv	p, atm.	pv
−113.97°C		−116.01°C	
33.758	0.4369	43.947	0.3541
37.979	0.4133	50.445	0.2836
43.890	0.3739	50.506	0.2816
48.304	0.3385	52.446	0.2477
51.059	0.3061	53.469	0.2213
52.543	0.2951	54.200	0.1959
54.066	0.2672	54.319	0.1638
56.761	0.2073	54.635	0.1792
58.518	0.1754	55.050	0.1667

p, atm.	pv
−116.99°C	
20.264	0.4891
22.298	0.4783
26.413	0.4579
30.248	0.4371
34.117	0.4144
37.210	0.3958
43.662	0.3458
48.344	0.2936
49.507	0.2790
51.297	0.2388
52.072	0.1745
52.218	0.1671
52.343	0.1989
52.649	0.1776
53.000	0.1587

p_0, atm.	100α (3)			100β (3)	
	0 to 15.6°C	0 to 99.5°C	99.5 to 199.5°C	0 to 15.6°C	0 to 99.5°C
100	0.538	0.486		0.480	0.492
200	0.561	0.534	0.300	0.570	0.613
300	0.528	0.512	0.297	0.641	0.696
400	0.450	0.459	0.280	0.691	0.731
500	0.388	0.405	0.264	0.697	0.740
600	0.341	0.357	0.245	0.737	
700	0.301	0.320	0.226		
800	0.270	0.288	0.212	0.705	
900	0.248	0.261	0.198		
1000	0.233	0.241		0.679	
1200	0.212			0.668	
1500	0.190			0.657	
1800	0.174				
2000	0.165			0.602	
2400	0.148			0.580	
2500	0.145				
2800	0.137			0.538	
3000	0.134				

p, m Hg	100α (52)		$\frac{1}{v}$	100β (52)	
	0 to 50°C	0 to 100°C		0 to 50°C	0 to 100°C
0	0.3660	0.3660	0	0.3660	0.3660
1	0.3679	0.3676	1	0.3677	0.3676
5	0.3752	0.3739	5	0.3739	0.3734
10	0.3842	0.3817	10	0.3817	0.3809
15	0.3932	0.3894	15	0.3894	0.3882
20	0.4019	0.3971	20	0.3970	0.3956
25	0.4107	0.4047	25	0.4044	0.4028
30	0.4193	0.4123	30	0.4117	0.4101
35	0.4279	0.4199	35	0.4190	0.4174
40	0.4364	0.4274	40	0.4262	0.4247
45	0.4446	0.4347	45	0.4337	0.4322
50	0.4530	0.4420	50	0.4411	0.4396
55	0.4614	0.4492	55	0.4488	0.4472
60	0.4696	0.4563	60	0.4565	
65	0.4777	0.4632	65	0.4642	
70	0.4856	0.4701			
75	0.4935	0.4768			

p, respectively p_0 = 1 atm. (70)

100α		100β	
0°C	0 to 100°C	0°C	0 to 100°C
0.3675	0.3672	0.3672	0.3671

Xe, Xenon

v = 1.000 at 0°C and 1 atm. (113)

p, atm.	pv	p, atm.	pv	p, atm.	pv
11.2°C				237.3°C	
25.65	0.697	36.39	0.628	53.53	1.397
26.62	0.691	38.42	0.612	57.97	1.389
27.68	0.685	40.69	0.598	63.21	1.377
28.79	0.677	43.24	0.576	69.62	1.375
30.07	0.670	46.22	0.552	77.54	1.359
31.40	0.659	49.39	0.522	88.15	1.354
32.92	0.650	53.20	0.437	102.55	1.357
34.57	0.640				

Air

p, atm.	pv (3)			
	0°C	15.70°C	99.40°C	200.4°C
1	**1.0000**			
100	0.9730	1.0389	1.4030	
150	0.9840	1.0555	1.4310	1.8430
200	1.0100	1.0855	1.4670	1.8860
250	1.0490	1.1260	1.5110	1.9340
300	1.0975	1.1740	1.5585	1.9865
350	1.1540	1.2250	1.6085	2.0410
400	1.2145	1.2835	1.6625	2.0960
450	1.2765	1.3460	1.7200	2.1530
500	1.3400	1.4110	1.7815	2.2110
550	1.4040	1.4740	1.8440	2.2700
600	1.4700	1.5375	1.9060	2.3300
650	1.5365	1.6015	1.9670	2.3900
700	1.6020	1.6670	2.0300	2.4515
750	1.6690	1.7340	2.0930	2.5130
800	1.7345	1.8000	2.1555	2.5750
850	1.7990	1.8655	2.2180	2.6370
900	1.8640	1.9300	2.2830	2.7000
950	1.9280	1.9960	2.3490	2.7640
1000	1.9920	2.0600	2.4150	2.8280

p, atm.	pv (3)		
	0°C	15.7°C	45.10°C
1	**1.0000**		
500	1.3400		
1000	1.9990	2.0615	2.1765
1100	2.1329	2.1912	2.3067
1200	2.2596	2.3196	2.4360
1300	2.3842	2.4440	2.5610
1400	2.5081	2.5676	2.6838

Air.—(*Continued*)

p, atm.	*pv* (3) 0°C	15.7°C	45.10°C
1500	2.6310	2.6902	2.8072
1600	2.7528	2.8112	2.9320
1700	2.8738	2.9325	3.0540
1800	2.9916	3.0510	3.1725
1900	3.1103	3.1692	3.2927
2000	3.2260	3.2860	3.4100
2100	3.3400	3.4209	3.5248
2200	3.4540	3.5156	3.6388
2300	3.5661	3.6294	3.7547
2400	3.6804	3.7428	3.8688
2500	3.7912	3.8550	3.9837
2600	3.9000	3.9650	4.0963
2700	4.0081	4.0770	4.2052
2800	4.1146	4.1860	4.3148
2900	4.2195	4.2934	4.4225
3000	4.3230	4.3980	4.5285

p in atm.; *pv* = 1.0000 at 0°C and 1 atm.; range, 0 to 100 atm. (53)

0°C	$pv = 1.0006 - 0.0_3603p + 0.0_5302p^2$
50°C	$pv = 1.1838 - 0.0_3141p + 0.0_5217p^2$
100°C	$pv = 1.3668 + 0.0_3159p + 0.0_5179p^2$
150°C	$pv = 1.5500 + 0.0_3380p + 0.0_5135p^2$
200°C	$pv = 1.7328 + 0.0_3550p + 0.0_5105p^2$

Leiden Temperature Scale

pv = 1.0000 at 0°C and 1 atm. (108)

p, atm.	*pv*	*p*, atm.	*pv*
20.00°C		−70.09°C	
28.548	1.0654	52.810	0.6611
34.103	1.0637	58.860	0.6533
42.747	1.0613		
57.300	1.0598		
61.426	1.0595		
−84.08°C		−103.48°C	
48.031	0.5979	40.760	0.5099
52.753	0.5890	43.411	0.5024
56.250	0.5830	45.017	0.4979
		48.400	0.4882

p atm.	*pv*	*p*, atm.	*p*
−122.03°C		−129.97°C	
34.122	0.4232	30.961	0.3864
36.736	0.4112	33.458	0.3717
39.458	0.3985	35.729	0.3580
−135.00°C		140.00°C	
28.877	0.3627	27.055	0.3374
31.113	0.3476	30.174	0.3106
33.009	0.3337		

p, atm.	*pv*
−145.05°C	
25.033	0.3126
26.721	0.2947
27.876	0.2805

p, atm.	100α (3) 0 to 15.7°C	0 to 99.4°C	99.4 to 200.4°C	100β (3) 0 to 15.7°C	0 to 99.4°C
100		0.444		0.446	0.462
200	0.475	0.455	0.287	0.541	0.552
300	0.436	0.422	0.275	0.616	0.600
400	0.370	0.371	0.261	0.621	0.617
500	0.327	0.331	0.241	0.637	0.617
600	0.294	0.294	0.222	0.616	
700	0.265	0.269	0.207		
800	0.241	0.244	0.194	0.605	
900	0.223	0.226	0.182		
1000	0.206	0.214	0.171	0.567	
1200	0.177			0.504	
1500	0.144			0.467	
1800	0.124			0.439	
2000	0.116			0.417	
2400	0.108			0.403	
2500	0.107				
2800	0.110				
3000	0.110				

p, m Hg	100α (53, 55) 0 to 50°C	0 to 100°C	0 to 150°C	0 to 200°C
1	0.3676	0.3674	0.3673	0.3672
10	0.3803	0.3785	0.3769	0.3760
20	0.3943	0.3904	0.3876	0.3855
30	0.4078	0.4019	0.3978	0.3947
40	0.4203	0.4126	0.4072	0.4031
50	0.4315	0.4224	0.4156	0.4106
60	0.4412	0.4309	0.4230	0.4172
70	0.4502	0.4385	0.4295	0.4230
75	0.4543	0.4418	0.4325	0.4255

$\frac{1}{v}$	100β (53, 55) 0 to 50°C	0 to 100°C	0 to 150°C	0 to 200°C
1	0.3675	0.3675	0.3674	0.3674
10	0.3798	0.3794	0.3790	0.3788
20	0.3940	0.3932	0.3925	0.3919
30	0.4080	0.4067	0.4056	0.4048
40	0.4216	0.4201	0.4186	0.4178
50	0.4351	0.4337	0.4322	
60	0.4486			
65	0.4557			

p, atm.	100α, constant pressure (141) 0 to 100°C	0 to 16°C	0 to −35°C	0 to −78.5°C	0 to −103.5°C	0 to −130°C	0 to −135°C	0 to −140°C	0 to −145°C
10	0.375	0.376							
20	0.383	0.387		0.401	0.410	0.427		0.440	0.450
30	0.392	0.398		0.420	0.434	0.462	0.477	0.492	0.519*
40	0.402	0.408		0.438	0.461	0.508	0.544	0.632	
50	0.410	0.419	0.430	0.457	0.487	0.569	0.619		
60	0.418	0.429	0.442	0.476	0.512	0.610	0.622		
70	0.425	0.438	0.454	0.494	0.536	0.612			
80	0.431	0.446	0.467	0.512	0.557	0.607			
90	0.437	0.452	0.479	0.527	0.572				
100	0.441	0.458	0.489	0.537	0.579				
110	0.445	0.462	0.497	0.545	0.580				
120	0.449	0.465	0.501	0.550	0.577				
130		0.468		0.551	0.571				

* *p* = 29 atm.

𝔅-Table, Chemical Compounds

Standard arrangement

NH_3, Ammonia (63)

v = 39 cm^3/g		v = 44 cm^3/g		v = 49 cm^3/g		v = 54 cm^3/g		v = 59 cm^3/g	
t, °C	p, atm.	t, °C	p, atm.	t, °C	p, atm.	t, °C	p, atm.	t, °C	p, atm.
75.14	32.522	69.65	28.992	62.00	25.709	61.96	23.891	55.70	21.597
75.21	32.509	75.86	29.951	69.68	26.750	69.69	24.825	60.31	22.105
80.16	33.371	79.86	30.547	75.81	27.532	75.24	25.475	65.98	23.075
84.73	34.153	89.42	31.863	79.77	28.059	79.69	25.955	73.57	23.553
89.51	34.925	94.03	32.522	84.81	28.689	84.66	26.536	73.83	23.576
93.81	35.628	100.32	33.416	89.37	29.262	84.60	26.511	79.16	24.114
100.32	36.703	104.94	34.057	94.09	29.858	89.35	27.058	79.71	24.172
105.66	37.584	110.81	34.864	100.37	30.638	94.06	27.574	83.22	24.537
110.78	38.397	115.88	35.532	105.02	31.201	100.38	28.274	88.06	25.022
115.95	39.234	121.29	36.261	111.18	31.953	104.88	28.757	92.82	25.514
121.25	40.047	127.01	37.011	115.91	32.508	111.05	29.422	97.61	25.992
				121.14	33.142	115.94	29.938	103.46	26.561
				126.66	33.788	121.21	30.507	109.25	27.125
				131.91	34.384	126.55	31.070	115.10	27.699
						132.00	31.632	119.34	28.084
								123.92	28.526
								128.81	29.016
								134.89	29.549
								140.47	30.079
								146.23	30.629
								152.47	31.203
								158.70	31.780
								164.31	32.292

v is expressed in cm^3/g (75)

t, °C \ v	1300	500	300	200	150	115	85.5
	p (kg/cm^2)						
−35	0.8935						
−30	0.9110						
−20	0.9512						
−10		2.5017					
0	1.0305	2.6116					
+ 5			4.3267				
10			4.4212				
15				6.573			
25	1.1288	2.8788	4.7000	6.866	8.905		
30					9.105	11.499	
35						11.770	

t, °C \ v	1300	500	300	200	150	115	85.5
	p (kg/cm^2)						
50	1.2263	3.1403	5.1504	7.571	9.885	12.566	16.245
100	1.4199	3.6549	6.0256	8.919	11.730	15.051	19.745
150	1.6128	4.1639	6.8854	10.231	13.510	17.419	23.026
200	1.8050	4.6695	7.7376	11.524	15.257	19.733	26.204
250		5.1735	8.5847	12.807	16.986	22.014	29.322
300			9.4291	14.084	18.703	24.278	

p, respectively p_0 = 1 atm. (70)

100α		100β	
0°C	0 to 100°C	0°C	0 to 100°C
0.386	0.380	0.380	0.377

CO_2, Carbon dioxide

p, atm.	Values of pv (3)									
	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C
1	**1.0000**									
50	0.1050	0.1145	0.6800	0.7750	0.8500	0.9200	0.9840	1.0430	1.0960	1.1530
75	0.1530	0.1630	0.1800	0.2190	0.6200	0.7470	0.8410	0.9180	0.9880	1.0515
100	0.2020	0.2130	0.2285	0.2550	0.3090	0.4910	0.6610	0.7770	0.8725	0.9535
125	0.2490	0.2620	0.2785	0.3000	0.3350	0.3950	0.5100	0.6430	0.7590	0.8580
150	0.2950	0.3090	0.3260	0.3460	0.3770	0.4190	0.4850	0.5750	0.6805	0.7815
175	0.3405	0.3550	0.3725	0.3930	0.4215	0.4570	0.5055	0.5730	0.6515	0.7410
200	0.3850	0.4010	0.4190	0.4400	0.4675	0.5000	0.5425	0.5955	0.6600	0.7315
225	0.4305	0.4455	0.4655	0.4875	0.5130	0.5425	0.5825	0.6285	0.6815	0.7460
250	0.4740	0.4900	0.5100	0.5335	0.5580	0.5865	0.6250	0.6670	0.7135	0.7690
275	0.5170	0.5340	0.5545	0.5775	0.6040	0.6330	0.6675	0.7070	0.7515	0.8015
300	0.5595	0.5775	0.5985	0.6225	0.6485	0.6765	0.7100	0.7485	0.7900	0.8375
350	0.6445	0.6640	0.6850	0.7090	0.7365	0.7650	0.7980	0.8325	0.8725	0.9135
400	0.7280	0.7475	0.7710	0.7950	0.8230	0.8515	0.8840	0.9180	0.9560	0.9660
450	0.8090	0.8310	0.8550	0.8800	0.9075	0.9365	0.9690	1.0035	1.0400	1.0775
500	0.8905	0.9130	0.9380	0.9630	0.9900	1.0210	1.0540	1.0880	1.1240	1.1610
550	0.9700	0.9935	1.0200	1.0465	1.0740	1.1035	1.1370	1.1720	1.2085	1.2430

CO_2, Carbon dioxide.—(*Continued*)

p, atm.	Values of *pv* (3)									
	0°C	10°C	20°C	30°C	40°C	50°C	60°C	70°C	80°C	90°C
600	1.0495	1.0730	1.0995	1.1275	1.1570	1.1865	1.2190	1.2540	1.2900	1.3265
650	1.1275	1.1530	1.1800	1.2075	1.2375	1.2680	1.3010	1.3360	1.3725	1.4085
700	1.2055	1.2320	1.2590	1.2890	1.3190	1.3500	1.3825	1.4170	1.4535	1.4900
750	1.2815	1.3105	1.3395	1.3700	1.4000	1.4315	1.4640	1.4985	1.5335	1.5705
800	1.3580	1.3870	1.4170	1.4475	1.4790	1.5105	1.5435	1.5780	1.6140	1.6505
850	1.4340	1.4625	1.4935	1.5245	1.5570	1.5885	1.6225	1.6575	1.6925	1.7285
900	1.5090	1.5385	1.5685	1.6000	1.6325	1.6650	1.6995	1.7345	1.7710	1.8075
950	1.5830	1.6115	1.6430	1.6740	1.7065	1.7395	1.7745	1.8100	1.8470	1.8845
1000	1.6560	1.6850	1.7160	1.7480	1.7800	1.8140	1.8475	1.8840	1.9210	1.9590

p, atm.	100°C	137°C	198°C	258°C	*p*, atm.	100°C	137°C	198°C	258°C
50	1.2065	1.3800			450	1.1190	1.2880	1.6160	1.9280
75	1.1180	1.3185	1.6150	1.8670	500	1.2005	1.3620	1.6775	
100	1.0300	1.2590	1.5820	1.8470	550	1.2830	1.4400	1.7450	
125	0.9470	1.2050	1.5530	1.8310	600	1.3655	1.5180	1.8120	
150	0.8780	1.1585	1.5295	1.8180	650	1.4475	1.5960	1.8835	
175	0.8320	1.1230	1.5100	1.8095	700	1.5285	1.6760	1.9560	
200	0.8145	1.0960	1.4960	1.8040	750	1.6100	1.7565	2.0330	
225	0.8175	1.0835	1.4890	1.8035	800	1.6890	1.8355	2.1080	
250	0.8355	1.0810	1.4870	1.8060	850	1.7680	1.9150	2.1860	
275	0.8600	1.0885	1.4875	1.8115	900	1.8460	1.9940	2.2600	
300	0.8900	1.1080	1.4935	1.8200	950	1.9230	2.0720	2.3350	
350	0.9615	1.1565	1.5210	1.8465	1000	1.9990			
400	1.0385	1.2175	1.5630	1.8830					

COMPRESSIBILITY IN THE NEIGHBORHOOD OF SATURATION

p in atm.; *v* = 1.0000 at 0°C and 1 atm. (62)

v	*p*, atm.	*pv*
25.55°C		
0.008573	63.12	0.5411
0.007812	64.36	0.5028
28.15°C		
0.009338	63.44	0.5924
0.008565	65.19	0.5583

v	*p*, atm.	*pv*
28.15°C		
0.007807	66.75	0.5212
0.007030	67.99	0.4780
0.006950	68.19	0.4739
0.006673	68.39	0.4564

BORDER CURVE IN THE NEIGHBORHOOD OF THE CRITICAL POINT (62)

Beginning condensation			End condensation		
t, °C	*v*	*p*, atm.	*t*, °C	*v*	*p*, atm.
30.05	0.005594	71.47	30.11	0.003328	71.53
30.82	0.004833	72.72$_5$	30.81	0.003725	72.74

Critical temperature = 30.98°C; critical pressure = 72.93 atm.; critical volume = 0.00443; *v* = 1.0000 at 0°C and 1 atm. (62)

v	*p*, atm.	*pv*	*v*	*p*, atm.	*pv*
Critical isothermal (30.98°C)			Critical isothermal (30.98°C)		
0.010068	63.36	0.6379	0.003959	72.96	0.2888
0.009314	65.39	0.6090	0.003656	72.99$_5$	0.2669
0.008582	67.22	0.5769	0.003296	73.53	0.2423
0.007809	69.08$_5$	0.5395	0.003230	73.89	0.2387
0.007031	70.73	0.4973	0.003051	75.43	0.2302
0.006275	71.95	0.4515	0.002862	79.43	0.2273
0.005483	72.74$_5$	0.3988	0.002721	86.10	0.2343
0.005102	72.87	0.3718	0.002593	95.70	0.2482
0.004777	72.93	0.3484	0.002509	106.18	0.2664
0.004403	72.94	0.3211	0.002435	119.35	0.2906
0.004254	72.98	0.3104	0.002362	138.65	0.3275

v	*p*, atm.	*pv*	*v*	*p*, atm.	*pv*
31.89°C			34.02°C		
0.010086	63.87	0.6442	0.010067	65.18	0.6562
0.009314	65.99$_5$	0.6147	0.009337	67.29$_5$	0.6283
0.008570	67.94$_5$	0.5823	0.008560	69.49	0.5948
0.007771	70.03	0.5442	0.007791	71.64	0.5581
0.007017	71.68	0.5030	0.007023	73.65	0.5173
0.006267	73.03$_5$	0.4577	0.006255	75.34	0.4712
0.005528	73.94	0.4087	0.005529	76.60$_5$	0.4236
0.005117	74.24	0.3799	0.004672	77.57$_5$	0.3624
0.004742	74.44	0.3530	0.003971	78.38$_5$	0.3113
0.004364	74.56	0.3254	0.003243	81.11	0.2630
0.003942	74.69	0.2944	0.002955	86.16	0.2546
0.003610	75.00	0.2707	0.002746	95.02	0.2609
0.003228	76.20	0.2460	0.002614	105.95	0.2770
0.002883	82.02	0.2365	0.002510	119.53	0.3000
0.002717	89.90	0.2443	0.002426	136.66	0.3316
0.002593	99.77	0.2587			
0.002503	111.45	0.2790			
0.002439	122.79	0.2995			
0.002377	136.71	0.3249			
37.09°C			41.95°C		
0.010863	64.56	0.7013	0.011546	64.85	0.7487
0.010093	66.90	0.6752	0.010794$_5$	67.28	0.7262
0.009339	69.20	0.6471	0.010047	69.81	0.7014
0.008554	71.73	0.6135	0.009211	72.78	0.6704
0.007810	74.11	0.5788	0.008486	75.48	0.6405
0.007059	76.40	0.5394	0.007640	78.57	0.6003
0.006287	78.58$_5$	0.4940	0.006915	81.31	0.5622
0.005525	80.47	0.4446	0.006181	84.04	0.5194
0.004770	82.11	0.3917	0.005320	87.18	0.4638
0.004011	83.89	0.3365	0.004530	90.13	0.4082
0.003230	88.89	0.2871	0.003778	94.10	0.3555
0.002799	103.08	0.2885	0.003087	105.01	0.3242
0.002609	119.27	0.3112	0.002817	117.96	0.3323
0.002495	136.01	0.3393	0.002642	134.85	0.3563

v	p, atm.	pv	v	p, atm.	pv
48.10°C			57.75°C		
0.012311	65.20	0.8027	0.013174	66.27	0.8730
0.011572	67.69	0.7833	0.012356	69.20	0.8550
0.010787_5	70.52	0.7607	0.011586	72.18	0.8363
0.009970	73.61	0.7339	0.010807	75.42	0.8151
0.009232	76.61	0.7073	0.010009	78.99	0.7906
0.008442	80.07	0.6760	0.009271	82.49	0.7648
0.007678	83.38	0.6402	0.008482	86.62	0.7347
0.006899	87.07	0.6007	0.007668	91.16	0.6990
0.006118	90.90	0.5561	0.006930	95.79	0.6638
0.005380	94.78	0.5099	0.006113	101.32	0.6194
0.004570	99.62	0.4552	0.005372	107.06	0.5751
0.003823	105.50	0.4033	0.004596	114.45	0.5260
0.003129_5	119.38	0.3736	0.003795	126.10	0.4786
0.002864	135.56	0.3883	0.003421	135.81	0.4647

p, m Hg	100α (25)			100β (25)		
	0 to 20°C	0 to 40°C	0 to 100°C	0 to 20°C	0 to 40°C	0 to 100°C
0.518	0.3713	0.3710	0.3707	0.3734	0.3730	0.3726
0.998	0.3760	0.3754	0.3741			
1.377	0.3797	0.3791	0.3770			

p, respectively p_0 = 1 atm. (70)

100α		100β	
0°C	0 to 100°C	0°C	0 to 100°C
0.3750	0.3722	0.3723	0.3711

VALUES OF pv

v = 1.0000 at 0°C and 1 atm. (62)

$\frac{1}{v}$	25.55°C	28.15°C	30.98°C	31.89°C	34.02°C	37.09°C	41.95°C	48.10°C	57.75°C
80									0.8583
100			0.6355	0.6411	0.6538	0.6719	0.6997	0.7349	0.7903
120		0.5467	0.5653	0.5715	0.5844	0.6036	0.6335	0.6712	0.7285
140		0.4839	0.5037	0.5094	0.5240	0.5440	0.5746	0.6135	0.6743
160			0.4499	0.4566	0.4708	0.4918	0.5237	0.5640	0.6273
180			0.4039	0.4106	0.4254	0.4466	0.4796	0.5212	0.5864
200			0.3646	0.3716	0.3863	0.4081	0.4416	0.4847	0.5521
220			0.3314	0.3387	0.3494	0.3754	0.4094	0.4536	0.5226
240			0.3041	0.3109	0.3226	0.3477	0.3819	0.4264	0.4991
260			0.2806	0.2875	0.3021	0.3243	0.3597	0.4048	0.4812
280			0.2611	0.2680	0.2825	0.3052	0.3423	0.3872	0.4692
300			0.2448	0.2521	0.2677	0.2915	0.3302	0.3763	
320			0.2333	0.2410	0.2590	0.2835	0.3245	0.3737	
340		0.2058	0.2273	0.2321	0.2554	0.2863	0.3255	0.3817	
360	0.1806	0.2043	0.2305	0.2401	0.2588	0.2900	0.3362		
380	0.1886	0.2140	0.2427	0.2530	0.2742	0.3073			
400	0.2084	0.2379	0.2690	0.2800	0.3031	0.3376			
420	0.2442	0.2780	0.3199	0.3230					
440	0.3118								

Values of $\left(\frac{10^5(v_{t_2} - v_{t_1})}{v_{t_1}(t_2 - t_1)}\right)$ at various pressures (3)

p, atm.	0 to 10°C	10 to 20°C	20 to 30°C	30 to 40°C	40 to 50°C	50 to 60°C	60 to 70°C	70 to 80°C	80 to 90°C	90 to 100°C	100 to 137°C	137 to 198°C	198 to 258°C
50	905		1394	1097	823	695	600	508	520	464			
60	800	1259		1557	1081	853	705	604	560	521			
75	654	1043	2166	18310	2048	1258	916	762	643	595	485	369	260
85	637	872	1425	9079	4965	1813	1222	921	753	696			
100	544	728	1159	2128	5899	3462	1755	1229	928	802	601	420	279
125	522	630	772	1666	1791	2911	2608	1804	1304	1037			
150	474	550	613	922	1114	1575	1855	1835	1484	1247	864	525	313
175	423	493	550	728	842	1061	1335	1370	1374	1228	945	565	330
200	416	449	501	625	695	850	977	1083	1083	1134	934	798	343
250	337	408	461	459	511	656	672	697	778	865	794	616	358
300	322	364	401	418	432	495	542	554	601	627	662	570	364
400	268	314	311	352	346	382	384	414	419	426	466	465	341
500	253	274	266	280	313	323	322	330	329	349	364	386	
600	224	247	255	261	255	274	287	287	283	293	302	317	
800	214	216	215	218	223	219	224	228	226	233	234	243	
1000	175	184	180	183	191	184	198	197	198	204	234		

NO, Nitric oxide

p, atm.	pv (21)				
	+9.0°C	−20°C	−40°C	−60°C	−78.6°C
1	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
30	0.962_5	0.9475	0.936_5	0.921_5	0.893
40	0.950	0.931	0.913_5	0.891	0.779
50	0.938	0.913_5	0.889_5	0.859_5	0.779
60	0.926	0.897	0.864_5	0.824_5	0.709_5
70	0.913_5	0.880_5	0.838_5	0.785	0.642
80	0.902_5	0.863_5	0.812_5	0.764_5	0.573_5
90	0.892	0.845_5	0.789	0.707_5	0.520
100	0.881_5	0.849_5	0.768	0.662	0.475_5
110	0.862	0.813_5	0.747_5	0.617	0.441
120	0.862	0.800	0.727	0.576	0.419
130	0.854_5	0.787	0.711	0.545	0.424
140	0.854_5	0.776	0.692	0.528	0.433_5
150	0.843	0.767	0.674_5	0.518	0.443_5
160	0.837_5	0.758	0.659	0.524	0.452_5

CH_4, Methane (64)*

v, cm³/g	p, atm.	pv	p, atm.	pv	p, atm.	pv
	0°C		50°C		100°C	
	1.00	**1.0000**				
35.104	36.37	0.9156	44.55	1.1216	52.63	1.3250
30.089	41.89	0.9040	51.55	1.1124	61.17	1.3200
25.074	49.21	0.8849	61.20	1.1005	72.96	1.3120
20.059	59.85	0.8610	75.35	1.0840	90.56	1.3028
15.045	76.47	0.8251	98.34	1.0611	119.88	1.2935
10.030	107.25	0.7715	143.66	1.0334	179.61	1.2920
9.026	117.08	0.7579	159.21	1.0306	200.51	1.2980
8.024	129.73	0.7465	179.03	1.0303	227.58	1.3096
	150°C		200°C			
35.104	60.70	1.5282	68.66	1.7286		
30.089	70.68	1.5252	80.09	1.7283		
25.074	84.64	1.5220	96.22	1.7303		
20.059	105.63	1.5196	120.42	1.7324		
15.045	140.95	1.5208	161.76	1.7454		
10.030	214.59	1.5436	250.03	1.7985		
9.026	240.62	1.5576	280.55	1.8161		
8.024	275.10	1.5831	321.92	1.8525		

* *See* (155) for revision of this table.

p, m Hg	t	100α	100β	Lit.
0.760	0 to 100°C	0.3683	0.3680	(64)

p, respectively p_0 = 1 atm. (70)

100α		100β	
0°C	0 to 100°C	0°C	0 to 100°C
0.369	0.3680	0.368	0.3677

CH_3Cl, Methyl chloride

v = 1.0000 at 0°C and 1 atm. (56, 65)

p, atm.	pv	p, atm.	pv
69.9°C		84.95°C	
15.065	1.0251	16.19	1.0909
15.425	1.0190	16.586	1.0834
15.76	1.0115	17.09	1.0734
16.10	1.0062	17.61	1.0665
16.44	0.9966	18.13	1.0561
		18.74	1.0477
		19.36	1.0368
		19.40	1.0367
		20.00	1.0239
		20.68	1.0106
		21.49	0.9969
		22.24	0.9813
99.95°C		115.0°C	
17.67	1.1519	18.26	1.2231
18.26	1.1438	20.12	1.2000
19.02	1.1338	21.57	1.1805
19.86	1.1210	22.99	1.1627
20.76	1.1108	28.99	1.0785
21.82	1.0902	33.53	0.9499
23.15	1.0698	38.30	0.9172
25.14	1.0361	40.66	0.8665
25.94	1.0220		
26.66	1.0112		
27.55	0.9952		
30.71	0.9309		

At 16.8°C (17)	p (mm)	760	1200	1650	2100	2800
	pv	**1.0000**	0.9796	0.9648	0.9533	0.9335

p, respectively p_0 = 1 atm. (70)

100α		100β	
0°C	0 to 100°C	0°C	0 to 100°C
0.403	0.389	0.392	0.385

C_2H_2, Acetylene (150)

p, atm.	pv	
	0°C	25°C
0.5	1.0057	1.0989
1.0	1.0000	1.0937
2.0	0.9891	1.0841
4.0	.9708	1.0684
6.0	.9530	1.0531
8.0	.9360	1.0385
10.0	.9194	1.0255
12.0	.9026	1.0139

C_2H_4, Ethylene

Values of $\left(\frac{10^5(v_{t_2} - v_{t_1})}{v_{t_1}(t_2 - t_1)}\right)$ at various pressures (3)

p, atm.	0 to 10°C	10 to 20°C	20 to 30°C	30 to 40°C	40 to 50°C	50 to 60°C	60 to 70°C	70 to 80°C	80 to 90°C	90 to 100°C	100 to 137.5°C	137.5 to 198.5°C
50		4976	1622	1135	902	744	671	585	539	502	406	332
75	948	1714	3826	3500	2136	1355	1019	834	743	663	516	387
100	661	893	1195	1427	2040	1790	1407	1109	945	847	641	438
125	533	696	769	967	1122	1252	1353	1171	972	875	728	478
150	420	566	619	689	799	917	925	945	941	883	733	504
175	377	468	539	555	640	679	744	746	746	781	699	517
200	354	419	467	486	508	583	611	614	620	629	643	506
250	306	346	362	382	406	439	461	464	492	493	509	456

C_2H_4, Ethylene.—(*Continued*)

p, atm.	0 to 10°C	10 to 20°C	20 to 30°C	30 to 40°C	40 to 50°C	50 to 60°C	60 to 70°C	70 to 80°C	80 to 90°C	90 to 100°C	100 to 137.5°C	137.5 to 198.5°C
300	267	302	305	336	347	351	376	387	392	409	417	397
350	239	265	273	296	297	303	303	335	354	358	352	344
400	212	241	254	261	263	269	274	304	322	324	303	303
450	199	231	234	241	243	249	250	266	281	284	271	275
500	195	227	226	224	230	232	234	242	240	270	243	251
600	177	177	200	199	199	210	203	207	206	216	212	215
700	152	167	177	178	187	185	184	184	191	193	187	188
800	151	154	159	166	167	167	170	173	172	174	172	164
900	148	149	149	149	149	160	157	159	159	157	165	145
1000	138	142	142	145	145	147	147	146	146	150	157	

p, atm.	Values of *pv* (3)							
	0°C	20°C	40°C	60°C	80°C	100°C	137.5°C	198.5°C
1	**1.0000**							
50	0.1755	0.6290	0.8140	0.9535	1.0770	1.1920	1.3736	1.6520
100	0.3100	0.3600	0.4705	0.6680	0.8465	1.0050	1.2466	1.5800
150	0.4405	0.4850	0.5505	0.6490	0.7760	0.9240	1.1780	1.5400
200	0.5650	0.6095	0.6690	0.7440	0.8380	0.9460	1.1740	1.5368
250	0.6870	0.7325	0.7880	0.8560	0.9370	1.0315	1.2284	1.5690
300	0.8055	0.8520	0.9075	0.9720	1.0475	1.1330	1.3100	1.6276
350	0.9229	0.9690	1.0250	1.0875	1.1580	1.2420	1.4060	1.7010
400	1.0365	1.0840	1.1405	1.2020	1.2725	1.3560	1.5104	1.7900
450	1.1465	1.1975	1.2550	1.3175	1.3865	1.4660	1.6150	1.8858
500	1.2555	1.3075	1.3670	1.4310	1.5000	1.5775	1.7212	1.9846
550	1.3640	1.4165	1.4770	1.5420	1.6115	1.6855	1.8290	2.0868
600	1.4725	1.5250	1.5865	1.6520	1.7215	1.7950	1.9376	2.1910
650	1.5785	1.6325	1.6930	1.7610	1.8305	1.9035	2.0450	2.2950
700	1.6835	1.7375	1.7995	1.8670	1.9365	2.0115	2.1526	2.3990
750	1.7865	1.8420	1.9050	1.9720	2.0420	2.1190	2.2604	2.5030
800	1.8880	1.9460	2.0100	2.0775	2.1495	2.2245	2.3684	2.6060
850	1.9900	2.0495	2.1140	2.1820	2.2555	2.3300	2.4762	2.7104
900	2.0905	2.1530	2.2175	2.2865	2.3595	2.4345	2.5848	2.8104
950	2.1900	2.2535	2.3200	2.3900	2.4635	2.5390	2.6916	
1000	2.2890	2.3535	2.4215	2.4925	2.5660	2.6425	2.7980	

p, atm.	0°C	5°C	7.5°C	10°C	20°C	30°C	40°C	50°C
38	0.5955	0.6490	0.6735					
40	0.5330	0.6155	0.6425	0.6685				
41	0.1610							
42	0.1570	0.5730	0.6085	0.6370	0.7320			
43	0.1580	0.5470						
44	0.1600	0.5150	0.5675	0.6030				
45		0.4770			0.6980			
46	0.1645	0.1890	0.5100	0.5620	0.6840			
47		0.1850	0.4670					
48	0.1695	0.1855	0.3300	0.5075			0.8300	
49		0.1875	0.2150	0.4700				
50	0.1755	0.1900	0.2075	0.4200	0.6290	0.7310	0.8140	0.8865
51				0.2900				
52	0.1810	0.1945	0.2060	0.2400	0.5975			
54			0.2090	0.2290	0.5610	0.6905	0.7810	0.8595
56		0.2050	0.2125	0.2270	0.5235			
58			0.5180	0.2285	0.4805			
60	0.2025	0.2145		0.2315	0.4300	0.6195	0.7285	0.8170
65					0.3310	0.5500	0.6805	
70					0.3110	0.4830	0.6310	0.7430
75	0.2425	0.2535		0.2655	0.3110	0.4300	0.5805	0.7045
80	0.2565			0.2785	0.3165	0.3990	0.5390	0.6660
90					0.3370	0.3915	0.4875	0.6060
100	0.3100			0.3305	0.3600	0.4030	0.4710	0.5665

C_2H_4, Ethylene.—(*Continued*)

p, atm.	pv (73)	p, atm.	pv (73)
24.95°C		24.95°C	
1	1.0000	65	0.4681
5	0.9745	70	0.4076
10	0.9443	75	0.3666
15	0.9198	80	0.3493
20	0.8818	85	0.3445
25	0.8495	90	0.3466
30	0.8143	95	0.3524
35	0.7764	100	0.3596
40	0.7364	105	0.3679
45	0.6940	110	0.3774
50	0.6467	115	0.3875
55	0.5949	120	0.3975
60	0.5360	125	0.4081

p, respectively p_0 = 1 atm. (70)

100α		100β	
0°C	0 to 100°C	0°C	0 to 100°C
0.376	0.3734	0.373	0.3721

COEFFICIENTS OF EXPANSION OF VARIOUS GASES AS CALCULATED BY LEDUC (70)

p, respectively p_0 = 1 atm.

Gas	100α		100β		Experimental values	
					100α	100β
	0°C	0 to 100°C	0°C	0 to 100°C	0 to 100°C	0 to 100°C
CO	0.3674	0.3671	0.3671	0.3672	0.3669*	0.3667*
NO	0.3677	0.3673	0.3673	0.3671		
N_2O	0.3761	0.3731	0.3733	0.3718	0.372*	0.368*
HCl	0.3769	0.3733	0.374	0.3720		
C_2H_2	0.3771	0.3738	0.3740	0.3725		
PH_3	0.379	0.375	0.376	0.374		
H_2S	0.382	0.377	0.378	0.376		
Cl_2	0.390	0.383	0.383	0.380	0.383†	0.381†
C_2N_2	0.396	0.387	0.387	0.383	0.388*	0.383*
SO_2	0.398	0.388	0.389	0.384	0.390*	0.384*
$(CH_3)_2O$	0.400	0.391	0.390	0.387		

* Regnault, 20 to 100°C (118).

† Pier (111).

LITERATURE

(For a key to the periodicals see end of volume)

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(40) Guye, *136*, **36**: 402; 12. (41) Guye, *42*, **15**: 561; 17. (42) Guye, *42*, **16**: 46; 18. (43) Guye and Batuecas, *37*, **5**: 532; 22. (44) Guye and Batuecas, *42*, **20**: 308; 23. (45) Guye and Davila, *34*, **141**: 826; 05. (46) Guye, Kovacs, and Wourtzel, *42*, **10**: 332; 12. (47) Guye and Pintza, *34*, **139**: 677; 04. (48) Guye and Pintza, *34*, **141**: 51; 05. *463*, **35**: 569; 08. (49) Henning and Heuse, *96*, **5**: 285; 21.

(50) Heuse, *26*, **15**: 518; 13. (51) Holborn, *8*, **63**: 674; 20. (52) Holborn and Otto, *96*, **10**: 367; 22. (53) Holborn and Otto, *96*, **23**: 77; 24. (54) Holborn and Otto, *96*, **33**: 1; 25. (55) Holborn and Schultze, *8*, **47**: 1089; 15. (56) Holst, *462*, **6**: 48; 15. *168*, No. **144**: 14. (57) Howarth and Burt, *83*, **20**: 544; 25. (58) Jaquerod and Pintza, *34*, **139**: 129; 04. *463*, **35**: 589; 08. (59) Jaquerod and Scheuer, *34*, **140**: 1384; 05.

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P-V-T RELATIONS FOR GAS MIXTURES

Components A	Components B	t, range	p, range	Lit.
A	O_2	At 24.95°C	Up to 125 atm.	(11)
A	N_2	−200 to −183°C	Up to 1200 mm	(8)
A	C_2H_4	At 24.95°C	Up to 125 atm.	(11)
O_2	N_2	At 20° and −141 to −120°C	32 to 56 atm.	(10)
O_2	CO_2	9 to 25°C	58 to 140 atm.	(9)
O_2	C_2H_4	At 24.95°C	Up to 125 atm.	(11)
H_2	CO_2	15 to 32°C	30 to 120 atm.	(13)
H_2	N_2	0 and 20°C	24 to 205 atm.	(14)
		0–300°C	Up to 1000 atm.	(16,17)
H_2O	NH_3	98 to 200°C	1 atm.	(15)
H_2O	CO_2	98 to 200°C	1 atm.	(15)
HCl	PH_3	24 to 54°C	Up to 80 atm.	(1)
HCl	CO_2	20 to 52°C	30 to 96 atm.	(6)
HCl	C_2H_6	13 to 53°C	32 to 78 atm.	(12)
SO_2	CH_3Cl			(3)
SO_2	$(CH_3)_2O$	56, 77, 109°C	6 to 37 atm.	(2)
Natural gas		15°C	Up to 40 atm.	(4, 5)
Natural gas		19 to 24°C	Up to 48 atm.	(7)

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(For a key to the periodicals see end of volume)

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N_2, NITROGEN

LOUIS DÉCOMBE

COMPRESSIBILITY

Low Pressures

At 16°C and between p = 76 and 152 cm Hg, $\frac{p_0 v_0}{pv} = 1 + 3 \times 10^{-6} (p - p_0)$ (13).

At 14.9°C and between $p_0 = \frac{1}{2}$ and p = 1 atm., $\frac{p_0 v_0}{pv} = 1.00015$ (15).

Between p = 1 and 1.4 m Hg and with unit of v = v at 0°C and 1 m Hg, $pv = 1.000571 - 0.000571p$, at 0°C; and $pv = 1.366966 + 0.000347p$, at 100°C (4).

Between p = 1 and 27 atm., and 4.1 and 5.2°C, $\frac{pv}{p_0 v_0} = 1 + A\left(\frac{v_0}{v} - 1\right) + B\left(\frac{v_0}{v} - 1\right)^2$, where $\log_{10}(-A) = \bar{4}.8389375$ and $\log_{10} B = \bar{6}.8476020$ (16).

High Pressures

MEASUREMENTS BY AMAGAT (1); *cf.* (19, 20)

Volume unit = v at 0° and 1 atm.

p, atm.	pv 0°	pv 16.0°	pv 43.6°	p, atm.	pv 0°	pv 16.0°	pv 43.6°
1	1.0000			1600	2.8456	2.9088	3.0264
100	0.9910			1700	2.9665	3.0328	3.1509
200	1.0390			1800	3.0861	3.1536	3.2715
300	1.1360			1900	3.2081$_5$	3.2765	3.3962
400	1.2570			2000	3.3270	3.3980	3.5170
500	1.3900			2100	3.4461	3.5175	3.6361
600	1.5260			2200	3.5640	3.6366	3.7554
700	1.6625			2300	3.6823	3.7536	3.8720
800	1.8016	1.8648		2400	3.8004	3.8724	3.9924
900	1.9368	2.0016	2.1186	2500	3.9200	3.9900	4.1100
1000	2.0700	2.1340	2.2420	2600	4.0378	4.1054	4.2276
1100	2.2038$_5$	2.2682	2.3782	2700	4.1553	4.2228	4.3416
1200	2.3352	2.4000	2.5140	2800	4.2700	4.3386	4.4576
1300	2.4654$_5$	2.5285	2.6455	2900	4.3558	4.4544	4.5733
1400	2.5942	2.6558	2.7748	3000	4.4970	4.5675	4.6890
1500	2.7202$_5$	2.7810	2.8995				

Unit of v = v at 16° and 1 atm.

p, atm.	pv, 16.0°	p, atm.	pv, 16.0°	p, atm.	pv, 16.0°	p, atm.	pv, 16.0°
1	1.0000	65	0.9897	130	1.0050	240	1.0783
5	0.9987	70	0.9900	135	1.0076	250	1.0867
10	0.9971	75	0.9904	140	1.0103	260	1.0954
15	0.9957	80	0.9908	145	1.0131	270	1.1048
20	0.9945	85	0.9914	150	1.0160	280	1.1145
25	0.9933	90	0.9921	160	1.0221	290	1.1243
30	0.9923	95	0.9930	170	1.0284	300	1.1340
35	0.9914	100	0.9941	180	1.0349	320	1.1552
40	0.9907	105	0.9953	190	1.0414	340	1.1765
45	0.9901	110	0.9967	200	1.0483	360	1.1990
50	0.9897	115	0.9984	210	1.0555	380	1.2215
55	0.9895	120	1.0004	220	1.0627	400	1.2445
60	0.9896	125	1.0026	230	1.0703	430	1.2785

VALUES OF $p_{\text{atm.}}$ AT CONSTANT v

v, const.	p, atm. 0°	p, atm. 16.0°	p, atm. 43.6°	v, const.	p, atm. 0°	p, atm. 16.03°	p, atm. 99.45°	p, atm. 199.5°
0.002070	1000	1088	1239	0.009910	100	107	146	192
.001946	1200	1298	1474	.005195	150	162	225	299
.001813$_5$	1500	1613	1812	.004330	200	217	307	414
.001714$_5$	1800	1937	2168	.003786	250	273	392	530
.001663$_5$	2000	2150	2401	.003414	300	328	474	644
.001583$_5$	2400	2572	2858	.003142	350	383	556	758
.001525	2800	2990		.002940	400	439	637	869
				.002780	450	494	718	
				.002652	500	548	797	
				.002543	550	602	875	
					600	656	957	

MEASUREMENTS BY BARTLETT (19, 20)

p, atm.	pv 0°	pv 50°	pv 99.85°	pv 198.9°	pv 299.8°	pv 399.3°
1	1.0000					
50	0.9846	1.1888	1.3888	1.7683		
100	0.9846	1.2046	1.4114	1.8071	2.1978	2.5729
200	1.0362	1.2742	1.4958	1.9073	2.3119	2.6944
300	1.1335	1.3711	1.5971	2.0169	2.4279	2.8166
400	1.2557	1.4870	1.7112	2.1407	2.5498	2.9422
600	1.5214	1.7473	1.9650	2.3914	2.8034	3.1949
800	1.7959	2.0155	2.2273	2.6510	3.0615	3.4559
1000	2.0641	2.2825	2.4942	2.9165	3.3195	3.7196

PHASE EQUILIBRIUM DATA

VAPOR PRESSURES OF P, S, SE, TE AND THE HALOGENS

ALAN W. C. MENZIES

THE CRYSTALLINE STATE

$\log_{10} p = \frac{0.05223\mathrm{A}}{T} + \mathrm{B}$; p in mm $\left(= \frac{1}{760}\mathrm{A_n}\right)$; t in °C, $T = t + 273.1$

BR, BROMINE (16, 18, 31)

t, °C	p, mm	t, °C	p, mm
	±5%		±5%
(−95)	(0.0022)	−45	1.83
−90	0.0052		±3%
−85	0.0117	−40	2.98
−80	0.0251	−35	4.77
−75	0.0513	−30	7.45
−70	0.102	−25	11.4
−65	0.192	−20	17.1
−60	0.357	−15	25.2
−55	0.628	−10	36.6
−50	1.09	− 7.3*	44.4

* M. P.

CL, CHLORINE (16)

A = −29 293; B = 9.950; accuracy, ±10%; range, −154 to −103°C

I, IODINE (1, 2, 14, 31)

t, °C	p, mm	t, °C	p, mm
	±5%		±1%
−50	$0.0_{4}37$	40	1.03
−40	$0.0_{3}19$	50	2.16
−30	$0.0_{3}80$	60	4.31
−20	0.0030	70	8.22
−10	0.0099	80	15.1
	±1%	90	26.8
0	0.0299	100	45.5
+10	0.0808	110	74.9
20	0.202	114.15*	90.1
30	0.471		

* M. P.

P, PHOSPHORUS (7, 24, 36)

For white P: A = −63 123; B = 9.6511; range, 20 to 44.1°C (M. P.); error ± <10%.

For violet P: A = −108 510; B = 11.0842; range, 380 to *ca.* 590°C; accuracy ±5% above 500°C.

S, SULFUR (13, 34)

t, °C	p, mm	t, °C	p, mm
50	0.0002	90	0.0049
60	0.0004	100	0.010
70	0.0010	110	0.021
80	0.0023	114.5*	0.028†

* M. P. † ±10%.

SE, SELENIUM (10)

Hexagonal form

t, °C	p, mm	t, °C	p, mm
	±10%		±10%
195	0.0010	210	0.0032
200	0.0015	215	0.0047
205	0.0022	217.4*	0.0055

* M. P.

THE LIQUID STATE UP TO ONE ATMOSPHERE

BR, BROMINE (4, 18, 28, 31)

t, °C	p, mm	t, °C	p, mm
	±2%		±2%
−7.3*	44.4	30	264
−5	50.5	35	324
0	65.9	40	392
+5	85.3	45	472
10	109	50	564
15	138	55	670
20	173	58.78†	760
25	214	(60)	(793)
		302‡	

* M. P. † ± 0.03°. ‡ Crit.

CL, CHLORINE (16, 19, 21, 29, 38)

t, °C	p, mm	t, °C	p, mm
	±5%		±3%
−103*	8.9	−50	363
−100	11.8	−40	594
−90	27.8		±1%
−80	58.7	−34.6	760
	±3%		±2%
−70	115	−30	935
−60	211	−20	1398

* M. P.

I, IODINE (31, 32, 37)

t, °C	p, mm	t, °C	p, mm
	±2%		±2%
114.15	90.1	160	394
115	92.9	170	521
120	111	180	679
130	157	184.35*	760
140	217	190	(869)
150	294	**553.4†**	

* ±0.1°. † ±3°crit.

P, PHOSPHORUS (20, 24, 25, 30, 36)

$\log_{10} p$,mm $= 11.5694 - \frac{2898.1}{T} - 1.2566 \log_{10} T$; range, 44.1 to 635°C; accuracy of $p = \pm 7\%$ except near the B. P., 279.7°C, where it is ±2% (equivalent to ±1°).

S, SULFUR (3, 5, 6, 8, 9, 12, 13, 15, 17, 26, 27, 32, 33, 34, 39)

t, °C	p, mm	t, °C	p, mm
	±10%	250	12
114.5 M. P.	0.028	260	16
120	0.040	270	21
130	0.074	280	28
140	0.13	290	37
150	0.22	300	48
160	0.37	310	60
	±7%	320	76
170	0.59	330	95
180	0.91		±5%
190	1.4	340	118
200	2.1	350	146
210	3.1	360	179
220	4.4	370	218
230	6.3	380	263
240	8.7		

S.—(*Continued*)

t, °C	p, mm	t, °C	p, mm
	±3%		± <0.1%
390	325	444.6_0	760.0
400	376		±0.3%
410	446	450	821
	±1%		±3%
420	525	460	948
430	613	470	109_3
	±0.3%	480	125_7
440	711		±5%
		490	144_1

$t = 444.6_0 + 0.0910(p - 760) - 0.0_449(p - 760)^2$, for $p = 695$ to 805 mm (±1–2 mm). Relative accuracy, ±0.1–0.2 mm (40).

Se, Selenium (10, 23, 30)

t, °C	p, mm	t, °C	p, mm
	±10%		±10%
217.4 M.P.	0.0055	480	28
220	0.0062	500	42
225	0.0078		±3%
230	0.0097	620	313
235	0.0120	640	420
390	3.0	660	550
400	4.0	680	700
420	7.0	688	760
440	11	700	865
460	17	710	970

Te, Tellurium (11, 35)

t, °C	p, mm	t, °C	p, mm
488	0.464	671	14.1
578	3.34	1390	760

VAPOR PRESSURES AND ORTHOBARIC DENSITIES ABOVE ONE ATMOSPHERE

d_l (resp. d_v) = density of saturated liquid (resp. vapor) in g per cm³; $d_m = \frac{1}{2}(d_l + d_v)$.

All values at the critical point are given in bold-face type.

The latent heat of vaporization (l) in joules per g is given by the equation:

$$l = 0.10133\left(\frac{1}{d_v} - \frac{1}{d_l}\right)T \cdot \frac{dp}{dT} = \frac{0.10133}{0.4343}\left(\frac{1}{d_v} - \frac{1}{d_l}\right)pT\,\frac{d\log_{10} p}{dT}$$

Cl, Chlorine (16, 19, 21, 22, 29, 38)

t, °C	p, atm.	d_l	d_v
	±1%		±0.5%
−34.6	1.00	1.561	
	±2%		
−30	1.23	1.550	
−20	1.84	1.524	
−10	2.61	1.496	
0	3.65	1.468	0.0128
+10	4.96	1.438	0.0175
20	6.57	1.408	0.0226
30	8.60	1.377	0.0300
	±?%		
40	11.1	1.344	0.0384
50	14.1	1.310	0.0486
60	17.6	1.375	0.0600
70	21.6	1.240	0.0740
80	26.2	1.199	0.0910
90	31.5	1.156	0.1125
100	37.6	1.109	0.136
110	44.4	1.059	0.164
120	52.4	0.998	0.206
130	61.4	0.920	0.258
140	71.4	0.750	0.405
144 ±1	**(76.1)**	**0.573**	

$d_m = 0.7403 - 0.0011618t$.

P, Phosphorus (20, 24, 25, 30, 36)

For white and violet P: $\log_{10} p$, mm $= 11.5694 - 2898.1/T - 1.2566 \log_{10} T$; ($p$ ± 7%) range, 44.1 to 635°C (±2% near B. P., 279.7°C); t, crit. $= 720._6 \pm 3$°C; p, crit. = 100 ± 10 atm. (calc. from equation).

S, Sulfur (5, 6, 8, 9, 12, 13, 15, 17, 26, 27, 32, 33, 34, 39)

t, °C	p, mm	t, °C	p, mm
	± <0.1%		±5%
444.6	760	500	164_7
	±0.3%	510	187_6
450	821	520	213_0
	±3%	530	241_0
460	948	540	271_8
470	109_3	550	305_5
480	125_7	560	342_3
	±5%	570	382_4
490	144_1	**1040 ± 5°**	

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VAPOR PRESSURES OF THE ATMOSPHERIC GASES

C. A. Crommelin

I. VAPOR PRESSURES UP TO TWO ATMOSPHERES

p, in mm Hg (=1/760 A_n); t, in °C (Leiden scale, *v.* Vol. I, p. 54); the following equation applies over the range covered by the tabulated data, except as otherwise indicated:

$$\log_{10} p_{mm} = \frac{0.05223A}{T} + B + CT + DT^2 + ET^3$$

Trp. = triple point.

1. Two-Phase, Crystal—Vapor, Sublimation Pressures

Argon	$t°$	−189.19 Trp.	−207.62	A = −7 814.5	(1)
	p	512.17	21.97	B = +7.5741	
Kr	$t°$	−169 Trp.	−188.7	A = −10 065	(31)
	p	132.5	9.0	B = +7.1770	
N_2	$t°$	−209.86 Trp.	−215.20	A = −6 881.3	(2); *cf.*
	p	96.4	28.82	B = +7.66558	(10, 35)

Neon (39)

t, °C	p_{mm}	t, °C	p_{mm}
−248.56	317	−253.64	20.0
−248.84	279	−254.07	14.9
−249.09	250	−254.63	9.8
−249.62	195	−254.92	7.8
−250.22	148	−255.43	5.1
−250.84	111	−255.79	3.7
−251.24	91	−256.46	2.1
−252.62	40	−256.79	1.3
−253.16	28.2	−257.62	0.55
−253.30	25.3		

Rn	$t°$	−70.5 Trp.	−78	−101	−127
	p	500	250*	50*	9*
	Lit.	(9)	(34)		

* These pressures probably too high, possibly on account of impurities.

2. Two-Phase, Liquid—Vapor

Argon (1)

t, °C	p_{mm}
−182.82	1026.0
−185.66	(760)
−189.19	512.17 Trp.

A = −6826.0
B = 6.9605

H_2 (3, 11, 28)

t, °C	p_{mm}
−248.50	2199.2
−252.45	823.7
−252.74	760.0
−254.73	397.6
−256.61	191.9
−258.46	79.9
−259.14	51.4 Trp.

A = −849.48
B = 4.5331
C = 0.03240
D = -0.0_34189
E = 0.0_5484

Helium (18, 19, 29)

t, °C	p_{mm}
−268.88	760
−269.20	565
−269.57	$359._5$
−269.92	197
−270.85	51
−271.61	4.1_5
−271.74	3

$\log_{10} p = 4.7290 - 7.9780/T - 0.13628/T^2 + 4.3634/T^3$. Range, 5.19 to 1.47_5°K

Kr (31)

−149.9	898.20
−152.1	760.0
−160.3	386.4
−169 Trp.	(132.5)

A = −9377.0
B = 6.92387

N_2 (2)

t, °C	p_{mm}
−188.88	1591.1
−193.91	938.6
−195.78	760.0
−198.26	561.3
−204.69	228.37
−208.58	120.90
−209.86	96.4 Trp.

A = −6407.0
B = 7.5777
C = −0.00476

Neon (4, 24, 39)

−228.66	19 797
−229.26	18 472
−231.71	13 245
−233.60	10 042
−236.82	6 057.2
−240.25	3 171.5
−241.77	2 264.8
−243.69	1 434.9
−245.68	816.2
−245.79	791.0
−245.88	767.1
−246.66	605.2
−247.33	486.0
−247.49	451.6
−247.82	410
−248.10	373
−248.29	350
−248.51	325.0

A = −1615.5
B = 5.69991
C = 0.0111800

O_2 (2, 10, 21, 22, 35)

t, °C	p_{mm}
−182.62	786.63
−182.95	760.00
−186.91	493.30
−192.01	263.19
−195.50	162.15
−201.38	64.01
−204.52	36.11
−210.72	9.59
−218.4	±2 Trp.

A = −8028.1
B = 8.1173
C = −0.00648
Range, −182 to −211°C

Rn Radon (9)

−38.6	2000
−61.8	(760)
−70.5 Trp.	500

A = −17 153
B = 7.12128

O_3 Ozone* (14, 32, 33)

t, °C ±1	p_{mm}
−193.1	0.01_5
−183.1	0.1_7
−173.1	$1._3$
−163.1	6.8_7
−153.1	$25._4$
−143.1	$74._6$
−133.1	$182._8$
−123.1	$387._7$
−112.4	760
−5	**17** atm. (critical)
−182	1.78 g/cm³ (d_l)

* Evaluated by C. S. Cragoe, cooperating expert.

Xenon (31)
Trp. = *ca.* −140°C

II. VAPOR PRESSURES AND ORTHOBARIC DENSITIES ABOVE ONE ATMOSPHERE

p = vapor pressure in normal atmospheres.
t = temperature, °C, Leiden scale (*v.* Vol. I, p. 54).
$T = t + 273.1°$.
d_l (resp. d_v) = density of saturated liquid (resp. vapor) in grams per cm³.
$d_m = \frac{1}{2}(d_l + d_v)$.
All values at the critical point are given in bold-face type.

Argon (1, 5, 6, 16)

t, °C	p, atm.
−122.44	**47.996**
−125.49	42.457
−129.83	35.846
−134.72	29.264
−140.80	22.185
−150.57	13.707
−161.23	7.4332
−185.66	1.0000

$\log_{10} p = 4.85033 - 634.391/T + 30\,769.09/T^2 - 1\,076\,464/T^3$; for $p > 1$.

t, °C	d_l	d_v
−122.44	**0.53078**	
−125.17	0.77289	0.29534
−135.51	0.97385	0.15994
−150.76	1.13851	0.06785
−161.23	1.22414	0.03723*
−175.39	1.32482	0.01457*
−183.15	1.37396	0.00801*

$d_m = 0.20956 - 0.0026235t$.

* Calculated from equation of state.

H_2 (3, 11, 12, 23, 26)

t, °C	p, atm.
−239.91	**12.80**
−240.49	11.752
−245.68	5.0566
−248.50	2.8937
−252.74	1.0000

$T \log_{10}p = -56.605 + 3.8015T - 0.10458T^2 + 0.003321T^3 - 0.0_43219T^4$; for $p > 1$.

t, °C	d_l	d_v
−239.91	**0.03102**	
−240.57	0.04316	0.01922
−243.03	0.05402	0.01081
−245.73	0.06050	0.00613
−249.89	0.06724	0.00264
−253.24	0.07134	0.00116*
−256.75	0.07494	0.00038*
−258.27	0.07631	0.00020*

$d_m = -0.063510 - 0.00039402t$.

* Calculated from equation ot state.

Helium (19, 20, 29, 36)

T, °K	p, atm.
5.19	**2.261**
5.16	2.195
4.90	1.749
4.21	1.000

$\log_{10} p = 1.8482 - 7.9780/T - 0.13628/T^2 + 4.3634/T^3$ (from critical point to $T = 1.47_5°$).

T, °K	d_l	d_v
5.19	**0.06930**	
4.71	0.1139	0.02699
4.59	0.1165	0.02389
4.23	0.1253	0.01637

Helium.—(*Continued*)

T, °K	d_l	d_v
4.22	0.1255	0.01618*
3.90	0.1311	0.01176*
3.30	0.1395	0.006435*
2.56	0.1457	0.002079*
2.37	0.1466	0.001368*
2.30	0.1469†	0.001159*
2.21	0.1466	
2.10	0.1464	
1.92	0.1462	
1.59	0.1460	
1.20	0.1459	

$d_m = -0.40263 - 0.0017616t.$

* Calculated from equation of state.

† Maximum.

Kr (31)

t, °C	p, atm.
− 62.6	**54.24**
− 70	41.12
− 90	24.27
−110	11.32
−130	4.315
−150	1.175
−151.8	1.000

d_l at −146° = 2.155.

N_2 (2, 7, 17, 27)

t, °C	p, atm.
−147.13	**33.490**
−152.11	25.889
−161.31	15.949
−173.58	7.3705
−182.47	3.7248
−195.78	1.0000

$\log_{10} p = 5.76381 - 853.522/T + 54\,372.3/T^2 - 1\,783\,500/T^3$; for $p > 1$.

A new series of determinations and discussion of all available data are given in (38).

t, °C	d_l	d_v
−147.13	**0.31096**	
−148.08	0.4314	0.2000
−153.65	0.5332	0.1177
−161.20	0.6071	0.06987
−173.73	0.6922	0.02962

N_2.—(*Continued*)

t, °C	d_l	d_v
−182.51	0.7433	0.01576*
−195.09	0.8043	0.00498*
−208.36	0.8622	0.000868*

$d_m = 0.022904 - 0.0019577t.$

* Calculated from equation of state.

Neon (4, 8, 13, 24, 25)

t, °C	p, atm.
−228.71	**26.86**
−231.71	17.428
−236.82	7.970
−241.77	2.980
−245.92	1.000

$T \log_{10} p = -84.380 + 2.81910T + 0.0111800T^2.$

t, °C	d_l	d_v
−228.71	**0.4835**	
−230.07	0.74866	0.23935
−234.01	0.92803	0.11592
−237.04	1.01750	0.06742
−242.96	1.14960	0.02013
−247.92	1.23824	0.00534*

$d_m = -1.154406 - 0.00716146t.$

* Calculated from equation of state.

O_2 (2, 15, 27)

t, °C	p, atm.
−118.82	**49.713**
−118.88	49.640
−125.28	38.571
−135.96	24.528
−149.25	12.506
−154.87	9.096
−182.95	1.000

A new series of determinations and discussion of all available data are given in (38).

t, °C	d_l	d_v
−118.82	**0.4299**	
−120.4	0.6032	0.2701
−123.3	0.6779	0.2022
−129.9	0.7781	0.1320
−140.2	0.8742	0.0805
−154.5	0.9758	0.0385

O_2.—(*Continued*)

t, °C	d_l	d_v
−182.0	1.1415	0.00490*
−210.4	1.2746	0.0000865*

$d_m = 0.1608 - 0.002265t.$

* Calculated from equation of state.

Rn, Radon (9)

t, °C	p, atm.
+104.4	**62.44**
100	59.43
70	37.67
40	13.64
+ 10	11.40
− 20	5.260
− 50	2.065
− 60	1.361
− 61.8	1.000

Xenon (30, 31)

t, °C	p, atm.
+ 16.6	**58.22**
0.0	41.24
− 20	26.73

Xenon.—(*Continued*)

t, °C	p, atm.
− 40	15.85
− 60	8.570
− 80	4.064
−100	1.629
−109.1	1.000

t, °C	d_l	d_v
+16.6	**1.154**	
16	1.468	0.844
15	1.528	0.791
+10	1.745	0.602
0	1.987	0.421
−10	2.169	0.313
−20	2.292	0.238
−30	2.410	0.180
−40	2.511	0.137
−50	2.605	0.108
−60	2.699	0.079
−70	2.792	0.048

$d_m = 1.205 - 0.003055t.$

LITERATURE

(For a key to the periodicals see end of volume)

(1) Born, *8*, **69**: 473; 22. (2) Cath, *64P*, **21**: 656; 19. *168*, No. **152d.** (3) Cath and Onnes, *64P*, **20**: 991, 1155; 18. *168*, No. **152a.** (4) Cath and Onnes, *64P*, **20**: 1160; 18. *168*, No. **152b.** (5) Crommelin, *64P*, **13**: 54; 10. *168*, No. **115.** (6) Crommelin, *64P*, **16**: 477; 13. *168*, No. **138c.** (7) Crommelin, *64P*, **17**: 959; 15. *168*, No. **145d.** (8) Crommelin, *70*, **42**: 814; 23. (9) Gray and Ramsay, *4*, **95**: 1073; 09.

(10) Holst, *64P*, **18**: 829; 16. *168*, No. **148a.** (11) Martinez and Onnes, *18*, **6**: 31; 22. *168*, No. **156b.** (12) Mathias, Crommelin and Onnes, *64P*, **23**: 1175; 22. *34*, **172**: 261; 21. *168*, No. **154b.** (13) Mathias, Crommelin and Onnes, *34*, **175**: 933; 22. *168*, No. **162b.** (14) Mathias, Crommelin, Onnes and Swallow, *64V*, **34**: 334; 25. *168*, No. **172b.** (15) Mathias and Onnes, *64P*, **13**: 939; 11. *168*, No. **117.** (16) Mathias, Onnes and Crommelin, *64P*, **15**: 667, 960; 13. *168*, No. **131a.** (17) Mathias, Onnes and Crommelin, *64P*, **17**: 953; 15. *168*, No. **145c.** (18) Onnes, *64P*, **13**: 1093; 11. *168*, No. **119.** (19) Onnes, *64P*, **14**: 678; 12. *168*, No. **124b.**

(20) Onnes and Boks, *B60*, 215. *168*, No. **170b.** (21) Onnes and Braak, *64P*, **11**: 333; 08. *168*, No. **107a.** (22) Onnes and Crommelin, *64P*, **14**: 163; 11. *168*, No. **121c.** (23) Onnes and Crommelin, *64P*, **16**: 245; 13. *168*, No. **137a.** (24) Onnes and Crommelin, *64P*, **18**: 515; 15. *168*, No. **147d.** (25) Onnes, Crommelin and Cath, *64P*, **19**: 1058; 17. *168*, No. **151b.** (26) Onnes, Crommelin and Cath, *64P*, **20**: 178; 17. *168*, No. **151c.** (27) Onnes, Dorsman and Holst, *64P*, **17**: 950; 15. *168*, No. **145b.** (28) Onnes and Keesom, *64P*, **16**: 440; 13. *168*, No. **137d.** (29) Onnes and Weber, *64P*, **18**: 493; 15. *168*, No. **147b.**

(30) Patterson, Cripps and Gray, *5*, **86**: 579; 12. (31) Ramsay and Travers, *62*, **197**: 47; 01. (32) Riesenfeld and Beja, *147*, **6**: No. 7; 23. *93*, **132**: 179; 24. (33) Riesenfeld and Schwab, *25*, **55**: 2088; 22. *96*, **11**: 12; 22. (34) Rutherford, *3*, **17**: 723; 09. (35) von Siemens, *8*, **42**: 871; 13. (36) Spangenberg, *7*, **119**: 419; 26. (37) Travers, Senter and Jacquerod, *62*, **200**: 155; 03. (38) Dodge and Davis, *1*, **49**: 610; 27. (39) Crommelin and Gibson, *64V*, **36**: 173; 27. *168*, No. **185b.**

VAPOR PRESSURES OF THE METALS

J. JOHNSTON, F. FENWICK AND H. G. LEOPOLD

The value, for the several metals, of the coefficient A (in kilojoules) and of B (for pressures p in mm of mercury) in the equation $\log_{10} p = -52.23\ A/T + B$, together with the values (calculated from the equation) of the temperatures corresponding to the pressures 760, 1, and 0.001 mm Hg. (l) = liquid, (s) = solid.

Substance	State	Range covered by equation, °C	A (kilojoule)	B (for p in mm Hg)	°C at which p in mm Hg equals			Lit.
					760	1	0.001	
Ag	(l)	1650–1950	250	8.76$_{2}$	194$_{8}$	(121$_{8}$)	(83$_{7}$)*	(22, 23, 24, 25, 54, 63, 73, 85 88, 90)
Al	(l)				18$_{00}$			(22, 25, 88)
As	(l)	800– 860	47.1	6.69$_{2}$	Calculated triple point 36$_{.0}$ atm., 820°C			(34)
	(s)	440– 815	133	10.8$_{00}$	604$_{.3}$	(370$_{.2}$)	(230$_{.3}$)	(20, 21, 29, 30, 34, 38, 40, 47, 66, 68, 73, 81)
Au	(l)	2315–2500	385	9.85$_{3}$	(261$_{1}$)	(176$_{8}$)	(129$_{2}$)	(54, 73, 85, 88)
Ba	(l)	930–1130	35$_{0}$	15.7$_{65}$	(114$_{6}$)	(88$_{7}$)	(701$_{.1}$)*	(77)
Bi	(l)	1210–1420	200	8.87$_{6}$	(147$_{0}$)	(90$_{4}$)	(606$_{.8}$)	(22, 23, 24, 25, 54, 73, 81)
C	(l)	3880–4430	54$_{0}$	9.5$_{96}$	(39$_{27}$)	(26$_{66}$)*	(20$_{18}$)*	(1, 14, 15, 45, 46, 55, 56, 57, 69, 84, 92)
Ca†	(l)	960–1110	37$_{0}$	16.2$_{40}$	(117$_{4}$)	(91$_{7}$)	(73$_{1}$)*	(77, 79)
	(s)	500– 700	19$_{5}$	9.69$_{7}$	(122$_{1}$)‡	(77$_{7}$)	529	(64)
Cd	(l)	500– 840	99.9	7.89$_{7}$	767			(4, 5, 18, 32, 36, 54, 59, 73)
	(l)	320.9– 525	111–0.01T§	12.10$_{7}$	p = 10 °C = 485$_{.3}$	5 454$_{.6}$	1 392$_{.2}$	
	(s)	150– 320.9	109$_{.0}$	8.56$_{4}$		(391$_{.7}$)‡	219$_{.1}$	(9, 10, 13, 59)
Co‖	(l)	2375	30$_{9}$	7.5$_{71}$	(31$_{68}$)	(18$_{59}$)	(12$_{54}$)*	(80)
Cr	(l)	2200			22$_{00}$			(22, 25)
Cs	(l)	200– 350	73$_{.4}$	6.94$_{9}$	(669$_{.3}$)	278$_{.6}$	(112$_{.3}$)	(2, 12, 28, 45, 48, 52, 78, 82)
Cu	(l)	2100–2310	468	12.3$_{44}$	231$_{0}$	(170$_{7}$)	(132$_{0}$)	(16, 22, 23, 24, 25, 54, 58, 73, 81, 85)
Fe	(l)	2220–2450	309	7.48$_{2}$	(323$_{5}$)	(188$_{4}$)	(126$_{7}$)*	(22, 25, 76)
Hg	(l)	400–1300	58$_{.7}$	7.75$_{2}$	p = 10^4 °C = 544.1	10^5 84$_{1}$	5 × 10^5 122$_{0}$	(3, 6, 7, 9, 10, 12, 19, 26, 31, 32, 33, 36, 37, 41, 43, 44, 49, 60, 61, 62, 65, 67, 73, 82, 83, 86, 87, 94)
	(l)	−38.8$_{7}$–400			356.70	*See* special table, p. 206		
	(s)	(−80)–(−38.8$_{7}$)	73$_{.0}$	10.3$_{83}$	p = 10^{-9} °C = −76$_{.4}$	10^{-8} 10^{-7} −65$_{.7}$ −53$_{.6}$	10^{-6} −40$_{.4}$	(65)
K	(l)	260– 760	84$_{.9}$	7.18$_{3}$	758	344$_{.2}$	(162$_{.3}$)	(17, 28, 32, 42, 48, 78, 82)
Mg	(l)	900–1070	26$_{0}$	12.9$_{93}$	107$_{0}$	(77$_{2}$)	(576$_{.0}$)*	(8, 22, 25, 77, 88)
Mn	(l)	1510–1900	2$_{67}$	9.3$_{00}$	19$_{00}$	(12$_{27}$)*	(8$_{61}$)*	(22, 25, 74)
Mo	(s)	1800–2240	68$_{0}$	10.8$_{44}$	(41$_{88}$)‡	(30$_{03}$)‡	(22$_{93}$)	(39, 53, 54, 93)
Na	(l)	180– 883	103$_{.3}$	7.553	882	441$_{.2}$	238$_{.1}$	(19, 27, 28, 32, 37, 50, 70, 78, 91)
Ni‖	(l)	2360	30$_{9}$	7.6$_{00}$	(31$_{47}$)	(18$_{51}$)	(12$_{50}$)*	(75)
Pb	(l)	525–1325	188$_{.5}$	7.82$_{7}$	(171$_{8}$)	98$_{5}$	636$_{.2}$	(11, 12, 22, 23, 24, 25, 35, 54, 71, 72, 73, 88, 90)
Pt	(s)	1425–1765	48$_{6}$	7.78$_{6}$	(49$_{01}$)‡	(29$_{87}$)‡	(20$_{80}$)‡	(39, 53, 54)
Rb	(l)	250– 370	76	6.97$_{6}$	(696$_{.0}$)	295$_{.8}$	(124$_{.8}$)	(12, 28, 42, 78, 82)
Sb	(l)	1070–1325	189	9.05$_{1}$	132$_{7}$	(81$_{8}$)	(546$_{.0}$)*	(22, 25, 54, 73, 81)
Si	(s)	1200–1320	1$_{70}$	5.95$_{0}$	(26$_{20}$)‡	12$_{19}$	(71$_{9.2}$)	(89); *cf.* (96)
Sn	(l)	1950–2270	328	9.64$_{3}$	(226$_{0}$)	(150$_{3}$)	(128$_{2}$)	(22, 23, 24, 25, 54, 73, 88)
Sr	(l)	940–1140	36$_{0}$	16.0$_{56}$	(115$_{4}$)	(89$_{9}$)	(713$_{.4}$)*	(77)
W	(l)	950–1200	12$_{0}$	6.14$_{0}$	(165$_{0}$)	(74$_{8}$)	(412$_{.7}$)	(20, 47, 88, 90)
Tl	(s)	2230–2770	89$_{7}$	9.92$_{0}$	(63$_{83}$)‡	(44$_{50}$)‡	(33$_{53}$)	(39, 51, 54, 95)
Zn	(l)	600– 985	118$_{.0}$	8.10$_{8}$	906			(4, 5, 12, 23, 24, 32, 36, 54, 59, 71, 73)
	(l)	419.4– 625	127–0.01T§	12.18$_{4}$	p = 20 °C = (632$_{.3}$)	10 5 594$_{.1}$ 558$_{.9}$	1 487$_{.7}$	
	(s)	250– 419.4	133	9.20$_{0}$		(532$_{.0}$)‡	296$_{.3}$	(9, 10)

( ) Extrapolated beyond experimental range.

* Extrapolated below freezing point.

† These two curves are mutually inconsistent.

‡ Extrapolated above melting point.

§ These are the only two cases in which the accuracy of the present data seems to justify the use of a curved line. The equations of these curves are respectively:

$$\log_{10} p_{\mathrm{Cd}} = -111 \times 52.23/T - 1.203 \log_{10} T + 12.107$$

and

$$\log_{10} p_{\mathrm{Zn}} = -127 \times 52.23/T - 1.203 \log_{10} T + 12.184$$

‖ Slope made equal to that of iron.

THE VAPOR PRESSURE OF MERCURY FROM −39 TO +400°C

Unit, mm of Hg = $\frac{1}{760}$ A_n

t, °C	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
−30	0.0_5478	0.0_5415	0.0_5359	0.0_5309	0.0_5266	0.0_5229	0.0_5197	0.0_5169	0.0_5145	0.0_5124
−20	$.0_4181$	$.0_4159$	$.0_4140$	$.0_4123$	$.0_4108$	$.0_5947$	$.0_5828$	$.0_5723$	$.0_5630$	$.0_5549$
−10	$.0_4606$	$.0_4540$	$.0_4481$	$.0_4428$	$.0_4380$	$.0_4337$	$.0_4298$	$.0_4263$	$.0_4232$	$.0_4205$
− 0	$.0_3185$	$.0_3166$	$.0_3149$	$.0_3133$	$.0_3119$	$.0_3107$	$.0_4954$	$.0_4853$	$.0_4762$	$.0_4680$
+ 0	$.0_3185$	$.0_3206$	$.0_3228$	$.0_3251$	$.0_3276$	$.0_3304$	$.0_3335$	$.0_3369$	$.0_3406$	0_3446
+10	$.0_3490$	$.0_3537$	$.0_3588$	$.0_3644$	$.0_3706$	$.0_3773$	$.0_3846$	$.0_3925$	.001009	.001101
20	.001201	.001309	.001426	.001553	.001691	.001840	.002000	.002173	.002359	.002560
30	.002777	.003010	.003261	.003532	.003823	.004135	.004471	.004832	.005219	.005634
40	.006079	.006556	.007067	.007614	.008200	.008827	.009497	.01021	.01098	.01180
50	.01267	.01360	.01459	.01565	.01677	.01797	.01925	.02061	.02206	.02360
60	.02524	.02698	.02883	.03079	.03287	.03507	.03740	.03988	.04251	.04530
70	.04825	.05138	.05469	.05819	.06189	.06580	.06993	.07429	.07889	.08375
80	.08880	.09430	.1000	.1060	.1124	.1191	.1261	.1335	.1413	.1495
90	.1582	.1673	.1769	.1870	.1976	.2086	.2202	.2324	.2453	.2588
100	.2729	.2877	.3032	.3195	.3366	.3544	.3731	.3927	.4132	.4347
110	.4572	.4807	.5052	.5308	.5576	.5857	.6150	.6456	.6776	.7109
120	.7457	.7820	.8198	.8592	.9004	.9434	.9882	1.035	1.084	1.134
130	1.186	1.241	1.298	1.357	1.419	1.484	1.551	1.620	1.692	1.767
140	1.845	1.926	2.010	2.097	2.188	2.282	2.379	2.480	2.585	2.694
150	2.807	2.924	3.046	3.172	3.303	3.438	3.578	3.723	3.873	4.028
160	4.189	4.356	4.528	4.706	4.890	5.080	5.277	5.480	5.689	5.905
170	6.128	6.358	6.596	6.842	7.095	7.356	7.626	7.905	8.193	8.490
180	8.796	9.111	9.436	9.711	10.116	10.472	10.839	11.217	11.607	12.009
190	12.423	12.849	13.287	13.738	14.203	14.681	15.173	15.679	16.200	16.736
200	17.287	17.854	18.437	19.036	19.652	20.285	20.936	21.605	22.292	22.998
210	23.723	24.468	25.233	26.019	26.826	27.654	28.504	29.376	30.271	31.190
220	32.133	33.100	34.092	35.110	36.153	37.222	38.318	39.442	40.595	41.777
230	42.989	44.231	45.503	46.806	48.141	49.509	50.909	52.343	53.812	55.316
240	56.855	58.431	60.044	61.695	63.384	65.113	66.882	68.692	70.543	72.437
250	74.375	76.356	78.381	80.451	82.568	84.732	86.944	89.206	91.518	93.881
260	96.296	98.763	101.28	103.85	106.48	109.17	111.91	114.71	117.57	120.49
270	123.47	126.51	129.62	132.79	136.02	139.34	142.69	146.13	149.64	153.22
280	156.87	160.59	164.39	168.26	172.21	176.24	180.34	184.52	188.79	193.14
290	197.57	202.09	206.70	211.39	216.17	221.04	226.00	231.06	236.21	241.46
300	246.80	252.24	257.78	263.42	269.17	275.02	280.98	287.04	293.21	299.49
310	305.89	312.40	319.02	325.76	332.62	339.60	346.70	353.92	361.26	368.73
320	376.33	384.06	391.92	399.91	408.04	416.31	424.71	433.25	441.94	450.77
330	459.74	468.86	478.13	487.55	497.12	506.85	516.74	526.79	537.00	547.37
340	557.90	568.59	579.45	590.48	601.69	613.08	624.64	636.38	648.30	660.40
350	672.69	685.17	697.83	710.68	723.73	736.98	750.43	764.08	777.92	791.97
360	806.23	820.70	835.38	850.26	865.36	880.68	896.23	912.01	928.02	944.27
370	960.66	977.38	994.34	1011.5	1028.9	1046.5	1064.4	1082.5	1100.9	1119.5
380	1138.4	1157.6	1177.0	1196.6	1216.6	1236.8	1257.3	1278.1	1299.1	1320.3
390	1341.9	1363.9	1386.1	1408.6	1431.3	1454.3	1477.7	1501.3	1525.2	1549.5
400	1574.1	(For continuation use the equation, $\log_{10} p = \frac{-52.23 \times 58.7}{T} + 7.75_2$, valid up to 1300°C)								

LITERATURE

(For a key to the periodicals see end of volume)

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VAPOR PRESSURE OF CHEMICAL COMPOUNDS IN THE CRYSTALLINE STATE

A. C. Egerton and W. Edmondson

This section covers the pressure-temperature relations for systems composed of a single crystalline phase in contact with its own vapor. In the case of substances which dissociate on vaporization the value given is the total pressure. The literature references given first are to data to which most weight has been given.

𝔅-TABLE, STANDARD ARRANGEMENT (*v.* p. viii)

$$\log_{10} p_{\text{mm}} = \frac{-0.05223\text{A}}{T} + \text{B}$$

Key No.	Formula	Range, °C	A, joule	B	Lit.
2	H_2O	*v.* p. 210			
	HCl*	−158 to −110	$19\ 58_{8}$	8.443_{0}	(29, 32, 45); *cf.* (20, 52)
	HBr†	−114 to − 86	$22\ 42_{0}$	8.734	(29, 52, 93); *cf.* (20)
	HI‡	− 97 to − 51	$24\ 16_{0}$	8.259	(29, 52, 93); *cf.* (92)
8	SO_2	− 95 to − 75	$35\ 82_{7}$	10.591_{6}	(6, 13, 14); *cf.* (92)
	SO_3	4 crystalline forms			(50)
	H_2S	−110 to − 83	$20\ 69_{0}$	7.880	(52); *cf.* (93)
	SeO_2§	*t*, °C	*p*, mm		(38)
		72.0	13.43		
		112.5	21.28		
		180.9	39.00		
		213.5	50.12		
		236.9	66.07		
		259.9	109.6		
		289.2	316.2		
		319.9	849.0		
		317.0	760.0		
	H_2Se	−78.11	82.5		(12)
		−70.27	157.3		
		−70.15	158.1		
	H_2SeO_4	25 to 56	$82\ 40_{0}$	14.130	(38)
		t, °C	*p*, mm		
10	TeH_2	−60	34		(11)
		−50	79		
		−45.4	102		
	N_2O	−144 to − 90	$23\ 59_{0}$	9.579	(13, 14)
	NO	−200 to −161	16 423	10.048	(26, 30); *cf.* (57, 61)
	N_2O_4‖	−100 to − 40	$55\ 16_{0}$	13.400	(23); *cf.* (76)
		− 40 to − 10	$45\ 44_{0}$	11.214	(76); *cf.* (27, 74)
	N_2O_5	− 30 to + 30	$57\ 18_{0}$	12.647	(17, 75)
	NH_3¶	−127 to − 78	$31\ 21_{1}$	9.997_{4}	(15, 45, 53, 88); *cf.* (7, 13, 14, 57)
	NOCl	*p* = 55.0 mm at −68.6°			(10)
	NH_4Cl**	100 to 400	83 486	10.0164	(40, 41, 67, 85, 86, 87); *cf.* (34, 66)
		t, °C	*p*, mm		
		338.0	760		
		427	4 560		
		459	8 360		(67)
		490	15 200		
		520	26 220		
	NH_4Br	250 to 400	90 208	9.9404	(41, 85)
		760 mm at 394.2°			
	NH_4I††	300 to 400	95 730	10.270_{0}	(41, 85)
		760 mm at 403.5°			
	NH_4HS	6 to 40	$46\ 02_{5}$	10.75_{00}	(35, 109)
		760 mm at 32.7°			
12	PCl_5	*t*, °C	*p*, mm		
		156.1	562.3		(85)
		143.6	354.8		
		136.7	266.1		
		122.2	133.4		
		101.4	37.58		
	PH_4Cl	−78.2	10.0		(102)
		−63.0	39.81		
		−41.1	251.2		
		−26.8	760.0		
		−23.1	$1\ 000._{0}$		
		+ 0.9	$5\ 623._{0}$		
		29.9	$38\ 90_{0}._{0}$		
	PH_4Br	−80 to +40	$48\ 11_{5}$	10.956_{1}	(43)
		760 mm at 38.1°			
	PH_4I	10 to 60	$51\ 85_{4}$	10.950_{0}	(43, 85)
		760 mm at 62.5°			
	As_2O_3	100 to 310	$111\ 3_{50}$	12.127	(59, 84); *cf.* (94)
		355.8° at 760.0 mm			
	$SbCl_3$	50.3° at 1.1 mm			(54)
		59.9° at 3.4 mm			
	$BiCl_3$	91 to 213	$13\ 12_{5}$	2.68_{1}	(54)
		t, °C	*p*, mm		
16	CO	−220.6	4		(24, 33, 60)
		−209.1	50		
		−205.70	111.33 ±0.04		
	CO_2‡‡	−135 to −56.7	$26\ 179._{8}$	9.9082	(31, 32, 47, 62, 83, 96); *cf.* (33, 107, 116)
		p = 760.0 at -78.5_{2}°			
		$\log_{10} p = -\frac{1275.6_{2}}{T} + 0.00683_{8}T + 8.307_{1}$ (−183° to −135°)			
	CCl_4	−70 to −50	34 608	8.05	(57)
		−36.53° at 3.52 mm			
		−27.19° at 6.17 mm			(68)
	$(CN)_2$	−72 to −28	32 437	9.653_{9}	(63, 103)
	NH_4CN	7 to 17	$41\ 48_{4}$	9.97_{8}	(36)
	$NH_2CO_2NH_4$	Data conflicting			(9, 37)
	$(NH_4)_2CO_3$				(8)
		t, °C	*p*, mm		
	CNCl	−32.69	58.6		(68)
		−30.65	60.1		
		−24.7	101.71		
		−11.41	250.67		
	CNBr	−17 to +35	$47\ 05_{1}$	10.32_{8}	(5)

For other C-compounds, *see* the ℭ-table, p. 208

Key No.	Formula	Range, °C	A, joule	B	Lit.
18	$SiCl_4$	1.0 mm at −70°			(100)
		t, °C	*p*, mm		
	SiH_3Cl	−125.3	0.5		(99)
		−119.0	1.0		
	SiH_3Br	−94.0	2.5		(98)
	$SnCl_4$	−52 to −38	$46\ 74_{0}$	9.824	(57)
		t, °C	*p*, mm		
	$PbCl_2$	400	0.00174		(22)
		425	.0058		
		450	.0178		
		475	.051		

Key No.	Formula	Range, °C	A, joule	B	Lit.
23	PbS	*t*, °C	*p*, mm		(77)
		850	2.0		
		917	4.0		
		968	10.5		
		995	17.0		
	HgF_2	Data unreliable			(71)
	Hg_2Cl_2	*t*, °C	*p*, mm		(54)
		90	0.004		
		100	0.0089		
		110	0.011 } Less accurate		
		120	0.016		
		130	0.0227		
		140	0.038		
		150	0.07		
		160	0.15		
		170	0.27		
		180	0.45		
	$HgCl_2$	60 to 130	85 03$_0$	10.888	(42, 95); *cf.* (3)
		130 to 270	78 85$_0$	10.094	
	$HgBr_2$	111 to 235	79 8$_{00}$	10.181	(42, 95); *cf.* (3)
	HgI_2	100 to 250	82 34$_0$	10.057	(42, 95); *cf.* (3, 19)
	HgS	760 mm at 580°			(2)
31		*t*, °C	*p*, mm		
	CuO	600	1.34×10^{-7}		(55)
		800	1.15×10^{-4}		
		950	6.8×10^{-4}		
	$CuCl_2$	487.6	223.9		(54)
		470.5	128.8		
		407.2	22.39		
		335.2	5.0		
		318.6	3.55		
	Ag_2O	1 435	3.4		(110)
		1 316	0.46		
	$AuCl_3$§§	100	7.0		(64)
		138.5	11.0		
		181	61.2		
		202	154.5		
		229	424.2		
		251	808.7		
	OsO_4	−38 to 40.1	56 5$_{00}$	10.71$_{00}$	(111)
	$FeCl_2$	700 to 930	135 $_{200}$	8.33	(54)
		t, °C	*p*, mm		
	$FeCl_3$	245.0	19.95		(54)
		256.0	35.48		
		292.3	316.2		
	$Co_2(CO)_8$	15	0.072 mm		(56)
49	UF_6	0 to 69	41 73$_0$	9.521	(72)
		t, °C	*p*, mm		
	NbF_5	184.5	303.1		(73)
		191.6	329.7		
		194.5	358.9		
	BBr_3	−50	0.7		(97)
	BN	*v.* Vol. IV, p. 84			
	$B(CH_3)_3NH_3$§§	0 to 40	53 18$_4$	10.172	(101)
	$AlCl_3$	70 to 190	115 $_{000}$	16.24	(54)
82	NaCl	2.4 mm at 746.9°			(54)

* Over the range −150 to −114°C, Karwat gives the equation:

$$\log p = -\frac{1171.62}{T} - 2.3577 \log T + 14.57497,$$

the coefficient of log T being obtained from specific heat measurements at low temperatures.

† Henglein gives the equation:

$$\log p = -\frac{2202.0}{T^{1.1602}} + 7.5030,$$

over the range of his measurements from −130 to −95°C.

‡ Henglein gives the equation:

$$\log p = -\frac{1435.9}{T^{1.0496}} + 7.5030$$

§ The results when plotted give an unusual curve.

‖ For amount of dissociation see (76).

¶ Karwat gives the equation: $\log p = -\frac{1790.00}{T} - 1.81630 \log T + 14.97593,$ the coefficient of log T being obtained from specific heat measurements at low temperatures.

** Smith and Calvert give the equation:

$$\log p = -\frac{1920.357}{T} + 9.778609 \log T - 21.21708.$$

†† Smith and Calvert give the equation:

$$\log p = -\frac{7714.591}{T} + 10.04345 \log T + 42.69560.$$

‡‡ Over the range −110 to −80°C Henning, to express his experimental results, gives the equation:

$$\log p = -\frac{1279.11}{T} + 1.75 \log T - 0.0020757T + 5.85242.$$

The simpler equation:

$$\log p = -\frac{1352.6}{T} + 9.8318$$

expresses his experimental results closely.

§§ The vapor is strongly dissociated.

C-TABLE

$$\log_{10} p_{\text{mm}} = \frac{-0.05223\text{A}}{T} + \text{B}$$

Formula	Name	Range, °C	A	B	Lit.
CH_4	Methane*.	−194 to −184	9 896.2	7.6509	(16, 32, 45); *cf.* (33, 61)
C_2H_2	Acetylene.	−140 to −82	21 91$_4$	8.933	(13); *cf.* (106)
$C_2H_2O_4$	Oxalic acid.	55 to 105	90 502.$_6$	12.222$_9$	(112)
$C_2H_4O_2$	Acetic acid.	·35 to 10	41 689	8.502	(57, 79, 113, 114); *cf.* (49)
C_6H_4BrCl	*p*-Bromochlorobenzene.	23 to 63	69 75$_5$	11.629	(91)
$C_6H_4Cl_2$	*p*-Dichlorobenzene.	30 to 50	72 21$_8$	12.48$_0$	(91); *cf.* (46, 48)
C_6H_6	Benzene.	−58 to −30	42 904	9.556	(25, 57); *cf.* (4, 68, 114)
		−30 to +5	44 222	9.846	
		0.018 mm at −77.5°			
C_6H_{12}	Cyclohexane.	−5 to +5	37 39$_4$	8.594	(115)
$C_7H_6O_2$	Benzoic acid.	60 to 110	63 82$_0$	9.033	(59)
$C_{10}H_8$	Naphthalene.	0 to 80	71 401	11.450	(1, 4, 78, 104); *cf.* (70, 90)
$C_{10}H_{16}O$	Camphor.	0 to 180	53 55$_9$	8.799	(1, 65, 94, 105); *cf.* (18, 59)
$C_{14}H_8O_2$	Anthraquinone.	224 to 286	110 04$_0$	12.305	(58, 94)
$C_{14}H_{10}$	Anthracene.	100 to 160	70 39$_0$	8.706	(59)

* Using specific heats at low temperatures, for log T coefficient, Karwat gives:

$$\log_{10} p_{\text{mm}} = \frac{-554.518}{T} - 1.0831 \log_{10} T + 10.1840$$

VALUES OF *p* AND *t*

CH_2O_2, Formic acid (44)

t, °C	*p*, mm
1	8.8
2	9.7
3	10.6
4	11.6
5	12.8
6	14.1
7	15.5
8	17.4

$C_2H_4Br_2$, Ethylene bromide* (M. P., 9.55°) (69)

−28.21	1.51
−23.16	1.90
−12.30	2.65
− 7.18	3.24
0	3.47
+ 5.62	5.53
6.54	6.16

* M. P. of pure $C_2H_4Br_2$, 7.7°.

C_2H_9NS, $NH_3(C_2H_5)HS$ (109)

5.0	33
13.4	55
17.0	73
23.2	109
31.4	183
35.0	228
37.2	264
40.5	322

C_3H_4, Allylene (51)

−110	1$_0$

C_3H_4, Allene (51)

−146	1$_0$

C_3H_6O, Acetone (21)

−94.8	0.017

$C_3H_6O_2$, Methyl acetate (39)

−135	0.00354

$C_4H_{10}O$, Ethyl ether (21)

−119.8	0.0027
−117.3	0.0065

$C_4H_{12}ClN$, Tetramethylammonium chloride (85)

231.5	690
227.1	567
222.5	430
213.3	312
202.4	187
186.6	108

$C_4H_{12}IN$, Tetramethylammonium iodide (85)

306.2	781
303.0	698
295.8	547
287.4	421
276.6	298
260.6	166
242.6	83

$C_6H_3N_3O_7$, Picric acid (81)

100.4	0.00249

$C_6H_4Br_2$, *p*-Dibromobenzene (46, 48, 91)

t, °C	*p*, mm
84.0	7.58$_6$
69.4	2.63
52.8	0.660$_7$
32.8	.0794
21.0	.0158

$C_6H_4N_2O_5$, 2, 4-Dinitrophenol (81)

100	0.228

$C_6H_6N_2O_2$, *p*-Nitroaniline (82)

100	0.0136

$C_6H_6O_2$, Hydroquinol (94)

155.0	5.9
157.6	7.1
164.3	1.0

$C_7H_5ClO_2$, Chlorobenzoic acid (80)

o-	100	0.1803
m-	100.63	.197
p-	100	.045

$C_7H_5NO_4$, *p*-Nitrobenzoic acid (80)

100	0.0096

$C_7H_6O_3$, Hydroxybenzoic acid (80)

o-	100	0.397
m-	101.06	.00149
p-	100.91	.00030

$C_8H_8N_2O_3$, Nitroacetanilide (82)

m-	100	0.0042
p-	100	.0021

$C_8H_8O_2$, *p*-Toluic acid (80)

100	0.216

$C_8H_8O_3$, Hydroxytoluic acid (80)

o-3	100	0.235
o-4	100	.121
o-5	100	.182
m-4	100	.0176
p-3	100.17	.00072

$C_{10}H_{18}O$, Borneol (105)

154.3	114.8
129.1	38.9
107.1	12.88
90.5	5.012
79.0	2.455

$C_{13}H_{10}O$, Benzophenone (108)

0	2.03×10^{-5}
8	6.94×10^{-5}
26	6.859×10^{-4}
	7.614×10^{-4}
32	1.418×10^{-3}
40	3.198×10^{-3}
	3.933×10^{-3}

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THE VAPOR PRESSURES OF ICE AND WATER UP TO 100°C

E. W. WASHBURN

In the following tables, the values given are the vapor pressures for the condition that the solid or liquid phase is under its own vapor pressure. If the solid or liquid phase is in contact with the atmosphere, the corresponding vapor pressures will be somewhat higher, and can be obtained by adding to the value given in the table a small increment, Δp, computed by means of the following equations:

Dans les tables suivantes, les valeurs données sont les tensions de vapeur dans la condition de la phase solide ou liquide se trouvant sous la pression de sa propre vapeur. Si la phase liquide ou la phase solide se trouve en contact avec l'atmosphère, les tensions de vapeur correspondantes seront un peu plus élevées, et elles peuvent être obtenues en additionnant aux valeurs données dans les tables un petit accroissement, Δp, calculé au moyen des équations suivantes:

Die in den folgenden Tafeln angegebenen Werte für die Dampfdrucke gelten für den Zustand, dass die feste oder flüssige Phase unter dem eigenen Dampfdruck steht. Ist die feste oder flüssige Phase mit der Atmosphäre in Verbindung, so werden die entsprechenden Dampfdrucke etwas höher sein. Man erhält sie, wenn man zu dem in der Tafel angegebenen Wert das Inkrement Δp addiert, das sich nach den Gleichungen berechnen lässt:

Nelle tabelle seguenti le tensioni riportate sono quelle del solido o del liquido a contatto col solo vapore proprio. Quando il solido o il liquido si trovano in contatto con l'atmosfera, le tensioni di vapore corrispondenti sono un po'più alte e si possono avere aggiungendo al valore della tabella, un incremento Δp, calcolato per mezzo della seguente equazione:

For ice and for water below 0°C:

$$\frac{100\Delta p}{p} = \frac{20}{t + 273}$$

For water above 0°C:

$$100\,\frac{\Delta p}{p} = 0.0775 - 3.13 \times 10^{-4}t \text{ (valid up to } t = 40\text{°C)}$$

and

$$100\,\frac{\Delta p}{p} = 0.0652 - 8.75 \times 10^{-5}p \text{ (valid above 50°C)}$$

THE VAPOR PRESSURE OF ICE

Computed from the equation

$$\log_{10}p = \frac{-2445.5646}{T} + 8.2312\log_{10}T - 0.01677006T + 1.20514 \times 10^{-5}T^2 - 6.757169, \text{ mm Hg}$$

Based upon the measurements of Weber (2) and Scheel and Heuse (1); *see* Washburn (3).

$$T = 273.1 + t$$

−90° to −30°; unit, 0.001 mm Hg

t, °C	0	1	2	3	4	5	6	7	8	9
−90	0.070	0.058	0.048	0.040	0.033	0.027	0.022	0.018	0.015	0.012
−80	0.40	0.34	0.29	0.24	0.20	0.17	0.14	0.12	0.10	0.084
−70	1.94	1.67	1.43	1.23	1.05	0.90	0.77	0.66	0.56	0.47
−60	8.08	7.03	6.14	5.34	4.64	4.03	3.49	3.02	2.61	2.25
−50	29.55	26.1	23.0	20.3	17.8	15.7	13.8	12.1	10.6	9.25
−40	96.6	86.2	76.8	68.4	60.9	54.1	48.1	42.6	37.8	33.4
−30	285.9	257.5	231.8	208.4	187.3	168.1	150.7	135.1	120.9	108.1

−30° to 0°; mm Hg

t, °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
−29	0.317	0.314	0.311	0.307	0.304	0.301	0.298	0.295	0.292	0.289
−28	0.351	0.348	0.344	0.341	0.337	0 334	0.330	0.327	0.324	0.320
−27	0.389	0.385	0.381	0.377	0.374	0.370	0.366	0.362	0.359	0.355
−26	0.430	0.426	0.422	0.418	0.414	0.409	0.405	0.401	0.397	0.393
−25	0.476	0.471	0.467	0.462	0.457	0.453	0.448	0.444	0.439	0.435
−24	0.526	0.520	0.515	0.510	0.505	0.500	0.495	0.490	0.486	0.481
−23	0.580	0.574	0.569	0.563	0.558	0.552	0.547	0.541	0.536	0.531
−22	0.640	0.633	0.627	0.621	0.615	0.609	0.603	0.597	0.592	0.586
−21	0.705	0.698	0.691	0.685	0.678	0.672	0.665	0.659	0.652	0.646
−20	0.776	0.769	0.761	0.754	0.747	0.740	0.733	0.726	0.719	0.712
−19	0.854	0.846	0.838	0.830	0.822	0.814	0.806	0.799	0.791	0.783
−18	0.939	0.930	0.921	0.912	0.904	0.895	0.887	0.879	0.870	0.862
−17	1.031	1.021	1.012	1.002	0.993	0.984	0.975	0.966	0.956	0.947
−16	1.132	1.121	1.111	1.101	1.091	1.080	1.070	1.060	1.051	1.041
−15	1.241	1.230	1.219	1.208	1.196	1.186	1.175	1.164	1.153	1.142

−30° to 0°; mm Hg.—(*Continued*)

t, °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
−14	1.361	1.348	1.336	1.324	1.312	1.300	1.288	1.276	1.264	1.253
−13	1.490	1.477	1.464	1.450	1.437	1.424	1.411	1.399	1.386	1.373
−12	1.632	1.617	1.602	1.588	1.574	1.559	1.546	1.532	1.518	1.504
−11	1.785	1.769	1.753	1.737	1.722	1.707	1.691	1.676	1.661	1.646
−10	1.950	1.934	1.916	1.899	1.883	1.866	1.849	1.833	1.817	1.800
−9	2.131	2.112	2.093	2.075	2.057	2.039	2.021	2.003	1.985	1.968
−8	2.326	2.306	2.285	2.266	2.246	2.226	2.207	2.187	2.168	2.149
−7	2.537	2.515	2.493	2.472	2.450	2.429	2.408	2.387	2.367	2.346
−6	2.765	2.742	2.718	2.695	2.672	2.649	2.626	2.603	2.581	2.559
−5	3.013	2.987	2.962	2.937	2.912	2.887	2.862	2.838	2.813	2.790
−4	3.280	3.252	3.225	3.198	3.171	3.144	3.117	3.091	3.065	3.039
−3	3.568	3.539	3.509	3.480	3.451	3.422	3.393	3.364	3.336	3.308
−2	3.880	3.848	3.816	3.785	3.753	3.722	3.691	3.660	3.630	3.599
−1	4.217	4.182	4.147	4.113	4.079	4.045	4.012	3.979	3.946	3.913
−0	4.579	4.542	4.504	4.467	4.431	4.395	4.359	4.323	4.287	4.252

THE VAPOR PRESSURE OF LIQUID WATER FROM −16 TO 0°C (IN MM HG)

Computed from the above table with the aid of the thermodynamic equation

$$\log_{10}\frac{p_w}{p_i} = \frac{-1.1489t}{273.1+t} - 1.330\times10^{-5}t^2 + 9.084\times10^{-8}t^3 \; (^3)$$

t, °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
−15	1.436	1.425	1.414	1.402	1.390	1.379	1.368	1.356	1.345	1.334
−14	1.560	1.547	1.534	1.522	1.511	1.497	1.485	1.472	1.460	1.449
−13	1.691	1.678	1.665	1.651	1.637	1.624	1.611	1.599	1.585	1.572
−12	1.834	1.819	1.804	1.790	1.776	1.761	1.748	1.734	1.720	1.705
−11	1.987	1.971	1.955	1.939	1.924	1.909	1.893	1.878	1.863	1.848
−10	2.149	2.134	2.116	2.099	2.084	2.067	2.050	2.034	2.018	2.001
−9	2.326	2.307	2.289	2.271	2.254	2.236	2.219	2.201	2.184	2.167
−8	2.514	2.495	2.475	2.456	2.437	2.418	2.399	2.380	2.362	2.343
−7	2.715	2.695	2.674	2.654	2.633	2.613	2.593	2.572	2.553	2.533
−6	2.931	2.909	2.887	2.866	2.843	2.822	2.800	2.778	2.757	2.736
−5	3.163	3.139	3.115	3.092	3.069	3.046	3.022	3.000	2.976	2.955
−4	3.410	3.384	3.359	3.334	3.309	3.284	3.259	3.235	3.211	3.187
−3	3.673	3.647	3.620	3.593	3.567	3.540	3.514	3.487	3.461	3.436
−2	3.956	3.927	3.898	3.871	3.841	3.813	3.785	3.757	3.730	3.702
−1	4.258	4.227	4.196	4.165	4.135	4.105	4.075	4.045	4.016	3.986
−0	4.579	4.546	4.513	4.480	4.448	4.416	4.385	4.353	4.320	4.289

THE VAPOR PRESSURE OF LIQUID WATER FROM 0°C TO 100°C (IN MM HG)

From the Physikalisch-Technische Reichsanstalt "Wärmetabellen," Holborn, Scheel and Henning, Vieweg und Sohn, Braunschweig, 1909. By permission

t, °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	4.579	4.613	4.647	4.681	4.715	4.750	4.785	4.820	4.855	4.890
1	4.926	4.962	4.998	5.034	5.070	5.107	5.144	5.181	5.219	5.256
2	5.294	5.332	5.370	5.408	5.447	5.486	5.525	5.565	5.605	5.645
3	5.685	5.725	5.766	5.807	5.848	5.889	5.931	5.973	6.015	6.058
4	6.101	6.144	6.187	6.230	6.274	6.318	6.363	6.408	6.453	6.498
5	6.543	6.589	6.635	6.681	6.728	6.775	6.822	6.869	6.917	6.965
6	7.013	7.062	7.111	7.160	7.209	7.259	7.309	7.360	7.411	7.462
7	7.513	7.565	7.617	7.669	7.722	7.775	7.828	7.882	7.936	7.990
8	8.045	8.100	8.155	8.211	8.267	8.323	8.380	8.437	8.494	8.551
9	8.609	8.668	8.727	8.786	8.845	8.905	8.965	9.025	9.086	9.147
10	9.209	9.271	9.333	9.395	9.458	9.521	9.585	9.649	9.714	9.779
11	9.844	9.910	9.976	10.042	10.109	10.176	10.244	10.312	10.380	10.449
12	10.518	10.588	10.658	10.728	10.799	10.870	10.941	11.013	11.085	11.158
13	11.231	11.305	11.379	11.453	11.528	11.604	11.680	11.756	11.833	11.910
14	11.987	12.065	12.144	12.223	12.302	12.382	12.462	12.543	12.624	12.706

The Vapor Pressure of Liquid Water from 0°C to 100°C (in mm Hg).—(*Continued*)

t, °C	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
15	12.788	12.870	12.953	13.037	13.121	13.205	13.290	13.375	13.461	13.547
16	13.634	13.721	13.809	13.898	13.987	14.076	14.166	14.256	14.347	14.438
17	14.530	14.622	14.715	14.809	14.903	14.997	15.092	15.188	15.284	15.380
18	15.477	15.575	15.673	15.772	15.871	15.971	16.071	16.171	16.272	16.374
19	16.477	16.581	16.685	16.789	16.894	16.999	17.105	17.212	17.319	17.427
20	17.535	17.644	17.753	17.863	17.974	18.085	18.197	18.309	18.422	18.536
21	18.650	18.765	18.880	18.996	19.113	19.231	19.349	19.468	19.587	19.707
22	19.827	19.948	20.070	20.193	20.316	20.440	20.565	20.690	20.815	20.941
23	21.068	21.196	21.324	21.453	21.583	21.714	21.845	21.977	22.110	22.243
24	22.377	22.512	22.648	22.785	22.922	23.060	23.198	23.337	23.476	23.616
25	23.756	23.897	24.039	24.182	24.326	24.471	24.617	24.764	24.912	25.060
26	25.209	25.359	25.509	25.660	25.812	25.964	26.117	26.271	26.426	26.582
27	26.739	26.897	27.055	27.214	27.374	27.535	27.696	27.858	28.021	28.185
28	28.349	28.514	28.680	28.847	29.015	29.184	29.354	29.525	29.697	29.870
29	30.043	30.217	30.392	30.568	30.745	30.923	31.102	31.281	31.461	31.642
30	31.824	32.007	32.191	32.376	32.561	32.747	32.934	33.122	33.312	33.503
31	33.695	33.888	34.082	34.276	34.471	34.667	34.864	35.062	35.261	35.462
32	35.663	35.865	36.068	36.272	36.477	36.683	36.891	37.099	37.308	37.518
33	37.729	37.942	38.155	38.369	38.584	38.801	39.018	39.237	39.457	39.6772
34	39.898	40.121	40.344	40.569	40.796	41.023	41.251	41.480	41.710	41.94
35	42.175	42.409	42.644	42.880	43.117	43.355	43.595	43.836	44.078	44.320
36	44.563	44.808	45.054	45.301	45.549	45.799	46.050	46.302	46.556	46.811
37	47.067	47.324	47.582	47.841	48.102	48.364	48.627	48.891	49.157	49.424
38	49.692	49.961	50.231	50.502	50.774	51.048	51.323	51.600	51.879	52.160
39	52.442	52.725	53.009	53.294	53.580	53.867	54.156	54.446	54.737	55.030
40	55.324	55.61	55.91	56.21	56.51	56.81	57.11	57.41	57.72	58.03
41	58.34	58.65	58.96	59.27	59.58	59.90	60.22	60.54	60.86	61.18
42	61.50	61.82	62.14	62.47	62.80	63.13	63.46	63.79	64.12	64.46
43	64.80	65.14	65.48	65.82	66.16	66.51	66.86	67.21	67.56	67.91
44	68.26	68.61	68.97	69.33	69.69	70.05	70.41	70.77	71.14	71.51
45	71.88	72.25	72.62	72.99	73.36	73.74	74.12	74.50	74.88	75.26
46	75.65	76.04	76.43	76.82	77.21	77.60	78.00	78.40	78.80	79.20
47	79.60	80.00	80.41	80.82	81.23	81.64	82.05	82.46	82.87	83.29
48	83.71	84.13	84.56	84.99	85.42	85.85	86.28	86.71	87.14	87.58
49	88.02	88.46	88.90	89.34	89.79	90.24	90.69	91.14	91.59	92.05
50	92.51	97.20	102.09	107.20	112.51	118.04	123.80	129.82	136.08	142.60
60	149.38	156.43	163.77	171.38	179.31	187.54	196.09	204.96	214.17	223.73
70	233.7	243.9	254.6	265.7	277.2	289.1	301.4	314.1	327.3	341.0
80	355.1	369.7	384.9	400.6	416.8	433.6	450.9	468.7	487.1	506.1
90	525.76	527.76	529.77	531.78	533.80	535.82	537.86	539.90	541.95	544.00
91	546.05	548.11	550.18	552.26	554.35	556.44	558.53	560.64	562.75	564.87
92	566.99	569.12	571.26	573.40	575.55	577.71	579.87	582.04	584.22	586.41
93	588.60	590.80	593.00	595.21	597.43	599.66	601.89	604.13	606.38	608.64
94	610.90	613.17	615.44	617.72	620.01	622.31	624.61	626.92	629.24	631.57
95	633.90	636.24	638.59	640.94	643.30	645.67	648.05	650.43	652.82	655.22
96	657.62	660.03	662.45	664.88	667.31	669.75	672.20	674.66	677.12	679.59
97	682.07	684.55	687.04	689.54	692.05	694.57	697.10	699.63	702.17	704.71
98	707.27	709.83	712.40	714.98	717.56	720.15	722.75	725.36	727.98	730.61
99	733.24	735.88	738.53	741.18	743.85	746.52	749.20	751.89	754.58	757.29
100	760.00	762.72	765.45	768.19	770.93	773.68	776.44	779.22	782.00	784.78
101*	787.57	790.37	793.18	796.00	798.82	801.66	804.50	807.35	810.21	813.08

* For higher temperatures, *v.* p. 233.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Scheel and Heuse, *16*, **29**: 731; 09. (2) Weber, *168*, No. **150**: 37; 15. (3) Washburn, *406*, **52**: 488; 24.

VAPOR PRESSURES OF CHEMICAL COMPOUNDS IN THE LIQUID STATE FOR PRESSURES UP TO TWO ATMOSPHERES

Otto Maass

In addition to the vapor-pressure data for the compounds given, the 𝔅-Table is a complete index to the vapor-pressure data for all pure chemical compounds in the liquid state. The literature references given first are those upon which the values given are based; confirmatory references are marked *cf.*

𝔅-TABLE, STANDARD ARRANGEMENT (*v.* p. viii)

$$\log_{10} p_{\mathrm{mm}} = \frac{-0.05223\mathrm{A}}{T} + \mathrm{B}$$

The tables contain either the values of A and B in the above equation (together with the range of applicability of the equation), tabulated values of *t* and *p*, or both.

The values in the B. P. column are based on the best available direct determinations of the boiling point. These values not infrequently differ considerably from those interpolated from the vapor-pressure data, a situation which can be cleared up only by further research.

Formula	Range, °C	A, joule	B	Normal B. P., °C	Lit.
H_2O	*v.* p. 210				
H_2O_2	10 to 90	485_{80}	8.85_{8}		(31)
HF	−83 to +48	251_{80}	7.37_{0}		(60)
ClO_2	−59 to +11	272_{60}	7.89_{8}		(29)
HCl				−85.0	(25); *cf.* (32, 64)
	t, °C	*p*, mm			
	−108	$168._{5}$			
	−104	$226._{2}$			
	−100	$329._{8}$			
	− 96	$503._{4}$			
	− 88	$640._{8}$			
HBr	−86 to −66	179_{60}	7.42_{7}		(32); *cf.* (63, 64)
HI	−50 to −34	215_{80}	7.63_{0}		(32); *cf.* (63)
SO_2				−10.02	(7, 25, 37)
	t, °C	*p*, mm	*t*, °C	*p*, mm	
	−70	$19._{9}$	−30	$286._{0}$	
	−65	$30._{0}$	−25	$373._{0}$	
	−60	$42._{8}$	−20	$478._{0}$	
	−55	$61._{8}$	−15	$607._{0}$	
	−50	$86._{7}$	−10	$761._{0}$	
	−45	$119._{6}$	− 5	$947._{0}$	
	−40	$162._{8}$	0	$1164._{0}$	
	−35	$217._{1}$			
SO_3	24 to 48	434_{50}	10.02_{2}		(8)
H_2S				−59.4	(32); *cf.* (63, 64)
	t, °C	*p*, mm	*t*, °C	*p*, mm	
	−82	17_{2}	−66	53_{5}	
	−78	23_{5}	−62	66_{0}	
	−74	33_{9}	−58	83_{0}	
	−70	43_{2}			
S_2Cl_2	0 to 138	359_{90}	7.45_{5}		(23)
$SOBr_2$					(85)
H_2Se	−66 to −26	202_{10}	7.43_{1}		(11)
H_2SeO_3	70 to 110	430_{00}	8.15_{0}		(27)
$SeOCl_2$				176.4	(30)
	t, °C	*p*, mm	*t*, °C	*p*, mm	
	85	$22._{0}$	135	$21_{8}._{0}$	
	95	$37._{4}$	145	$30_{4}._{0}$	
	105	$58._{9}$	155	$41_{8}._{0}$	
	115	$94._{4}$	165	$56_{0}._{0}$	
	125	$114._{0}$			
H_2Te	−46 to 0	227_{60}	7.26_{0}		(10)
N_2O	−90.1 to −88.7	164_{40}	7.5_{85}		(12); *cf.* (7, 46)
NO	−163.7 to −148	1304_{0}	8.440		(21, 24)
N_2O_3	−25 to 0	394_{00}	$10._{80}$		(22)
N_2O_4	−8 to +43.2	3343_{0}	8.814		(5, 56); *cf.* (45, 85.5)
H_3N				−33.35	(13, 25); *cf.* (7, 12, 43)
	t, °C	*p*, mm	*t*, °C	*p*, mm	
	−77	$47._{8}$	−47	$365._{5}$	
	−74	$60._{5}$	−44	$432._{9}$	
	−71	$76._{7}$	−41	$510._{8}$	
	−68	$94._{7}$	−38	$598._{6}$	
	−65	$117._{1}$	−35	$699._{1}$	
	−62	$143._{8}$	−32	$812._{9}$	
	−59	$175._{5}$	−29	$941._{8}$	
	−56	$212._{7}$	−26	$108_{5}._{0}$	
	−53	$256._{3}$	−23	$124_{7}._{0}$	
	−50	$307._{0}$	−20	$142_{7}._{0}$	
NOCl	−61.5 to −5.4	255_{00}	7.8_{70}		(80); *cf.* (9)
P_2O_3	*t*, °C	*p*, mm	*t*, °C	*p*, mm	(57)
	30	$_{8}$	70	6_{0}	
	50	$9._{0}$	80	15_{0}	
	60	2_{0}	90	30_{0}	
PH_3				−87.4	(25); *cf.* (64)
	t, °C	*p*, mm	*t*, °C	*p*, mm	
	−133	$29._{8}$	−109	$209._{9}$	
	−129	$43._{0}$	−105	$274._{6}$	
	−125	$61._{8}$	−101	$354._{2}$	
	−121	$85._{7}$	− 97	$450._{4}$	
	−117	$117._{5}$	− 93	$564._{5}$	
	−113	$158._{3}$	− 89	$699._{5}$	
PCl_3	0–70	318_{60}	7.6_{81}	73.5	(46)
As_2O_3	315 to 490	521_{20}	6.51_{8}		(55)
$AsCl_3$	50 to 100	391_{10}	7.95_{8}		(6)
$SbCl_3$	170 to 253	494_{40}	8.09_{0}		(49)
	t, °C	*p*, mm			
	120	29			
	130	43			
	140	64			
	150	92			
	160	127			
$SbBr_3$	235 to 324	550_{00}	8.00_{5}		(49)
	t, °C	*p*, mm	*t*, °C	*p*, mm	
	180	42	210	111	
	190	59	220	148	
	200	82	230	195	
SbI_3	330 to 445	641_{50}	7.83_{1}		(49)
	t, °C	*p*, mm	*t*, °C	*p*, mm	
	250	23	295	80	
	265	35	310	115	
	280	53	325	166	
CO	−290 to −206	6354	6.976		(18); *cf.* (3, 39)
CO_2, *v.* p. 235					
C_3O_2	−100 to +6	254_{60}	7.6_{40}	6.3	(77)
CCl_4, *see also* p. 215	*t*, °C	*p*, mm	*t*, °C	*p*, mm	(16, 84)
	−20	9.9	60	439.0	
	0	33.1	90	1112	
	+30	139.5	110	1880	
CCl_2O	−15 to +22	253_{90}	7.59_{5}	*v.* p. 215	(41)
CS_2				46.25	(4, 25, 37, 59); *cf.* (46, 47)
	t, °C	*p*, mm	*t*, °C	*p*, mm	
	−70	$1._{6}$	+10	$198._{1}$	
	−60	$3._{5}$	20	$297._{5}$	
	−50	$7._{1}$	30	$432._{7}$	
	−40	$14._{0}$	40	$616._{7}$	
	−30	$26._{2}$	50	$854._{0}$	
	−20	$46._{5}$	60	$117_{8}._{0}$	
	−10	$78._{8}$	70	$157_{0}._{0}$	
	0	$127._{8}$			
COS	−80 to −50	192_{20}	7.38_{8}		(68)
	t, °C	*p*, mm			
	−130	$1._{5}$			
	−110	$13._{0}$			
	− 90	$73._{0}$			

Formula	Range, °C	A, joule	B	Normal B. P., °C	Lit.
CSSe	*t*, °C 0 +15 30 50 70	*p*, mm 26 55 112 246 485		84.5	(78)
$(CN)_2$	−32 to − 6	23750	7.808		(79)
HCN	− 8 to +27	27830	7.7446		(42); *cf.* (87)
CNCl	− 5 to +40	27100	7.840		(46)
For other C-compounds, *v.* the 𝕮-Table, p. 215					
SiO_2	1860 to 2230	506000	13.43	2230	(52)
H_4Si	−160 to −112	12690	6.996		(71); *cf.* (1)
H_6Si_2	−115 to −14.6	21700	7.258		(71)
H_8Si_3	−70 to +52	29850	7.676		(71, 76)
$(SiH_3)_2O$	−110 to −15	23590	7.686		(75)
$SiCl_4$	−70 to +5	30100	7.644		(46, 75)
Si_2Cl_6	40 to 103	45900	8.700	139	(33)
Si_3Cl_8	124 to 149	50500	8.300	213	(33)
$(SiCl_3)_2O$	30 to 137 *t*, °C 0 10 20	39850 *p*, mm 1.5 3.0 6.0	7.980		(75)
SiH_3Cl	−110 to −30	21400	7.483		(73)
SiH_2Cl_2	−100 to + 8	25500	7.613		(73)
SiH_3Br	− 90 to + 2	24480	7.524		(71)
SiH_2Br_2	− 65 to +18	31010	7.654		(72)
$(SiH_3)_3N$	− 60 to +15	30620	7.883		(74)
For methylsilicanes, *v.* p. 215					
Ge_2H_6	− 98 to +30	26400	7.444		(14)
Ge_3H_8	0 to 111	31900	7.224		(14)
$GeCl_4$	10.4 to 86	38500	7.340		(38)
SnH_4	−148 to −49	19140	7.400		(40)
$SnCl_4$	*t*, °C −10 +10 30 60	*p*, mm 2.8 10.3 31.3 112.0	*t*, °C 90 120 140	*p*, mm 360.5 895.0 1497.0	(84)
PbF_2	1078 to 1289	165100	8.391	1292	(82)
$PbCl_2$	500 to 950	141900	8.961	945	(17); *cf.* (82)
$PbBr_2$	735 to 918	118000	8.064	916	(82)
TlF	282 to 298	105000	12.52	298	(82)
TlCl	665 to 807	105200	7.974	806	(82)
TlBr	634 to 817	105400	7.940	815	(82)
TlI	693 to 822	105400	7.902	824	(82)
CdI_2	385 to 450	122200	9.269		(58)
HgCl	*t*, °C 310 330 350 370	*p*, mm 108.0 189.2 329.9 548.9		383	(61); *cf.* (2, 48)
$HgCl_2$	275 to 309	61020	8.409		(28, 44, 65)
$HgBr_2$	238 to 331	61250	8.284		(28, 44, 65)
HgI_2	266 to 360	62770	8.115		(28, 44, 65)
Cu_2Cl_2	878 to 1369	80700	5.454	1366	(82)
Cu_2Br_2	997 to 1351	79900	5.460	1345	(82)
Cu_2I_2	991 to 1154	80700	5.570	1293	(82)
AgCl	1255 to 1442	185500	8.179	1554	(82)
OsF_8	38 to 47.3	29200	7.650		(54)
$Co(CO)_3NO$	14 to 66	30210	7.366		(36)
$Ni(CO)_4$	2 to 40	29800	7.780	43	(15); *cf.* (34)
CrO_2Cl_2	79 to 116	36230	7.735	116.7	(35)
NbF_5	*t*, °C 182 200 210	*p*, mm 290 420 540		219	(51)
TaF_5	*t*, °C 182 200	*p*, mm 370 460	*t*, °C 218 229	*p*, mm 580 750	(51)
B_2H_6	−112 to −87	13050	6.556		(66)
B_5H_{11}					(86)
BCl_3	*t*, °C −80 −60 −30 −15 0	*p*, mm 4.0 18.0 116.0 251.0 477.0		+12.7	(70)
BBr_3	−40 to +90	33320	7.655		(67)
B_2H_5Br	−80 to −5	26260	7.640		(69)
$B_3N_3H_6$					(86)
For $B(C_aH_b)_x$, *v.* p. 215					
Al_2O_3	1840 to 2200	540000	14.22	2210	(52)
LiF	1398 to 1666	218400	8.753	1670	(53); *cf.* (83)
LiCl	1045 to 1325	155900	7.939	1387	(50); *cf.* (83)
LiBr	1010 to 1265	152700	8.068	1265	(50); *cf.* (83)
LiI	940 to 1140	148600	8.011	1189	(50); *cf.* (83)
NaOH	1010 to 1402	132000	7.030	1390	(81)
NaF	1562 to 1701	218200	8.640	1705	(53); *cf.* (83)
NaCl	1156 to 1430 976 to 1155	185800 180300	8.548 8.3297	1439	(81); *cf.* (50) (19)
NaBr	1138 to 1394	161600	7.948	1393	(81); *cf.* (50)
NaI	1063 to 1307	165100	8.371	1297	(81); *cf.* (50)
NaCN	800 to 1360	155520	7.472	1496	(26)
KOH	1170 to 1327	136000	7.330	1322	(81)
KF	1278 to 1500	207500	9.000	1498	(53); *cf.* (83)
KCl	1116 to 1418 906 to 1105	169700 174500	8.130 8.3526	1416	(81); *cf.* (50) (19)
KBr	1095 to 1375 906 to 1063	163800 168100	7.936 8.2470	1381	(81); *cf.* (50) (19)
KI	1063 to 1333 843 to 1028	155700 157600	7.949 8.0957	1331	(81); *cf.* (50) (19)
RbF	1142 to 1400	183200	8.570	1408	(53); *cf.* (83)
RbCl	1142 to 1395	198600	9.111	1388	(50); *cf.* (83)
RbBr	1050 to 1365	165000	8.223	1340	(50); *cf.* (83)
RbI	1075 to 1325	156600	8.067	1304	(50); *cf.* (83)
CsF	1033 to 1255	140900	7.703	1253	(53); *cf.* (83)
CsCl	986 to 1295	163200	8.340	1289	(50); *cf.* (83)
CsBr	978 to 1305	153600	7.990	1297	(50); *cf.* (83)
CsI	1052 to 1280	185700	9.124	1280	(50); *cf.* (83)

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(For a key to the periodicals see end of volume)

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VAPOR PRESSURES OF ORGANIC LIQUIDS

H. R. Raikes and E. J. Bowen

ℭ-TABLE

The ℭ-arrangement, *v.* p. viii

$$\log_{10} p_{\mathrm{mm}} = -\frac{0.05223}{T} A + B$$

The values in the B. P. column are based upon the best available direct determinations of the boiling point. These values not infrequently differ considerably from those interpolated from the vapor-pressure data, a situation which can be cleared up only by further research.

Range, °C (or t, °C)	A, joule (or p_{mm})	B (for p in mm)	Normal B. P., °C
CCl_2O Carbonyl chloride (3, 76, 78); *cf.* (80)			
−90 to +25	24 684	7.460	8.45
CCl_3NO_2 Chloropicrin (5, 124)			
−20	1.5		111.91
−10	3.0		
0	5.7		
+10	10.4		
20	13.8		
25	18.3		
30	31.1		
35	40.15		
CCl_4 Carbon tetrachloride (28, 44, 72, 87, 124, 126, 136)			
−70 to −19	36 585	8.540	76.75
−19 to +20	33 914	8.004	
20	91		
25	114.5		
30	143.0		
35	176.2		
40	215.8		
45	262.5		
50	317.1		
55	379.3		
60	450.8		
65	530.9		
70	622.3		
80	843		
90	1 122		
100	1 463		
CN_4O_8 Tetranitromethane (65)			
40	26.6		125.7
50	44.2		
60	70.6	t, °C	p_{mm}
70	109	100	339
80	164	110	470
90	239	120	640
$CHBr_3$ Bromoform, 9.4 mm at 25.0° (97)			
$CHCl_3$ Chloroform (7, 28, 44, 89); *cf.* (87, 126)			
−60	0.81		61.20
−50	2.06		
−40	4.7		
−30	10.0		
−20	19.6		
−10	34.75	t, °C	p_{mm}
0	61.0	45	439.0
+10	100.5	50	526.0
20	159.6	55	625.2
25	199.1	60	739.6
30	246.0	60.9	760.0
35	301.3	70	1 019
40	366.4	80	1 403
HCN Hydrocyanic acid (41); *cf.* (80, 140)			
0 to 46	27 875	7.7526	25.75
CH_2Br_2 Methylene bromide (89)			
0	11.5		
10	20.4		
20	34.7		
30	56.4		
CH_2Cl_2 Methylene chloride (89, 116)			
0	147		
10	229.7		
20	348.9		
30	511.4		
CH_2O_2 Formic Acid (29, 34, 53, 55, 57, 92); *cf.* (96)			
10	18.9		100.5
20	33.1		
30	52.2		
40	82.6		
50	125.9		
60	189.7		
70	279.6		
80	398.1		
90	552.1		
100	753.4		
CH_3AsCl_2 Methylarsine dichloride (5)			
−17 to +35	43 686	8.6944	
CH_3Cl Methyl chloride (47, 100); *cf.* (87)			
−47 to −10	21 988	7.481	−23.47

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LITERATURE REFERENCES

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452. Die oesterreichische pharmazeutische Post.
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462. Bulletin institut international du froid.
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464. United States Public Health Service. Hygienic Laboratory Bulletins.
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PHASE-EQUILIBRIUM DATA

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ABBREVIATIONS, SYMBOLS, AND CONVENTIONS

The crystal phases (Bodenkörper) are indicated on the central line and apply to all the succeeding values until a new phase is indicated. ? indicates phase not definitely determined. In the composition column, solid state, two values

Les phases cristallines (Bodenkörper) sont indiquées sur la ligne centrale et se rapportent à toutes les valeurs successives, jusqu'à ce qu'une nouvelle phase soit indiquée. ? signifie une phase non déterminée d'une façon définie. Dans

Die Bodenkörper sind längst der Mitte angegeben und beziehen sich auf alle folgende Werte bis zur nächst angegebenen Phase. ? bedeutet, dass die Phase nicht genügend bestimmt ist. In der die Zusammensetzung angebende Colonne für

Le composizioni delle fasi cristalline (corpi di fondo) sono riportate nella linea centrale, e ognuna si riferisce a tutti i valori che seguono fin dove si trova indicata una fase nuova. ? indica una fase non determinata in modo preciso. Nella separated by a dash indicate that all intervening values are included.

Congruent melting points of molecular compounds are printed in bold-face type.

B. P. Boiling point.
Crit. Critical point.
E Eutectic point.
M Mole.
m Values in the metastable regions.
max. Maximum.
min. Minimum.
Mix. (resp. Mix$_1$, Mix$_2$) Mixed crystals. Where the composition of the mixed crystal is determined it is given in the left-hand composition column. Mix. + liq. indicates coincidence of solidus and liquidus.

M. P. Melting point.
t_L (resp. t_S) Temperature at which crystallization begins (resp. ends). All temperatures are t_L unless otherwise noted.
$t_{Tr.}$ Temperature of transition.

$\Delta t°$ Lowering of M. P. of A (resp. B) produced by B (resp. A) in solution.

Trip. Triple point.

U Transformation temperature or incongruent melting point.
Vis. Viscous solutions which solidify to glasses.

Vol. Volume.
Wt. Weight.
% per cent.
↓ A vertical arrow indicates that a linear relation holds over the range so designated.

( ) Values within parentheses are estimated.

la colonne des compositions, état solide, un trait séparant deux valeurs indique que toutes les valeurs qui interviennent sont incluses.

Les points de fusion des combinaisons moléculaires sont imprimés en caractères gras.

B. P. Point d'ébullition.
Crit. Point critique.
E Point eutectique.
M Mol. gr.
m Valeurs dans les régions métastables.
max. Maximum.
min. Minimum.
Mix. (resp. Mix$_1$, Mix$_2$) Cristaux mixtes. Lorsque la composition des cristaux mixtes a été déterminée, celle-ci est donnée dans la colonne des compositions à gauche. Mix. + liq. indique la coincidence du solidus avec le liquidus.
M. P. Point de fusion.
t_L (resp. t_S) Température à laquelle la cristallisation commence (resp. finit). Toutes les températures sont t_L à moins d'une autre indication.
$t_{Tr.}$ Température de transition.
$\Delta t°$ Abaissement du M. P. de A (resp. de B) produit par l'introduction de B (resp. de A) dans la solution.
Trip. Point triple.

U Température de transformation ou point de fusion incongruent.
Vis. Solutions visqueuses qui se solidifient en donnant des verres.
Vol. Volume.
Wt. Poids.
% Pour cent.
↓ Une flèche verticale indique qu'il existe une relation linéaire dans tout l'intervalle ainsi désigné.
( ) Les valeurs entre parenthèses sont des valeurs estimées.

den festen Zustand, drücken zwei durch einen Strich getrennte Angaben aus, dass alle dazwischen liegenden Werte eingeschlossen sind.

Kongruente Schmelzpunkte molekularer Verbindungen sind durch hervorgehobenen Druck gekennzeichnet.

B. P. Siedepunkt.
Crit. Kritischer Punkt.
E Eutektischer Punkt.
M Mol.
m Werte im metastabilen Gebiet.
max. Maximum.
min. Minimum.
Mix. (bezw. Mix$_1$, Mix$_2$) Mischkristalle. Ist die Zusammensetzung der Mischkristalle bestimmt, so ist dies in der linken Colonne, welche die Zusammensetzung angiebt, verzeichnet. Mix. + liq. zeigt Koinzidenz der festen und flüssigen Phase an.
M. P. Schmelzpunkt.
t_L (bezw. t_S) Temperatur bei welcher die Kristallisation beginnt (bezw. endet). Alle Temperaturen sind t_L wenn nichts anderes bemerkt.
$t_{Tr.}$ Umwandlungs - Temperatur.
$\Delta t°$ Schmelzpunktserniedrigung von A (bezw. B) durch B (bezw. A) in der Lösung.

Trip. Tripelpunkt.

U Transformations - Temperatur oder inkongruenter Schmelzpunkt.
Vis. Viskose Lösungen, welche zu Gläsern erstarren.

Vol. Volumen.
Wt. Gewicht.
% Prozente.
↓ Ein vertikaler Pfeil steckt das Gebiet linearer Abhängigkeit ab.

( ) In Klammer gesetzte Werte sind Schätzungen.

colonna delle composizioni dello stato solido, due valori separati da una lineetta, stanno a significare che sono pure compresi tutti i valori intermedi.

I punti di fusione congruenti dei composti molecolari sono stampati in grassetto.

B. P. Punto di ebollizione.
Crit. Punto critico.
E Punto eutettico.
M Grammimolecole.
m Valori nelle regioni metastabili.
max. Massimo.
min. Minimo.
Mix. (risp. Mix$_1$, Mix$_2$) Cristalli misti. Quando si conosce la composizione dei cristalli misti essa è indicata nella colonna delle composizioni a sinistra. Mix + liq. significa coincidenza del solidus e del liquidus.

M. P. Punto di fusione.
t_L (risp. t_S) Temperatura alla quale comincia (o finisce) la cristallizzazione. Tutte le temperature sono t_L quando non è indicato diversamente.
$t_{Tr.}$ Temperatura di transizione.
$\Delta t°$ Abbassamento del punto di fusione di A (o B) prodotto da B (o A) in soluzione.

Trip. Punto triplo.

U Temperatura di trasformazione oppure punto di fusione incongruente.
Vis. Soluzioni viscose che solidificano formando vetri.

Vol. Volume.
Wt. Peso.
% Percento.
↓ Una freccia verticale significa che esiste una relazione lineare in tutto l'intervallo così indicato.
( ) I valori fra parentesi sono apprezzati.

TRIPLE POINTS, TRANSITION POINTS AND MELTING POINTS AT ORDINARY AND LOW PRESSURES[1]

H. W. Foote

INTRODUCTION

The following triple points are possible: (1) Crystal—liquid—vapor. (2) Crystal—crystal—vapor. (3) Crystal—crystal—liquid. (4) Crystal—crystal—crystal.

The last two types have not been found at pressures below one atmosphere. In general, the temperature at a triple point, when the pressure is less than one atmosphere, coincides within the limits of experimental error with the freezing point or the transition point. For temperature and pressure data for such triple points, the reader should therefore consult the tables of freezing points or transition temperatures (Vol. I, p. 98); and of vapor pressures (of one-component systems, Vol. III, p. 199) respectively. It has, however, been shown by Richards, Carver and Schumb (11) that the freezing point of benzene saturated with air at a pressure of one atmosphere is 0.003° lower than the temperature at the triple point (5.496° and 35.4 mm). The temperature commonly given for the corresponding triple point of water (0.0075°) is based only upon the effect of pressure in defining the freezing point of water, 0°, and takes no account of the effect of dissolved air at atmospheric pressure. If the latter effect (0.0023°) is taken into account in defining the freezing point of water, the temperature of the triple point is +0.0098°C.

ONE-COMPONENT SYSTEMS

Melting Points Known with a Probable Accuracy of ±0.05°

For the purpose of this table, the *melting point* is defined as the temperature on the I. C. T. scale (*v.* Vol. I, p. 53), at which the crystalline and liquid phases are in equilibrium with dry air at a pressure of one atmosphere. Richards, Carver and Schumb (11) have shown that dissolved air, at a pressure of one atmosphere, lowers the freezing point of benzene 0.031°, so that the freezing point is lower by this amount than would be the case if the pressure were applied by a piston or an insoluble gas. The standard temperature of the melting point of ice, as usually determined, may also be slightly uncertain depending on the extent to which the water is saturated with air. The lowering in freezing point due to the solubility of the air in this case amounts to about 0.0023°. The melting points of all compounds in the following list were taken in air, but saturation with air was demonstrated only in the case of benzene. As it has been repeatedly shown that saturation of a liquid with air takes place rather rapidly when there is thorough contact between the two, the possible error in melting point from incomplete saturation is probably not greater than the other errors of experiment.

The table gives a list of melting points which appear to be known, with reasonable certainty, within ±0.05°. The list is quite probably incomplete; but where any doubt existed as to the accuracy of a result, it has not been included. For numerous melting points which are probably nearly as good, *see* de Visser (18), Block (3), and especially Timmermans (13, 14, 15, 16).

When more than one reference is given in the table, the melting point adopted is the weighted average of the data to which reference is made. No references are given to data which were not actually used, though nearly every melting point given has been determined repeatedly with considerable accuracy. Except for water, the melting point of benzene is probably the most accurately known.

Name	Formula	M. P., °C	Lit.
Acetic acid.	CH_3COOH	16.60	(4, 17)
Acetophenone.	$CH_3COC_6H_5$	19.655	(10)
Benzene.	C_6H_6	5.493 ±0.01	(11)
α-Bromonaphthalene.	$C_{10}H_7Br$	6.20	(7)
1, 2-Dibromomethane.	$C_2H_4Br_2$	9.99	(2, 9)
Formic acid.	$HCOOH$	8.39	(6)
Nitrobenzene.	$C_6H_5NO_2$	5.67	(12)
Sulfuric acid.	H_2SO_4	10.49	(5)
Sulfuric acid (monohydrate)	$H_2SO_4.H_2O$	8.62	(5)
Sulfur trioxide.	SO_3	16.83	(1, 8)

LITERATURE

(For key to the periodicals see end of volume)

(1) Berthoud, *42*, **20**: 77; 23. (2) Biron, *7*, **81**: 590; 13. (3) Block, *7*, **82**: 403; 13. (4) Bousfield and Lowry, *4*, **99**: 1432; 11. (5) Brönsted, *7*, **68**: 693; 10. (6) Ewins, *4*, **105**: 350; 14. (7) Jones and Lapworth, *4*, **105**: 1804; 14. (8) Lichty, *1*, **34**: 1440; 12. (9) Moles, *7*, **80**: 531; 12.
(10) Morgan and Lammert, *1*, **46**: 881; 24. (11) Richards, Carver and Schumb, *1*, **41**: 2019; 19. (12) Roberts and Bury, *4*, **123**: 2037; 23. (13) Timmermans, *28*, **25**: 300; 11. (14) Timmermans, *28*, **27**: 334; 14. (15) Timmermans, *28*, **30**: 62; 21. (16) Timmermans, Horst and Onnes, *18*, **6**: 180; 23. (17) de Visser, *70*, **12**: 101; 93. (18) de Visser, *70*, **17**: 182; 98.

Transition Temperatures

For the purpose of these tables, the term *transition temperature* refers to the temperature at which two crystalline forms of a substance are in equilibrium at a pressure of one atmosphere. This temperature coincides, within the limits of experimental error, with the triple point, crystal—crystal—vapor, when the vapor pressure in the latter system does not differ greatly from one atmosphere. In the tables, the transition temperatures given are the weighted averages of values, references to which are given by numbers. No references are given to data which were not used in obtaining the values in the tables. Where the number of determinations is sufficient, the weighted average deviation is given under the heading "±°C." Where this is not significant, a probable accuracy or reliability has been indicated.

Transition temperatures of molecular compounds such as double salts or salts with water of crystallization have, of course, only been included when the compounds behave as one-component systems, *i.e.*, when there is no change in composition of the phases at the transition point.

𝔄-Table, Non-Metallic Elements

For the metallic elements, *v.* Vol. II, p. 458

Formula	$t_{Tr.}$, °C	±, °C	Lit.	Formula	$t_{Tr.}$, °C	±, °C	Lit.
I_2.	47	*	(73)	O_2.	−240	*	(95)
N_2.	−237	>5	(65)	P.	− 77	<5	(24)
O_2.	−225	>5	(95)	S.	95.5	0.1	(72, 101)

* Existence of transition uncertain.

𝔅-Table, Chemical Compounds

Standard arrangement, *v.* Vol. I, p. 96

(Except oxides of Al, Ba, Fe, Mg, Ra, Ca, Sr, Zr, Si, the rare earths and their combinations with one another, for which *see* p. 83.)

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[1] Except "soaps" for which *v.* final index, and high melting oxides and other refractory substances, for which *v.* p. 83.

𝔅-Table, Chemical Compounds.—(*Continued*)

Formula	$t_{Tr.}$, °C	±, °C	Lit.
SO_3			(120.5)
NH_4NO_3	−17	<5	(7, 126, 133)
	32.2	0.2	(22, 30, 32, 85, 86, 126)
	50.5m	0.5	(19.5)
	83.9	<1	(22, 32, 126, 140)
	125.3	0.2	(12, 22, 32, 116, 126, 140)
NH_4Cl	184.3	<1	(23, 51, 113, 119)
NH_4ClO_4	240	>5	(127)
NH_4Br	137.4	<1	(114, 118)
NH_4I	−17	<1	(23, 114)
$(NH_4)_3H(SO_4)_2$	134	>5	(37)
As_2S_2	267	>5	(19)
As_2S_3	170	>5	(19)
$SbCl_3$	65	<5	(66)
	69.5	<5	(66)
Bi_2O_3	704	<5	(50)
NH_4CNS	90	<5	(21, 46, 129)
	120	*	(129)
For other carbon compounds belonging here, *v.* the ℭ-Table			
$(C_3H_7NH_3)_2SnCl_6$	186	>5	(104)
$[NH_2(C_2H_5)_2]_2SnCl_6$	146	*	(104)
SiO_2, *v.* p. 19			
PbO	587	*	(60)
$PbSO_4$	854	4	(26, 38, 47, 60, 115)
$PbSO_4.2PbO$	450	*	(60)
$3Pb_3(PO_4)_2.PbCl_2$, pyromorphite (artificial)	670	>5	(35)
$3Pb_3(AsO_4)_2.PbCl_2$, mimetite (artificial)	395	>5	(35)
$TlClO_4$	226	>5	(127)
TlI	173	<5	(43, 84)
$TlNO_3$	75	1.8	(22, 34, 46, 133)
	145	1.5	(22, 33, 34, 46)
$TlOC_6H_2(NO_2)_3$, thallium picrate	46	<1	(99)
ZnS	1020	<5	(1)
$ZnSO_4$	740	>5	(38)
HgI_2	127.4	0.4	(21, 90, 102, 109, 120, 122)
$HgS.HCNS$	110	*	(125)
$CuBr$	384	<5	(27, 54, 84)
CuI	401	2	(54, 84, 98)
Cu_2S	91	<5	(97)
Cu_2Se	110	*	(9)
Cu_2Te	351	>5	(29)
	387	>5	(29)
Cu_4Te_3	365	>5	(29)
$AgClO_4$	158	>5	(127)
$AgBrO_3$	98.5	<1	(100)
AgI	145.8	1	(21, 70, 79, 84, 98, 111, 116, 122, 124)
Ag_2S	177	<5	(40, 58, 83, 110)
Ag_2SO_4	411	<5	(38, 88)
Ag_2Se	133	<5	(8, 9)
$AgNO_3$	159.6	0.1	(22, 56, 116, 140)
$[NH_2(CH_3)_2]_2PtCl_6$	10	*	(75)
$[NH_3(iso\text{-}C_3H_7)]_2PtCl_6$	32	<5	(103, 123)
$[NH_2(C_2H_5)_2]_2PtCl_6$	144	*	(104)
$[NH(C_2H_5)_2CH_3]_2PtCl_6$	62	*	(104)
	122	*	(104)
$[NH_2(C_3H_7)_2]_2PtCl_6$	89	*	(104)
$[NH(C_3H_7)_2C_2H_5]_2PtCl_6$	107	>5	(103)
$[NH(C_3H_7)_3]_2PtCl_6$	59	*	(104)
	142	*	(104)
$[N(C_3H_7)_4]_2PtCl_6$	108	*	(104)
	201	*	(104)
$MnSO_4$	860	>5	(38)
FeS	298	>5	(78)
Fe_2P	80	*	(76)
Fe_3P	440	*	(76)
Ni_3S_2	550	>5	(18, 39)
$CrCl_2.4H_2O$	38	<5	(69)
$PbCrO_4$	707	>5	(60)
	783	>5	(60)
$2PbCrO_4.5PbO$	744	*	(60)
$PbWO_4$	877	>5	(60)
$3Pb_3(VO_4)_2.PbCl_2$, vanadinite (artificial)	710	>5	(35)
$AlBr_3$	70	<5	(66)
$MgF_2.Mg_3P_2O_8$, wagnerite	845	>5	(138)
$6MgO.8B_2O_3.MgCl_2$, boracite	266	<5	(52, 81, 116)
$CaSO_4$	1193	>5	(47)
$CaCO_3$	970	*	(13)
$SrSO_4$	1152	>5	(47)
$SrCO_3$	908	>5	(16, 108)
$BaCl_2$	925	2	(42, 71, 96, 109, 112, 128)
$Ba(ClO_4)_2$	284	>5	(127)
$BaSO_4$	1149	>5	(47)
$BaCO_3$	806	5	(14, 16, 41, 74, 108)
$LiClO_3$, *v.* p. 233	982	>5	(16)
Li_2SO_4	576	4	(57, 87, 88, 129)
$NaOH$	300	<5	(55)
$NaClO_4$	158	>5	(127)
Na_2SO_4	236	3	(15, 25, 57, 61, 63, 67, 87, 88, 129, 139)
$Na_2SO_4.NaF$	105	<5	(139)
$Na_4P_2O_7$	387	*	(107)
	520	*	(107)
$Na_2HPO_4.12H_2O$	29.6	<1	(53)
Na_2CO_3	450	>5	(57)
Na_2MoO_4	424	>5	(15, 49, 57, 67)
	585	>5	(15, 49, 67)
	623	>5	(15, 49, 67)
Na_2WO_4	580	>5	(15, 68, 93)
	589	<5	(15, 68, 93)
Na_3AlF_6, cryolite	568	>5	(36, 89)
$Na_2O.Al_2O_3.2SiO_2$, nephelite	1150	>5	(44)
KOH	248	<5	(55)
$KClO_3$	255	>5	(37)
$KClO_4$	300	<5	(127)
K_2S	146.4	<5	(21)
K_2SO_4	588	5	(4, 47, 48, 57, 64, 67, 87, 88)
$KHSO_4$	164.2	<5	(23)
	180.5	<5	(23)

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* Existence of transition uncertain.

𝔅-Table, Chemical Compounds.—(*Continued*)

Formula	$t_{Tr.}$, °C	±, °C	Lit.
KNO_3	127.8	1.1	(10, 11, 22, 34, 56, 132, 133)
	147	*	(62)
KPO_3	450	>5	(3)
$K_4P_2O_7$	278	>5	(3)
K_2CO_3	410	>5	(57)
$KCNS$	143	<5	(21, 46, 129)
$K_2SO_4.PbSO_4$	544	>5	(47)
$2KI.CdI_2$	215	>5	(20)
$K_2Ni(C_2S_2O_2)_2$	20	>5	(105)
K_2CrO_4	666	<5	(4, 48)
$K_2Cr_2O_7$	237	<5	(107, 141)
K_2MoO_4	327	<5	(67)
	454	<5	(67)
	477	<5	(4, 67)
K_2WO_4	388	>5	(67)
	575	*	(4)
$K_2SO_4.2CaSO_4$	937	>5	(47, 87)
$K_2SO_4.2SrSO_4$	775	>5	(47)
$LiKSO_4$	435	>5	(88)
$RbOH$	245	>5	(55)
$RbClO_4$	279	>5	(127)
Rb_2SO_4	653	<5	(57, 87)
$RbNO_3$	163.5	<5	(22, 116, 133)
	219	<5	(116, 133)
$Rb_2SO_4.2CaSO_4$	787	>5	(87)
	915	>5	(87)
$LiRbSO_4$	142	>5	(87)
$CsOH$	223	<5	(55)
$CsCl$	451	>5	(142)
$CsClO_4$	219	>5	(127)
Cs_2SO_4	660	>5	(87)
$CsNO_3$	153.5	<5	(22, 46, 133)
$Cs_2SO_4.2CaSO_4$	722	>5	(87)

* Existence of transition uncertain.

ℭ-Table, the ℭ-Arrangement

Comparatively few transition temperatures of C-compounds are known, and most of them are quite inaccurate or uncertain. From the study of a large number of compounds, Schaeling (*Diss.*, Marburg, 1910) has concluded that polymorphous organic compounds are usually monotropic and that enantiotropy is rare.

For "liquid crystals," *v.* Vol. I, p. 314.

Formula	Name	$t_{Tr.}$, °C	±, °C	Lit.
CBr_4	Carbon tetrabromide	46.9	<1	(21, 66, 106, 116)
CCl_4	Carbon tetrachloride	−45	>5	(45)
C_2H_8BrN	Ethylamine hydrobromide	83	*	(80)
C_2H_8ClN	Ethylamine hydrochloride	80	*	(80)
$C_2Br_2Cl_4$	Dibromotetrachloroethane	80	>5	(46)
		109	>5	(46)
C_2Cl_6	Hexachloroethane	45	<5	(21, 116, 123)
		71.3	0.4	(21, 94, 116, 123)
		125	*	(94)
$C_3H_4O_4$	Malonic acid	94	*	(136)
$C_4H_{12}ClNO_4$	Tetramethylammonium perchlorate	355	*	(127)
$C_6H_4Br_2$	*p*-Dibromobenzene	8.5	*	(6)
$C_6H_4Cl_2$	*p*-Dichlorobenzene	25	*	(134)
		29	*	(134)
$C_6H_8N_2O_3$	Aniline nitrate	98	>5	(137)
C_7H_7NO	*α*-Benzaldoxime	−28	*	(6)
C_7H_9N	*p*-Toluidine	22	*	(6)
$C_8H_9NO_2$	*α*-Anisaldoxime	20	*	(6)
$C_8H_9NO_2$	*α′*-Anisaldoxime	13	*	(6)
$C_{10}H_8O$	*α*-Naphthol	49	*	(6)
$C_{10}H_9N$	*α*-Naphthylamine	13.5	*	(6)
$C_{10}H_{13}NO$	Butyric anilide	16	>5	(5)
$C_{10}H_{15}ClO$	Camphor monochloride	74	<5	(92, 136)
$C_{10}H_{16}O$	Camphor	−32	>5	(23, 135)
$C_{10}H_{16}O$	Camphor	90	<5	(23, 135)
$C_{13}H_{10}N_4O_5$	*m*-Dinitrodiphenylcarbamide	55	*	(91)
		180	*	(91)
$C_{14}H_{10}Cl_4$	1, 1, 2, 2-Tetrachloro-1, 2-diphenylethane	100	*	(77)
$C_{14}H_{10}N_2O_2$	Phthalylphenylhydrazide	9.4	<1	(28)
$C_{14}H_{13}NO$	*o*-Hydroxy-*m*-methylbenzylideneanilide	34	>5	(59)
$C_{15}H_{12}N_2O_2$	Phthalylphenylmethylhydrazide	55.1	<1	(27)
$C_{16}H_{18}N_2O_2$	*p*-Azophenetole	95.5	<5	(17, 31)
$C_{20}H_{17}NO_3S$	*α*-Naphthylamine naphthalene-*α*-sulfonate	66	†	(131)
$C_{20}H_{17}NO_3S$	*α*-Naphthylamine naphthalene-*β*-sulfonate	54	†	(131)
$C_{27}H_{46}O$	Cholesterol	43	>5	(82)

* Existence of transition uncertain.

† This transition temperature undoubtedly exists, but it is uncertain whether the system is of 1 or 2 components.

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EFFECT OF PRESSURE UPON MELTING AND TRANSITION POINTS; VOLUME CHANGE ON MELTING AND TRANSITION; DIRECTLY MEASURED COMPRESSIBILITY- AND THERMAL EXPANSION-DIFFERENCES

P. W. Bridgman

INTRODUCTION

Units.—Throughout the following tables the pressure unit is the normal atmosphere; the temperature unit, the absolute centigrade degree; and all volume changes, unless otherwise indicated, are expressed in cm³/kg.

Abbreviations and Conventions.—The liquid phase is indicated by "L," and solid phases by the Roman numerals I, II, etc. In cases where the observed melting point at one atm. is less than the I. C. T. normal M. P. (*v.* Vol. I), the I. C. T. value is inserted in brackets for comparison.

Latent Heat.—The latent heat of any phase change may be calculated from the equation:

$$l\left(\frac{\text{joule}}{\text{kg}}\right) = T\Delta V\frac{\mathrm{d}P}{\mathrm{d}T} \times 0.10133,$$

where T is the absolute centigrade temperature, P is the pressure in atm. and ΔV is the accompanying volume change in cm³/kg. This calculation will be facilitated in many cases by reference to the original papers, where tabulated values of $\mathrm{d}T/\mathrm{d}P$ are given. An approximate method for computing differences of thermal expansion and specific heat for the reacting phases may be found in (8).

EINLEITUNG

Einheiten.—Grundsätzlich ist in den folgenden Tafeln die normale Atmosphäre die Druckeinheit, als Temperatureinheit gelten absolute Centigrade, die Volumänderungen sind (wenn nichts anderes angegeben) in cm³/kg ausgedrückt.

Abkürzungen und Festlegungen.—Die flüssige Phase ist durch "L" angezeigt, die festen Phasen durch römische Zahlen (I, II, III, . . .). In den Fällen, in denen der beobachtete Schmelzpunkt bei einer Atmosphäre niedriger ist, als der Normal-Schmelzpunkt [M. P. (Bd. I)] der I. C. T., so ist dieser letzte Wert zum Vergleich in Klammer daneben gesetzt.

Latente Wärme.—Die latente Wärme jeder Phasenänderung ergiebt sich nach der Gleichung:

$$l\left(\frac{\text{joule}}{\text{kg}}\right) = T\Delta V\frac{\mathrm{d}P}{\mathrm{d}T} \times 0{,}10133,$$

T = absolute Centigrad Temperatur, P = Druck in Atmosphären, ΔV ist die dabei auftretende Volumänderung in cm³/kg.

Diese Rechnung wird in vielen Fällen durch Heranziehung der in der Literatur sich vorfindenden Werte für $\mathrm{d}T/\mathrm{d}P$ erleichtert. Eine angenäherte Methode zur Berechnung der Differenz der thermischen Ausdehnungen beziehungsweise der spezifischen Wärme der Phasenänderung ist in (8) zu finden.

INTRODUCTION

Unités.—L'unité de pression utilisée dans les tables suivantes est l'atmosphère normale; l'unité de température, le degré centigrade absolu; et tous les changements de volume sont exprimés en cm³/kg à moins d'une autre indication.

Abréviations et conventions.—La phase liquide est indiquée par "L"et les phases solides par les chiffres romains I, II, etc. Lorsque le point de fusion observé sous une atm. est inférieur au Pt. de F. normal des T. C. I. (*v.* Vol. I), la valeur des T. C. I. a été écrite entre parenthèse pour comparaison.

Chaleur latente.—La chaleur latente de chaque changement de phase peut être calculée au moyen de l'équation:

$$l\left(\frac{\text{joule}}{\text{kg}}\right) = T\Delta V\frac{\mathrm{d}P}{\mathrm{d}T} \times 0{,}10133,$$

où T est la température absolue en degrés centigrades, P est la pression en atm. et ΔV est le changement de volume produit en cm³/kg. Ce calcul sera facilité dans bien des cas si l'on se réfère aux mémoires originaux, où l'on trouvera une table donnant les valeurs de $\mathrm{d}T/\mathrm{d}P$. On trouvera à (8) une méthode approximative pour le calcul des différences dans le cas de la dilatation thermique et de la chaleur spécifique pour les phases réagissantes.

INTRODUZIONE

Unità.—Nelle tabelle seguenti viene fatto sempre uso dell'atmosfera normale come unità di pressione, e di gradi centigradi assoluti come unità di temperatura. Tutte le variazioni di volume, tranne che non sia diversamente indicato, sono indicate in cm³/kg.

Abbreviazioni e convenzioni.—La fase liquida viene indicata con "L" e le fasi solide sono indicate con numeri romani (I, II, ecc.). Nei casi in cui il punto di fusione osservato ad un atmosfera, è più basso del punto normale di fusione [normale M. P. (*v.* Vol. I)], delle I. C. T., quest'ultimo valore, è riportato tra parentesi per confronto.

Calori latenti.—I calori latenti dei cambiamenti di fase si possono calcolare dall'equazione:

$$l\left(\frac{\text{joule}}{\text{kg}}\right) = T\Delta V\frac{\mathrm{d}P}{\mathrm{d}T} \times 0{,}10133,$$

dove T è la temperatura assoluta, P la pressione in atmosfere e ΔV è la variazione di volume in cm³/kg.

Questi calcoli sono in molti casi facilitati da richiami alla letteratura originale dove si trovano tabelle per i valori $\mathrm{d}T/\mathrm{d}P$. Un metodo approssimato per calcolare le differenze nel caso della dilatazione termica e dei calori specifici delle fasi reagenti si trova riportato in (8).

ELEMENTARY SUBSTANCES (*v.* p. 11)

CHEMICAL COMPOUNDS

PART I. MELTING-POINT DATA REPRODUCIBLE BY POWER SERIES (*v. also* Part II, p. 11)

$$\text{M. P. } (^\circ\text{C}) = t_0 + \text{a} \times 10^{-4}P - \text{b} \times 10^{-8}P^2. \quad \text{Range: up to } P_{\text{max}}.$$

Example: The M. P. of formic acid at 2000 atm. is 7.8 (resp. 8.4) + (132 × 10^{-4} × 2000) − (85 × 10^{-8} × $(2000)^2$) = 30.8° (resp. 31.4)°C.

Formula	Name	t_0 (obs.)	t_0 (I. C. T.)	a	b	$P_{\text{max.}}$	Lit.
H_3PO_4	*o*-Phosphoric acid	38.0	42.3	0.83		2600	(29)
PH_4Cl	Phosphonium chloride*†	28	26	300	165	3000	(29)
	C-Compounds, the ℭ-Arrangement						
CHN	Hydrocyanic acid	−13.4	−14	226	157	3800	(29)
CH_2O_2	Formic acid	7.8	8.4	132	85	3000	(29)
$C_2H_4Br_2$	Ethylene dibromide†	9.9	10.0	260	133	3000	(29)
$C_3H_4Br_2O_2$	1, 2-Dibromopropionic acid	64.0	64	201		1000	(34)
	1, 2-Dibromopropionic acid, metastable	51.0	51	191		1300	
$C_4H_6O_2$	*α*-Crotonic acid	71.4	72	373		300	(16)
$C_4H_8Cl_2S$	2, 2-Dichloroethyl sulfide†	13.9	13.5	150	49	2000(?)	(1)
$C_4H_{10}O$	Trimethyl carbinol†	24.9	25.5	355	397	2700	(29)
$C_4H_{10}O_4$	*dl*-Erythritol	117.0	126	83	59	3000	(15)
$C_5H_{12}O$	Dimethylethyl carbinol†	− 8.45	−11.9	228	278	3800	(29)
$C_6H_4Cl_2$	*p*-Dichlorobenzene	52.3	52.9	275	134	3000	(6)
$C_6H_5NO_3$	*o*-Nitrophenol	44.9	45	240		300	(16)
C_7H_7Br	*p*-Bromotoluene	26.5	28	301	140	3000	(6)
C_7H_7Cl	*p*-Chlorotoluene	6.9	7.8	275	130	3000	(6)
C_7H_7I	*p*-Iodotoluene	33.9	35	314	147	3000	(6)
C_7H_7NO	Formanilide	46.6	47.5	209	153	2900	(29)
$C_7H_7NO_3$	*p*-Nitroanisole	52.5	54	244	121	3000(?)	(27)
C_7H_8O	*p*-Cresol	33.3	33.8	236	67	2900	(29)
$C_7H_8O_2$	Guaiacol	28.4	28	184	107	3000	(15)
C_8H_8O	Acetophenone	19.2	19.7	243	162	3000	(29)
C_8H_{10}	*p*-Xylene†	13.2	13.2	355	183	2900	(29)
$C_8H_{10}O_2$	Veratrole	23.3		224	108	3000	(6)
$C_{10}H_8$	Naphthalene†	79.95	80.1	376	192	3500	(16, 19, 29)
$C_{10}H_8O$	*α*-Naphthol	95.8	96	248	65	3000	(22)
$C_{10}H_9N$	*α*-Naphthylamine	48.9	50	200		300	(16, 23, 26)
$C_{10}H_{12}O$	Anethole	22.27	22.5	212	94	3000	(6)
$C_{10}H_{14}O$	Thymol	49.2	51.5	210	197	3000	(6, 16)
$C_{10}H_{20}O$	Menthol, stable	41.1	42.5	248	192	3000	(6, 16)
	Menthol, metastable	36.5	35.5	248		300	(16)
$C_{12}H_{24}O_2$	Lauric acid	42.5	48.0	238	160	3000	(29)
$C_{13}H_{10}O_3$	Salol (Phenyl salicylate)	42.0	43	298	139	3000	(15)
$C_{13}H_{12}$	Diphenylmethane	26.9	27	264	124	3000	(6)
$C_{13}H_{13}N$	Benzylaniline	35.6	37	241	115	3000	(6)
$C_{14}H_{10}O_3$	Benzoic anhydride	41.2	43	267	59	3000	(15)
$C_{14}H_{14}N_2O_3$	*p*, *p*′-Azoxyanisole, liquid crystal transition	117.3	117.4	303	225	3000(?)	(16, 26)
	Melting	135.9		408			(26)
$C_{14}H_{28}O_2$	Myristic acid	51.8	58	245	171	2400	(29)
$C_{16}H_{18}N_2O_3$	*p*-Azoxyphenetole, liquid crystal transition	138.5	136.9	370		300	(16)
	Melting	168.0		476		300	(16)
$C_{16}H_{32}O_2$	Palmitic acid	61.2	64	211	46	1800	(29)
$C_{17}H_{12}O_3$	Betol (*β*-Naphthyl salicylate)	93.0	95	341	335	3000	(15)
$C_{18}H_{36}O_2$	Stearic acid	68.4	69.3	258		300	(16)
$C_{19}H_{16}$	Triphenylmethane	92.8	92.5	367	267	3000	(15)
$C_{22}H_{42}O_2$	Erucic acid	31.3	33.5	213	107	3000	(29)
$C_{34}H_{50}O_2$	Cholesteryl benzoate, ordinary melting	178.3	178.5	760		300	(16)

---

* The triple point vapor—liquid—solid is *ca.* 28° and 46 atm.

† Volume change on melting, cm^3/kg:

PH_4Cl—870 at the triple point.

$C_2H_4Br_2$—46 at 15°, 41 at 25°, 37 at 35°, 36 at 45°.

$C_4H_8Cl_2S$—54—0.0065*P*.

$C_4H_{10}O$—81.8 at 30°, 70.7 at 40°, 61.4 at 50°, 54.0 at 60°, 46.7 at 70°.

$C_5H_{12}O$—45.5 − 0.0850 (t + 8.5°).

C_8H_{10}—190 at 30°, 175 at 50°.

$C_{10}H_8$—145.8 − 0.688 (t − 80.1°). Range, ≯t = 140°.

NON-METALLIC ELEMENTARY SUBSTANCES

For metals, *v.* Vol. II, p. 459

H_2, Hydrogen (36)

He, Helium (17.5)

P, White phosphorus (7); *cf.* (16, 22, 29); *see* Fig. 1

P, atm.	*t*, °C	ΔV, cm³/kg
Liquid–I		
1	44.2	19.3
1 000	73.8	17.9
2 000	101.0	16.6
3 000	126.8	15.4
4 000	151.3	14.2
5 000	174.0	13.1
6 000	196.0	12.0
I–II		
6 000	0.1	8.46
7 000	12.5	8.29
8 000	24.5	7.92
9 000	36.0	7.64
10 000	47.2	7.37
11 000	58.0	7.10
12 000	68.4	6.84

S, Sulfur (29)

These results are uncertain because of slow internal changes

P, atm.	*t*, °C	ΔV, cm³/kg
L–monoclinic		
1	114.0	
180	120.0	41
510	130	40
860	140	
1240	150	
Monoclinic–rhombic		
1	96.7	
100	100	13.8
360	110	13.9
610	120	13.9
850	130	14.0
1090	140	14.0
1320	150	
Liquid–rhombic		
1630	100	
2060	170	
2550	180	
3060	190	

Triple point: 1400 atm., 153.7°C.

CHEMICAL COMPOUNDS, PART II

Standard arrangement (*v.* Vol. III, p. viii)

The temperatures are melting points unless otherwise indicated.

H_2O, Water (10); *cf.* (9, 29, 32); *see* Fig. 2

P, atm.	*t*, °C	ΔV, cm³/kg
L–I		
1	0.0	90.0
590	− 5.0	101.6
1 090	−10.0	112.2
1 540	−15.0	121.8
1 910	−20.0	131.3
L–III		
3 420	−17.0	23.1
2 820	−18.5	30.1
2 430	−20.0	37.1
2 045	−22.0	46.6
L–V		
6 160	0.0	52.7
5 270	− 5.0	60.3
4 360	−10.0	67.9
3 680	−15.0	75.4
3 040	−20.0	82.8
L–VI		
4 640	−15.0	98.0
5 110	−10.0	96.0
5 620	− 5.0	93.8
6 160	0.0	91.6
6 880	+ 5.0	88.4
7 390	10.0	84.4
8 040	15.0	79.8
8 710	20.0	75.1
10 250	30.0	66.3
11 990	40.0	59.0
L–VI		
13 970	50.0	52.3
16 150	60.0	47.7
18 530	70.0	
20 960*	80.0	
I–II		
2 094	−35.0	217.7
2 006	−45.0	217.0
1 916	−55.0	216.2
1 826	−65.0	215.4
1 736	−75.0	214.6
I–III		
2 035	−20.0	177.3
2 087	−30.0	191.9
2 108	−40.0	199.2
2 091	−50.0	202.3
2 049	−60.0	204.9
II–III		
3 260	−25.0	14.8
2 820	−28.0	16.4
2 450	−31.0	17.9
2 160	−34.0	20.6
II–V		
3 460	−25.0	40.1
3 680	−28.0	40.1
3 880	−31.0	40.1
4 070	−34.0	40.1
III–V		
3 409	−20.0	54.69
3 395	−25.0	54.61
3 383	−30.0	54.54
3 358	−35.0	54.46
V–VI		
6 176	0.0	38.86
6 172	− 5.0	38.66
6 169	−10.0	38.47
6 166	−15.0	38.28
6 162	−20.0	38.09

*Extrapolated from 76.4°.

TRIPLE POINTS AND VOLUME CHANGES

P, atm.	*t*, °C	Direction of volume change	ΔV, cm³/kg
III–L–I			
2 045	−22.0	III–L	46.6
		L–I	135.2
		II–I	181.8
II–III–I			
2 100	−34.7	II–III	21.5
		III–I	196.3
		II–I	217.8
V–III–L			
3 420	−17.0	V–III	54.7
		III–L	24.1
		V–L	78.8
V–II–III			
3 400	−24.3	V–II	40.1
		II–III	14.5
		V–III	45.6
VI–V–L			
6 175	0.16	VI–V	38.9
		V–L	52.7
		VI–L	91.6
L–I–vapor			
0.00602	0.0075		

NH_4NO_3 (12); *cf.* (4, 5, 14, 17, 20, 21, 29); *see* Fig. 3

P, atm.	*t*, °C	ΔV, cm³/kg
Liquid–I		
1	169.6	
1 000	203	*ca.* 51
I–II		
1	125.5	13.51
1 000	135.0	11.66
2 000	143.5	10.20
3 000	151.4	9.06
4 000	158.7	8.17
5 000	165.6	7.39
6 000	172.0	6.65
7 000	178.0	5.94
8 000	183.3	5.24
9 000	188.7	4.56
II–III		
1	82.7	7.58
200	79.1	7.96
400	74.8	8.33
600	69.8	8.70
800	64.2	9.08
II–IV		
1 000	65.8	12.10
2 000	80.5	12.11
3 000	94.8	12.12
4 000	108.6	12.16
5 000	121.8	12.21
6 000	134.6	12.30
7 000	147.1	12.41
8 000	159.1	12.54
9 000	170.8	12.70
III–IV		
1	32.0	20.26
200	38.7	20.52
400	45.9	20.79
600	53.7	21.05
800	61.9	21.31
IV–V		
1	−18.0	*ca.* 17
I–VI		
9 000	188.9	8.33
10 000	196.6	7.67
11 000	204.4	7.30
II–VI		
8 860	170.0	3.12
8 743	185.0	3.73
VI–IV		
9 000	170.4	9.58
10 000	178.8	9.56
11 000	187.3	9.53
12 000	195.8	9.51

TRIPLE POINTS AND VOLUME CHANGES

P, atm.	*t*, °C	Direction of volume change	ΔV, cm³/kg
II–III–IV			
830	63.3	III–IV	21.35
		II–III	9.25
		II–IV	12.10
I–II–VI			
8730	186.7	I–II	4.75
		I–VI	8.55
		II–VI	3.80
II–IV–VI			
8870	169.2	II–IV	12.67
		II–VI	3.09
		IV–VI	9.58

COMPRESSIBILITY DIFFERENCE, CM³/KG PER ATM.

I > II, by *ca.* 0.0_38.

I > VI, by *ca.* 0.0_35.

IV > II, by *ca.* 0.0_38.

NH_4NO_3.—(*Continued*)

II > III, by 0.0_213.

III < IV, by 0.0_238.

THERMAL EXPANSION DIFFERENCE

cm³/kg per °C

At 74 atm.

II > III by 0.038°.

IV > III by 0.115°.

The notation V is reserved for a form stable at atmospheric pressure below −20°C.

Cohen and Kooy (14) claim an error of 9 % in the changes of volume listed above for IV–III.

NH_4Cl (13)

P, atm.	t, °C	ΔV, cm³/kg
0	184.3	98.5
100	191.1	109.0
200	198.3	116.4
300	205.7	121.7

NH_4Br (13)

1	137.8	64.7
100	146.3	65.2
200	155.1	65.6
300	164.3	65.9
400	173.5	66.0
500	183.5	65.9
600	193.8	65.7
700	204.4	65.4

NH_4I (13)

1	−17.6*	56.1
237	0.0	55.4
487	+20.0	54.7
718	40.0	54.0
933	60.0	53.4
1 133	80.0	52.8
1 318	100.0	52.3
1 488	120.0	51.8
1 644	140.0	51.4
1 789	160.0	51.0
1 924	180.0	50.7
2 050	200.0	50.4

Difference of compressibility not greater than 0.001 cm³/kg. Not known which is the greater.

* Extrapolated.

NH_4HSO_4 (13); *see* Fig. 4

I–II		
1 180	40	13.3
1 330	60	12.9
1 470	80	12.6
1 620	100	12.2
1 750	120	11.9
I–III		
1 800	130	5.3
1 800	150	
II–III		
2 000	129.5	6.3
3 000	144.8	5.5
4 000	158.6	5.2
5 000	171.3	5.8

P, atm.	t, °C	ΔV, cm³/kg
III–IV		
5 470	177.0	1.7
5 350	181.0	2.7
IV–V		
6 000	179.3	4.5
7 000	184.1	3.9
8 000	188.1	3.5
9 000	191.6	3.2
10 000	194.8	2.9

Highly probable that there is a fifth modification at upper end of II–IV line.

TRIPLE POINTS

I–II–III: 1800 atm., 126.2°.

II–III–IV: 5480 atm., 176.9°.

SbI_3 (8)

At 200.8°, ΔV = 24.0 cm³/kg.

Melting pressure = 1120 atm. (data incomplete).

Sb_2S_3 (13)

The red modification has a reversible transformation running from 7550 atm., 0°, to 11 600 atm., 32°.

ΔV = *ca.* 10 cm³/kg.

CO_2 (7); *cf.* (29, 31)

P, atm.	t, °C	ΔV, cm³/kg
1	−56.6	
1 000	−36.7	
2 000	−19.4	
3 000	− 4.1	106.1
4 000	+10.1	96.7
5 000	23.1	88.3
6 000	35.4	80.8
7 000	46.9	74.1
8 000	57.9	68.3
9 000	68.3	63.3
10 000	78.3	58.9
11 000	87.8	55.2
12 000	97.0	52.0

For other carbon compounds *v.* the 𝕮-Table.

SiO_2, *v.* p. 19

$SiCl_4$ (8)

P, atm.	t, °C	ΔV, cm³/kg
2 000	− 8.2	51.8
3 000	+19.3	46.6
4 000	46.1	42.4
5 000	72.2	39.0
6 000	97.3	36.3
7 000	121.8	34.3
8 000	145.5	32.6
9 000	168.6	31.3
10 000	191.2	30.3
11 000	213.3	29.4

$TlNO_3$ (12)

P, atm.	t, °C	ΔV, cm³/kg
I–II		
1	144.6	2.44
1 000	153.2	2.42
2 000	161.6	2.41
3 000	170.0	2.39
4 000	178.4	2.37
5 000	186.6	2.35
6 000	194.6	2.34
7 000	202.4	2.32
II–III		
1	75.0	0.730
1 000	81.8	0.700
2 000	88.5	0.675
3 000	95.1	0.645
4 000	101.6	0.620
5 000	108.0	0.595
6 000	114.3	0.565
7 000	120.6	0.545
8 000	126.9	0.510
9 000	133.1	0.485
10 000	139.3	0.460
11 000	145.4	0.435
12 000	151.5	0.410

COMPRESSIBILITY DIFFERENCE

cm³/kg per atm.

I = II approx.

At 75°, III > II by 0.0_35.

At 105°, III > II by 0.0_33.

At 140°, III > II by 0.0_315.

HgI_2 (11); *cf.* (21); *see* Fig. 5

P, atm.	t, °C	ΔV, cm³/kg
1	127.0	3.4
1 000	150.4	2.1
2 000	166.0	1.2
3 000	175.6	0.6
4 000	180.2	+0.2
5 000	181.2	−0.1
6 000	177.0	−0.5
7 000	166.3	−1.0
8 000	145.7	−1.8
9 000	111.0	−2.9
10 000	62.2	−4.2

I more compressible than II by *ca.* 0.0_34 cm³/kg per atm.

Cu_2I_2 (13)

$P = 11\,570 - (t - 100) \times 19.70$ atm.

$\Delta V = 5.35 - (t - 100) \times 0.0050$ cm³/kg per atm.

The low temperature modification is less compressible than the high temperature modification by 0.0_34 cm³/kg per atm.

AgI (11); *cf.* (24, 29, 30)

P, atm.	t, °C	ΔV, cm³/kg
I–II		
1	144.6	8.6
1000	129.1	9.1
2000	112.4	9.6
3000	94.3	10.2
I–III		
3000	107.7	13.8
4000	138.0	12.7
5000	169.0	11.0
6000	201.9	8.9
II–III		
2904	30.0	23.9
2856	50.0	23.9
2804	70.0	24.0
2744	90.0	24.1
2710	100.0	24.1

TRIPLE POINT AND VOLUME CHANGE

P, atm.	t, °C	Direction of volume change	ΔV, cm³/kg
2720	99.4	I–II	10.1
		I–III	14.0
		II–III	24.1

$AgNO_3$ (12); *cf.* (17); *see* Fig. 6

P, atm.	t, °C	ΔV, cm³/kg
1	159.4	2.50
1000	151.5	2.54
2000	143.4	2.59
3000	135.0	2.66
4000	126.2	2.73
5000	117.2	2.81
6000	107.7	2.89
7000	95.9	2.99
8000	77.5	3.11
8500	64.0	3.17
9000	42.8	3.24
9460	0.0	3.30

COMPRESSIBILITY DIFFERENCE

P, atm.	I–II, cm³/kg per atm.
1	-0.0_345
2000	-0.0_334
4000	-0.0_324
6000	-0.0_314
8000	0.000
9000	$+0.0_311$
9460	0.0_316

$KClO_3$ (11)

$P = 5500 + 10.9t$, atm.

$\Delta V = 25.1 - 0.0022t$, cm³/kg per atm.

Difference of compressibility probably $\not> 0.0_32$ cm³/kg per atm.

K_2S (11)

$t = 146.4 + 0.0124P$.

$\Delta V = 0.95 - 0.00003P$ cm³/kg per atm.

Low temperature form is about 0.0_21 more compressible.

$KHSO_4$ (13); *see* Fig. 7

P, atm.	t, °C	ΔV, cm³/kg
I–II		
1	180.5	0.66
1000	190.7	1.39
2000	201.0	2.14
I–IV		
2000	202.6	3.06
3000	220.1	2.88
II–IV		
1750	200.0	1.13
2005	180.0	1.12
2265	160.0	1.11
2525	140.0	1.11
2780	120.0	1.10
II–III		
1	164.2	5.56
1000	147.9	5.61
2000	131.4	5.66
3000	115.0	5.72
III–IV		
3000	114.6	6.8
4000	94.8	6.4
5000	72.2	6.1
6000	46.0	5.7

TRIPLE POINTS AND VOLUME CHANGES

P, atm.	t, °C	Direction of volume change	ΔV, cm³/kg
I–II–IV			
1770	198.6	I–II	1.97
		II–IV	1.13
		I–IV	3.10
II–III–IV			
2805	118.2	II–III	5.70
		II–IV	1.10
		III–IV	6.80

THERMAL EXPANSION DIFFERENCE

At 1 atm. I > II by 0.5 cm³/kg per °C.

At 1 atm. II > III by 0.04 cm³/kg per °C.

III probably > IV.

KNO_2 (11)

P, atm.	t, °C	ΔV, cm³/kg
5 000	− 0.3	31.0
6 000	+17.4	32.4
7 000	35.7	33.8
8 000	56.6	35.1
9 000	83.1	36.5
10 000	122.3	37.8

KNO_3 (12); *cf.* (17); *see* Fig. 8

P, atm.	t, °C	ΔV, cm³/kg
I–III		
1	125.8	14.2
1000	147.8	13.9
2000	169.1	13.7
3000	190.0	13.6
4000	210.6	13.5
I–II		
1	127.7	6.0
II–III		
495	120.0	10.5
1260	100.0	12.9
1840	80.0	14.1
2275	60.0	14.8
2605	40.0	15.3
2860	20.0	15.6
II–IV		
2580	0.0	44.7
2700	10.0	44.4
2825	20.0	41.0
III–IV		
3000	27.7	28.2
4000	66.3	27.3
5000	102.5	26.7
6000	136.3	26.3
7000	167.8	25.7
8000	196.3	25.3
9000	221.5	24.9

TRIPLE POINTS AND VOLUME CHANGES

P, atm.	t, °C	Direction of volume change	ΔV, cm³/kg
I–III–IV			
2835	21.3	II–III	15.6
		III–IV	28.4
		II–IV	44.0
I–II–III			
110	128.3	I–III	14.2
		II–III	8.9
		I–II	5.3

COMPRESSIBILITY DIFFERENCE

III > I, by *ca.* 0.001 cm³/kg per atm.

III > IV, by *ca.* 0.06 cm³/kg per atm.

III probably > II.

THERMAL EXPANSION

III > I, by *ca.* 0.06 cm³/kg per °C.

KCNS (11)

P, atm.	t, °C	ΔV, cm³/kg
L–I		
1	171.2* [173.2]	49.7*
1000	193.3	46.2

* Extrapolated.

P, atm.	t, °C	ΔV, cm³/kg
I–II		
1	140.0	3.06
1000	158.5	2.43
2000	174.9	1.98
3000	190.6	1.68
4000	205.7	1.49

$RbNO_3$* (12)

P, atm.	t, °C	ΔV, cm³/kg
II–III		
1	164.4	6.88
1000	174.4	6.45
2000	184.1	6.00
3000	193.5	5.57
4000	202.6	5.12
5000	211.5	4.69
6000	220.3	4.26

The difference of volume between I and II is probably very small (35).

* Material somewhat impure with acid.

$CsNO_3$ (12)

P, atm.	t, °C	ΔV, cm³/kg
1	153.7	4.05
1000	163.4	3.86
2000	172.9	3.68
3000	182.2	3.50
4000	191.3	3.32
5000	200.1	3.13
6000	208.8	2.94

At 80 atm., thermal expansion of I > II by 0.033 cm³/kg per °C. At 4850 atm., the compressibility of I > II by 0.00031 cm³/kg per atm.

ℭ-Table, the ℭ-arrangement

CBr_4 (11, 34); *see* Fig. 9

I–II

$t = 46.2 + 0.0315P$;

$\Delta V = 20.5 - 0.0026P$ cm³/kg per atm.

I–III

$t = 119.5 + (P - 2175) \times 0.1089$;

$\Delta V = 2.9$ cm³/kg per atm.

II–III

$t = 108.5 + (P - 1930) \times 0.0246$;

$\Delta V = 12.3 - 0.0013P$ cm³/kg per atm.

Triple point, I–II–III,
2110 atm., 112.6°

W. Wahl (34) has determined the melting point at atm. pressure to be 92° and finds this to be raised 1° by 15.5 atm. for a small pressure range. He also has made initial determinations of the transition I–II.

CCl_4 (7); *cf.* (2, 29); *see* Fig. 10

P, atm.	t, °C	ΔV, cm³/kg
L–I		
1	−22.6 [−23.0]	25.8
1 000	+15.3	19.9
2 000	48.9	16.3
3 000	78.9	13.8
4 000	106.0	11.6
5 000	130.8	9.9
6 000	154.2	8.3
7 000	176.2	7.0
8 000	197.4	6.0
9 000	217.6	5.2
I–II		
2 000	− 4.6	24.2
3 000	+15.7	23.3
4 000	35.3	22.4
5 000	54.1	21.3
6 000	72.3	20.2
7 000	90.0	19.0
8 000	107.2	17.9
I–III		
9 000	125.8	22.5
10 000	145.9	22.2
11 000	166.0	21.7
12 000	186.2	21.1
II–III		
6 500	+ 6.7	5.6
7 000	34.3	5.6
7 500	61.9	5.6
8 000	89.5	5.5
8 500	117.1	5.4

TRIPLE POINTS AND VOLUME CHANGES

P, atm.	t, °C	Direction of volume change	ΔV, cm³/kg
I–II–III			
8460	115	I–II	17.3
		I–III	22.7
		II–III	5.4

$CHBr_3$, Bromoform (8)

P, atm.	t, °C	ΔV, cm³/kg
1	7.78	39.1
1 000	32.3	35.4
2 000	55.3	32.0
3 000	77.2	28.9
4 000	97.3	26.3
5 000	116.3	23.8
6 000	134.1	21.7
7 000	151.1	19.9
8 000	167.4	18.4
9 000	183.3	17.3
10 000	199.0	16.3
11 000	214.6	15.4

$CHCl_3$, Chloroform (7)

P, atm.	t, °C	ΔV, cm³/kg
1	−61.0	
	[−63.5]	
1 000	−43.4	
2 000	−26.5	
3 000	−10.3	52.6
4 000	+ 5.4	49.2
5 000	20.4	46.0
6 000	34.8	43.2
7 000	48.7	40.6
8 000	62.0	38.3
9 000	75.1	36.3
10 000	87.9	34.5
11 000	100.4	33.0
12 000	112.6	31.6

CH_2I_2, Methylene iodide (29); *see* Fig. 11*

P, atm.	t, °C	
1	5.73	(L–I)
135	8.0	
230	10	(L–II)
710	20	
1200	30	
1750	40	
1995	44	(L–III)
2350	50	
2960	60	
1	−6.5	(I–IV)
175	0	
270	+5	
320	9	
180	8.6	(I–II)
325	9.4	
365	10	(II–IV)
1000	20	
1540	30	
1825	38	
1825	38.0	(II–III)
1930	42.8	
1825	38.0	(III–IV)
2195	44	
2450	48	

TRIPLE POINTS

P, atm.	t, °C	
180	8.6	(L–I–II)
325	9.4	(I–II–IV)
1930	42.8	(L–II–III)
1825	38.0	(II–III–IV)

* Details of this diagram somewhat uncertain; in particular the reality of the separate existence of III seems to need verification.

CH_4N_2O, Urea (13); *see* Fig. 12

P, atm.	t, °C	ΔV, cm³/kg
	I–III	
4180	0.0	49.6
4640	20.0	49.4
5100	40.0	49.2
5560	60	49.0
6020	80	48.8
6480	100	48.6
	I–II	
6521	100.0	48.2
6628	120.0	46.5
6735	140.0	44.2
6843	160.0	41.3

TRIPLE POINT AND VOLUME CHANGES

P, atm.	t, °C	Direction of volume change	ΔV, cm³/kg
		I–II–III	
6535	102.3	I–III	48.6
		I–II	48.0
		II–III	0.6

Melts 131.7° at 1 atm., 150° at 3000 atm. ΔV (L–I) = 10 cm³/kg.

COMPRESSIBILITY DIFFERENCE

I < II by *ca.* 0.004 cm³/kg per atm.

I < III by < 0.004 cm³/kg per atm.

NH_4CNS (11)

P, atm.	t, °C	ΔV, cm³/kg
1	87.7	40.9
1000	55.2	41.4
2000	+26.1	41.9
3000	− 0.5	42.4

COMPRESSIBILITY DIFFERENCE ON TRANSITION LINE

cm³/kg per atm.

P, atm.	Δ
1	0.0051
1000	0.0043
2000	0.0035
3000	0.0028

The high temp. phase is the less compressible.

C_2Cl_6, Hexachloroethane (11); *cf.* (29)

P, atm.	t, °C	ΔV, cm³/kg
	I–II	
1	71.1	28.0
1000	104.8	25.9
2000	138.5	23.7

P, atm.	t, °C	ΔV, cm³/kg
	II–III	
1	42.7	9.7
1000	70.7	8.5
2000	98.0	7.5
3000	123.4	6.7
4000	149.5	6.1
5000	173.2	5.6
6000	195.5	5.2

DIFFERENCE OF COMPRESSIBILITY

Δ = II–III; cm³/kg per atm.

P, atm.	Δ
1	0.0024
2000	0.0020
4000	0.0017
6000	0.0015

$C_2H_3ClO_2$, Chloroacetic acid (7, 18); *cf.* (16, 29)

P, atm.	t, °C*	ΔV, cm³/kg
	L–stable solid	
1	62.53	107
	[61.2]	
2 000	90	86
4 000	115	67
6 000	137	51
8 000	158	37
10 000	177	25
	L–unstable solid	
1	50.0	
800	65.0	

* Approximate values.

$C_2H_4O_2$, Acetic acid (13); *cf.* (25, 29, 33)

P, atm.	t, °C	ΔV, cm³/kg
	L–I	
1	16.68	156.0
500	28.2	132.3
1 000	38.3	113.8
1 500	47.3	99.3
2 000	55.3	87.3
	L–II	
2 000	55.2	99.6
3 000	70.9	89.9
4 000	85.2	81.8
5 000	98.4	75.0
6 000	110.5	68.8
7 000	121.8	63.6
8 000	132.3	59.2
9 000	142.1	55.8
10 000	151.1	53.0
11 000	159.5	50.8
	I–II	
1 040	0	14.0
1 485	25	13.6
1 930	50	13.1

TRIPLE POINT AND VOLUME CHANGES

P, atm.	t, °C	Direction of volume change	ΔV, cm³/kg
		I–II–L	
2033	55.7	L–II	99.2
		L–I	86.2
		I–II	13.0

At 76 atm. L more expansible than I by 0.50 cm³/kg per °C.

C_2H_5NO, Acetamide (13, 18)

P, atm.	t, °C	ΔV, cm³/kg
	L–I	
1	81.5	109.8
	[81.0]	
1 000	93.5	84.5
2 000	103.7	65.8
3 000	112.5	52.1
4 000	119.9	41.7
5 000	125.9	33.4
	L–II	
4 000	113.1	73.7
5 000	124.7	66.5
6 000	135.0	59.6
7 000	144.6	53.2
8 000	153.3	47.9
9 000	161.4	43.6
10 000	168.9	40.1
11 000	175.9	37.4
	I–II	
5 810	20.0	30.2
5 740	40.0	30.5
5 645	60.0	30.9
5 535	80.0	31.5
5 310	100.0	32.1
5 265	120.0	32.8
	L–unstable solid	
1	69.4	
1 000	86.6	
2 000	97.4	
3 000	105.0	

TRIPLE POINT AND VOLUME CHANGES

P, atm.	t, °C	Direction of volume change	ΔV, cm³/kg
		L–I–II	
5220	127.0	L–I	31.9
		L–II	64.9
		I–II	33.0

Compressibility difference, (II − I) = 0.0027 at 20°, and 0.0011 at 120°, cm³/kg per atm. Relation linear.

C_3H_6O, Acetone (7, 10)

Under 10 000 atm., freezing temperature = *ca.* 40°.

$C_3H_7NO_2$, Urethane (11); *cf.* (27, 29); *see* Fig. 13

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–I		
1	47.9	59.9
500	53.2	45.8
1 000	57.6	37.1
1 500	61.3	31.3
2 000	64.6	27.3
L–II		
2 500	67.9	29.5
3 000	71.2	22.8
3 500	74.0	19.7
4 000	76.4	18.6
L–III		
4 500	82.1	62.3
5 000	88.5	60.4
6 000	100.2	56.4
7 000	111.1	52.7
8 000	121.7	49.1
9 000	131.8	45.7
10 000	141.5	42.6
11 100	151.1	39.5
12 000	160.3	36.7
I–III		
3 060	0	57.2
3 150	10	57.3
3 240	20	57.4
I–II		
3 170	30	9.3
2 930	40	9.5
2 680	50	9.8
2 440	60	10.0
II–III		
3 360	30	48.0
3 520	40	47.5
3 680	50	47.0
3 830	60	46.4
4 000	70	45.9

TRIPLE POINTS AND VOLUME CHANGES

P, atm.	*t*, °C	Direction of volume change	Δ*V*, cm³/kg
L–I–II			
2270	66.2	L–I L–II I–II	25.3 35.5 10.2
L–II–III			
4090	76.8	L–II L–III II–III	18.4 64.0 45.6
I–II–III			
3290	25.5	I–II II–III I–III	9.2 48.2 57.4

$C_4H_6O_4$, Dimethyl oxalate (8); *cf.* (29)

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–solid		
1	54.24	145.3
1000	76.5	110.8
2000	97.1	95.0
3000	116.5	85.5
4000	134.9	79.0
5000	152.4	73.6
6000	169.1	68.6
7000	185.2	64.0
8000	200.8	59.5

$C_6H_4BrNO_2$, *m*-Bromonitrobenzene (37)

$C_6H_4ClNO_2$, *m*-Chloronitrobenzene (37)

C_6H_5Br, Bromobenzene (8)

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–solid		
1	−31.1	
1 000	−11.5	48.4
2 000	+ 6.4	42.5
3 000	22.8	37.8
4 000	37.8	34.0
5 000	51.5	30.9
6 000	64.5	28.3
7 000	76.9	26.2
8 000	88.7	24.4
9 000	100.2	23.0
10 000	111.1	21.8
11 000	121.6	20.9
12 000	131.8	20.2

DIFFERENCE OF COMPRESSIBILITY BETWEEN SOLID AND LIQUID ALONG MELTING CURVE (DIRECTLY MEASURED) cm³/kg per atm.

P, atm.	Δ
1	0.04
3 000	.006
6 000	.003
9 000	.001
12 000	.0005

C_6H_5Cl, Chlorobenzene (8)

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–solid		
1	−45.5	
1 000	−27.5	
2 000	−11.0	56.1
3 000	+ 4.3	50.8
4 000	18.5	46.4
5 000	31.8	42.6
6 000	44.2	39.4
7 000	55.9	36.6
8 000	66.9	34.2
9 000	77.5	32.2
10 000	87.9	30.6
11 000	97.8	29.2
12 000	107.4	28.1

$C_6H_5NO_2$, Nitrobenzene (7); *cf.* (29)

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–solid		
1	5.6	81.4
1 000	27.9	73.3
2 000	49.5	66.1
3 000	70.3	60.0
4 000	90.2	55.1
5 000	108.4	51.5
6 000	125.7	48.5
7 000	142.2	45.9
8 000	158.2	43.5
9 000	173.9	41.5
10 000	189.1	39.7
11 000	204.2	38.1

$C_6H_5NO_3$, *p*-Nitrophenol (8)

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–solid		
1	112.4	89.1
1000	138.5	73.6
2000	160.9	61.0
3000	181.8	51.2
4000	201.3	43.6

C_6H_6, Benzene (7); *cf.* (16, 28, 29)

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–I		
1	5.4	131.7
1 000	33.3	103.5
2 000	58.0	86.3
3 000	79.9	75.0
4 000	99.3	66.8
5 000	117.4	60.5
6 000	134.6	55.5
7 000	150.8	51.3
8 000	166.4	47.5
9 000	181.2	44.0
10 000	195.4	41.0
11 000	209.0	38.4
I–II		
11 860	100	10.5
11 690	120	11.1
11 560	140	11.6
11 480	160	12.1
11 430	180	12.6
11 460	200	13.0

C_6H_6O, Phenol (11); *cf.* (16, 29, 30)

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–I		
1	40.9	56.7
1 000	53.8	39.0
2 000	63.9	27.4
I–II		

$P = 1284 + 115t$, atm.

$\Delta V = 59.2 - 0.6t$, cm³/kg

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–II		
2 000	63.5	82.6
3 000	84.0	76.1
4 000	102.1	70.7
5 000	118.6	66.2
6 000	133.9	62.3
7 000	148.4	58.8
8 000	162.3	55.7
9 000	175.8	52.9
10 000	188.7	50.4
11 000	201.5	48.1
12 000	214.0	46.0

TRIPLE POINT AND VOLUME CHANGES

P, atm.	*t*, °C	Direction of volume change	Δ*V*, cm³/kg
L–I–II			
2015	64.0	L–I L–II I–II	27.0 82.5 55.5

COMPRESSIBILITY DIFFERENCE cm³/kg per atm.

At triple point, I > II by 0.005.

At 74 atm., L > I by 0.025.

$C_6H_6O_2$, Resorcinol (15)

L–I

$t = 110.0° + 0.0145P - 0.0_5110P^2$ (to 3000 atm.)

P, atm.	*t*, °C	Δ*V*, cm³/kg
I–II		
1	75	
500	44	
1000	20	
1500	+6	
2000	−2	
2500	−6	

Results at higher pressures in much doubt.

C_6H_7N, Aniline (7); *cf.* (29)

P, atm.	*t*, °C	Δ*V*, cm³/kg
L–solid		
1	− 6.4	85.4
1 000	+14.0	78.2
2 000	32.9	72.0
3 000	50.2	68.9
4 000	66.5	62.6
5 000	81.6	58.8
6 000	95.7	55.5
7 000	109.4	52.4
8 000	122.5	49.6
9 000	135.0	46.9
10 000	147.1	44.4
11 000	158.9	42.0
12 000	170.3	39.6

$C_6H_{11}NO_2$, Ethyl aminocrotonate (18)

P, atm.	t, °C, stable	t, °C, unstable
1	34.0	19.9
1000	51.2	37.6
2000	64.4	51.9
3000	75.6	63.5

$C_7H_7NO_3$, Nitroanisole (27.5)

C_7H_8O, *o*-Cresol (7); *cf.* (29)

P, atm.	t, °C	ΔV, cm³/kg
L–I		
1	30.8	83.8
1 000	48.2	67.1
2 000	62.8	55.0
3 000	75.2	46.3
4 000	86.1	40.0
5 000	95.8	35.0
6 000	104.5	31.2
7 000	112.6	28.2
8 000	120.0	25.9
L–II		
6 000	105.5	55.2
7 000	119.5	51.9
8 000	132.6	49.1
9 000	145.2	46.8
10 000	157.2	44.8
11 000	168.9	43.1
12 000	180.2	41.8

TRIPLE POINT AND VOLUME CHANGES

P, atm.	t, °C	Direction of volume change	ΔV, cm³/kg
L–I–II			
5900	130.2	L–I	31.7
		I–II	23.8
		L–II	55.5

C_7H_9N, *p*-Toluidine (8); *cf.* (16, 19, 23, 29)

P, atm.	t, °C	ΔV, cm³/kg
L–solid		
1	43.6	141.3
1000	69.8	118.9
2000	92.9	103.1
3000	114.0	92.2
4000	133.8	84.3
5000	153.1	77.9
6000	172.1	72.5
7000	190.8	67.8
8000	209.4	63.7

$C_8H_6O_2$, Phthalide (18)

P, atm.	t, °C	ΔV, cm³/kg
L–solid		
1	73.0	
1000	101	
2000	127	
3000	152	

C_8H_8O, Acetophenone (8)

At 200°, ΔV = 45 cm³/kg.

Melting pressure, 11 200 atm.

$C_{10}H_8$, Naphthalene (8)

Melting pressure at 200°, *ca.* 4000 atm.

$C_{10}H_{12}O$, Anethole (8)

ΔV at 74 atm. = 79.3 cm³/kg.

Melting pressure at 100°, *ca.* 4050 atm.

$C_{10}H_{16}O$, Camphor (13, 16); *see* Fig. 14

P, atm.	t, °C	ΔV,* cm³/kg
I–II		
1	87.1	1.87
500	118.6	1.87
1 000	148.0	1.87
1 500	175.8	1.87
2 000	202.5	1.87
II–III		
1 610	0	58.5
2 060	10	56.3
2 570	20	54.0
III–IV		
3 000	26.5	37.4
4 000	39.2	34.4
5 000	51.3	31.7
6 000	62.8	29.1
7 000	73.6	26.8
8 000	83.9	24.7
9 000	93.6	22.8
10 000	102.7	21.1
11 000	111.2	19.6
12 000	119.1	18.3
IV–V		
2 790	20	
3 350	60	
3 775	90	
II–V		
2 710	20	
2 864	40	
3 036	60	
3 226	80	
3 434	100	
3 662	120	
II–VI		
3 661	120	6.9
3 880	140	6.1
4 081	160	5.7
4 265	180	5.4
4 435	200	5.2
VI–IV		
4 000	90.1	3.5
5 000	108.8	2.2
6 000	124.2	1.2
7 000	136.5	0.5
V–VI		
3 660	90	
3 660	110	
L–I		
1	177.6	

*ΔV is not always very exact.

Initial rise of melting temperature, 129° for 1000 atm.

III is more compressible than IV; difference 0.005 at 3000 and 0.0017 at 12 000 cm³/kg per atm.

Triple points are not accurately located.

$C_{10}H_{20}O$, Menthol (8)

ΔV at 74 atm. = 61.2 cm³/kg.

$C_{12}H_{11}N$, Diphenylamine (7); *cf.* (3, 23, 27, 29)

P, atm.	t, °C	ΔV, cm³/kg
L–solid		
1	54.0	95.8
1000	80.3	80.1
2000	104.5	70.3
3000	126.8	63.3
4000	147.4	58.0
5000	166.5	53.4
6000	184.3	49.7
7000	201.0	46.6
8000	216.9	44.1

$C_{13}H_{10}O$, Benzophenone (8); *cf.* (16, 29)

P, atm.	t, °C	ΔV, cm³/kg
L–solid		
1	47.8	90.4
1000	75.4	77.3
2000	100.5	68.4
3000	123.4	61.8
4000	144.7	56.7
5000	164.5	52.6
6000	183.3	49.2
7000	201.1	46.2
8000	218.2	43.6

$C_{14}H_{14}$, Dibenzyl (19)

P, atm.	t, °C	ΔV, cm³/kg
L–solid		
1	51.3	113
500	68.4	105
1000	83.2	96
1500	97.3	88

DIAGRAMS

The arrows denote the direction in which the volume change on transition is becoming numerically less.

α, β, C_p. The location of these symbols shows the side of the transition line corresponding to the form having the higher value of compressibility, thermal expansion, or specific heat at constant pressure.

The dotted enclosing lines delimit the region of indifference.

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(For a key to the periodicals see end of volume)

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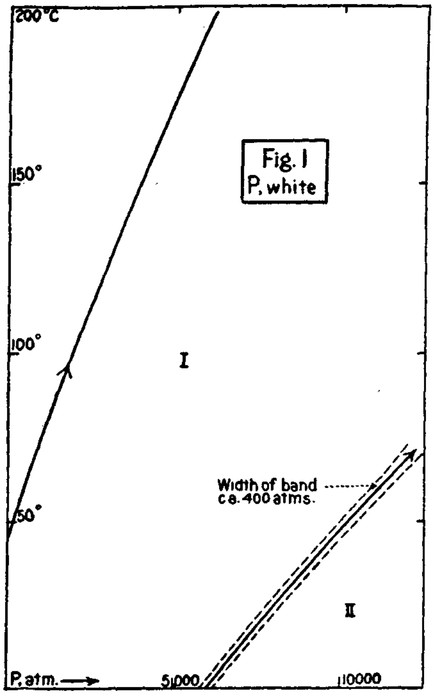


Fig. 1
P. white

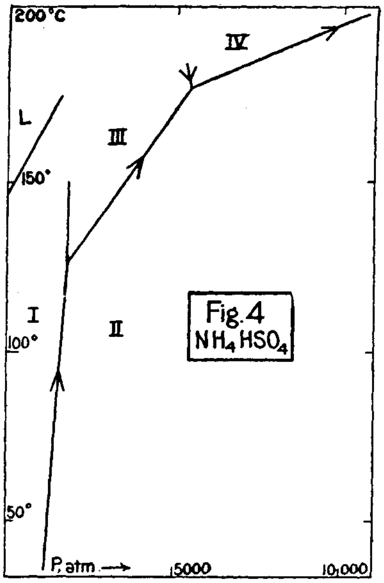


Fig. 4
NH$_4$HSO$_4$

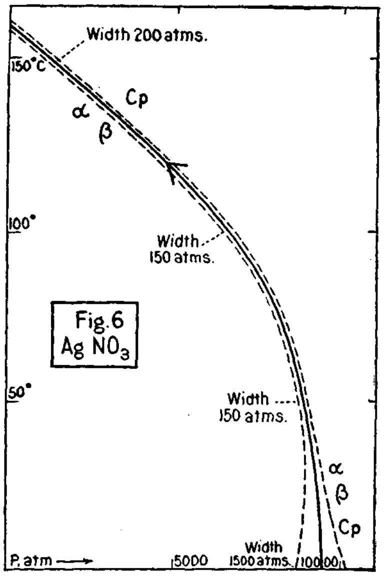


Fig. 6
Ag NO$_3$

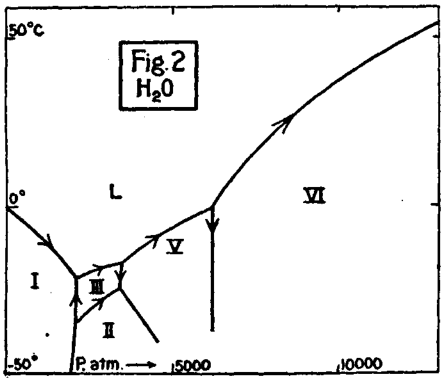


Fig. 2
H$_2$O

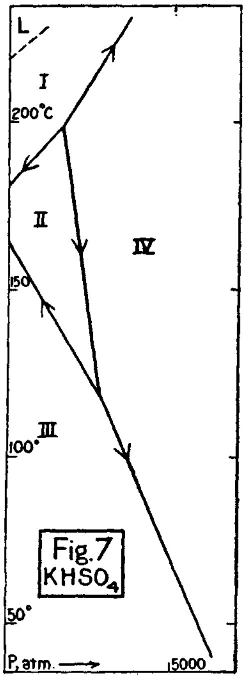


Fig. 7
KHSO$_4$

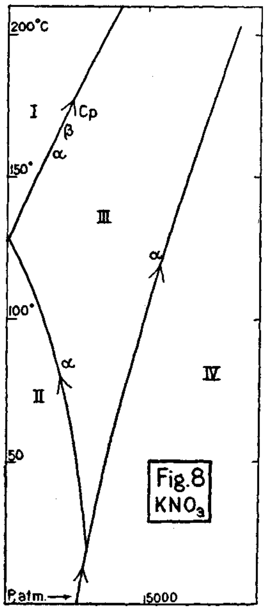


Fig. 8
KNO$_3$

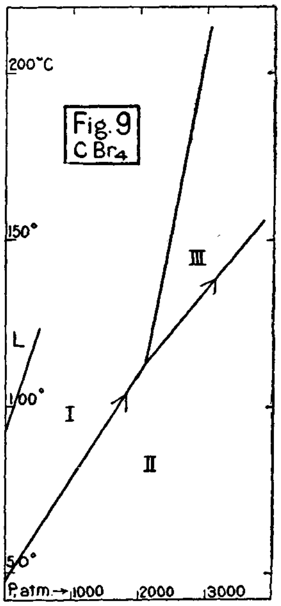


Fig. 9
C Br$_4$

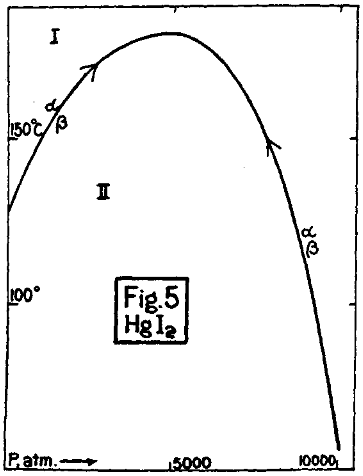


Fig. 5
Hg I$_2$

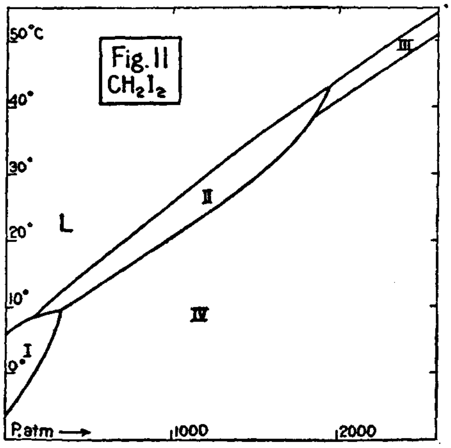


Fig. 11
CH$_2$I$_2$

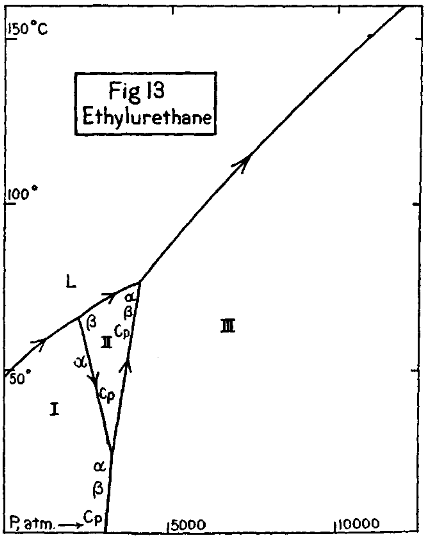


Fig 13
Ethylurethane

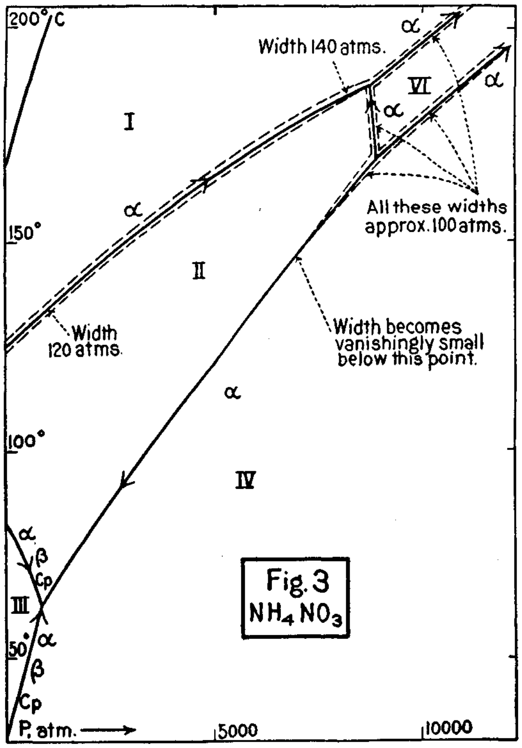


Fig. 3 NH_4NO_3

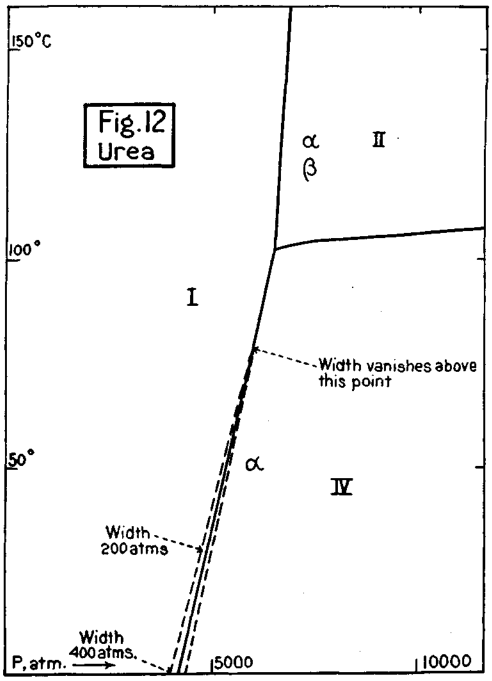


Fig. 12 Urea

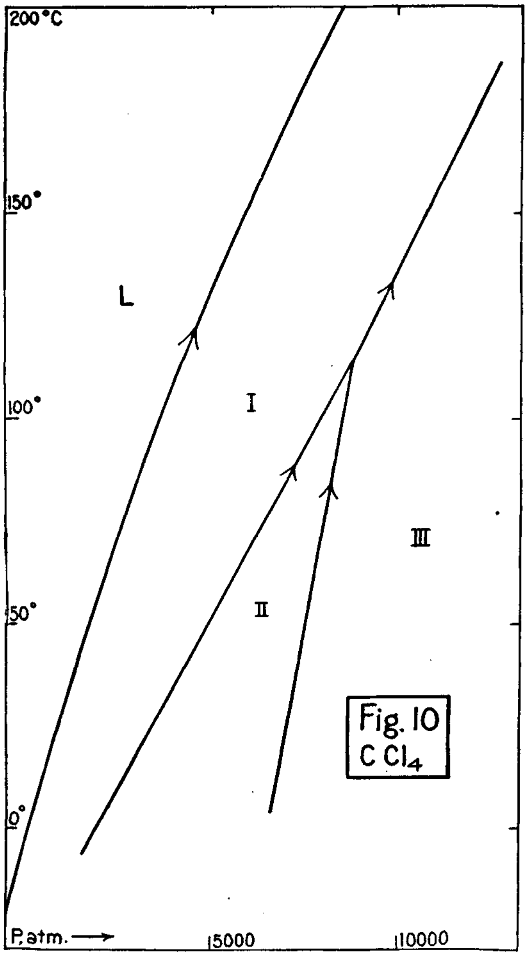


Fig. 10 $C\,Cl_4$

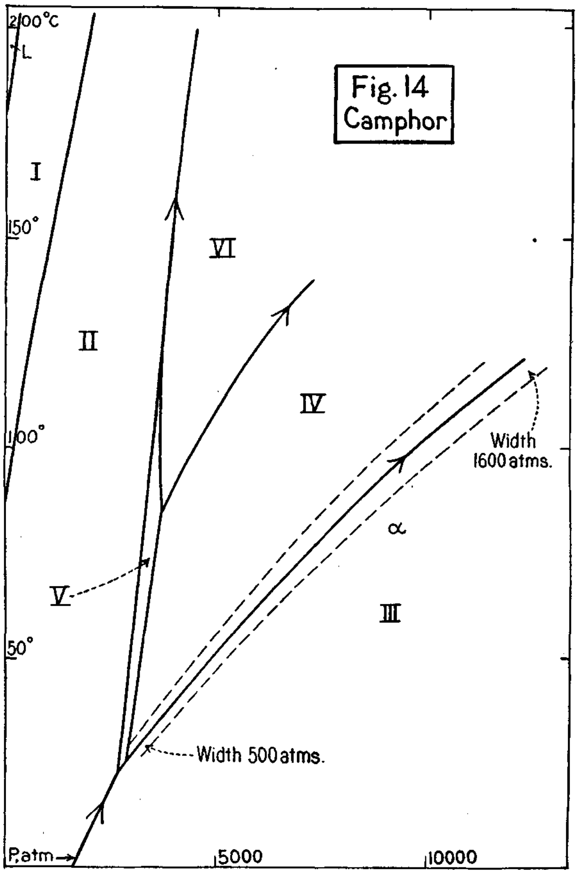
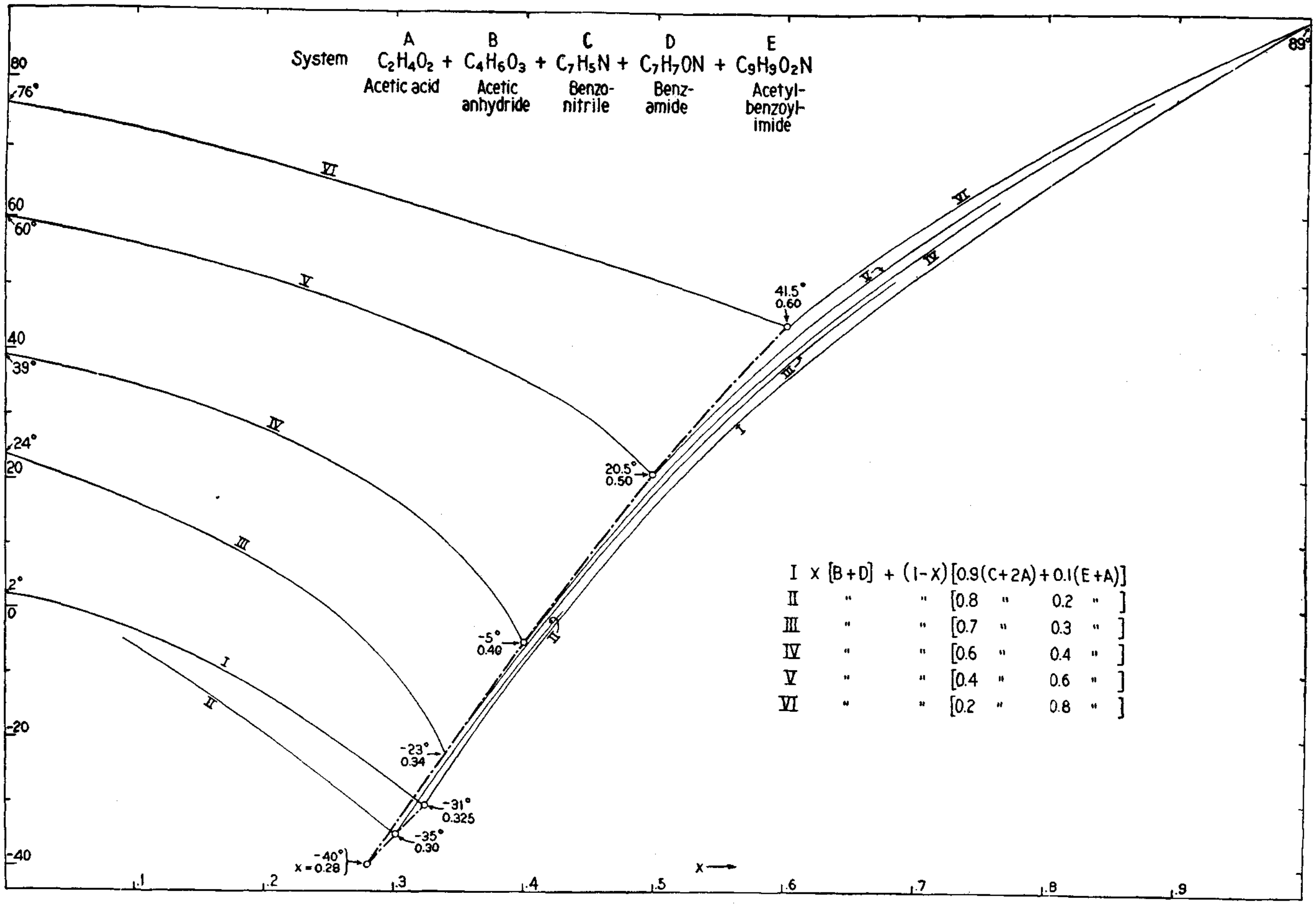


Fig. 14 Camphor



OSMOTIC PRESSURE

W. E. Garner

In this section are included data on osmotic pressure obtained by direct measurement. With few exceptions, only those pressures are given which are generated by solutions of pure substances when separated from the pure solvent by a semipermeable membrane. Where appreciable amounts of diffusion have occurred or the solution is not opposed by the pure solvent, this is indicated in the tables. Wherever possible the pressures are expressed in normal atmospheres and the concentrations of the solutions in gram formula weights per 1000 g of the solvent (M/1000) in terms of the table of atomic weights, Vol. I, p. 43. Where the pressures measured are small they are given in mm Hg. Values are given to the last significant figure for which *relative* accuracy can be claimed.

SOLUTIONS IN WATER MAINLY WITH COPPER FERROCYANIDE MEMBRANES

$C_{12}H_{22}O_{11}$, Sucrose, 342.2, $P_{osm.}$ in Atm. (41)

M/1000 \ °C	0	5	10	15	20	25	30	40	50	60	70	80
0.1	(2.48)	2.47	2.52	2.56	2.61	2.65	2.50	2.58	2.66	2.74		
0.2	4.76	4.86	4.93	5.03	5.11	5.19	5.09	5.21	5.32	5.48		
0.3	7.14	7.26	7.39	7.54	7.67	7.79	7.71	7.91	8.04	8.21		
0.4	9.52	9.69	9.87	10.03	10.22	10.38	10.38	10.69	10.81	10.96		
0.5	12.00	12.20	12.40	12.65	12.86	13.05	13.09	13.47	13.62	13.78	14.11	
0.6	14.50	14.73	14.98	15.27	15.52	15.76	15.85	16.28	16.46	16.67	16.96	
0.7	17.03	17.35	17.65	17.97	18.29	18.59	18.66	19.10	19.37	19.57	19.74	
0.8	19.65	19.99	20.34	20.72	21.09	21.44	21.56	21.99	22.31	22.52	22.76	23.26
0.9	22.32	22.68	23.09	23.51	23.93	24.34	24.44	24.95	25.35	25.50	25.79	26.14
1.0	25.05	25.51	25.92	26.42	26.87	27.29	27.47	27.94	28.46	28.63	28.87	29.07

$C_{12}H_{22}O_{11}$, 342.2, $P_{osm.}$ in Atm.—(*Continued*)

M/1000	0.1	0.3	0.6	1.0	2.0	3.0	4.0	5.0	6.0	Supersatd.
0°C (7)	2.25	6.91	14.22	24.76	54.9	90.0	129.7			
30°C (23, 35)					58.6	95.8	141.2	193		268.8
57.7°C (23, 35)					62.5	101.5	145.4	195.9	248	

$C_6H_{12}O_6$, Glucose, 180.09, $P_{osm.}$ in Atm. (39, 40)

M/1000 \ °C	0	10	23	M/1000 \ °C	0	10	23
0.1	2.42	2.41	2.41	0.6	14.13*	14.43	14.5
.2	4.69	4.80	4.79	.7	16.51	16.84	17.0
.3	7.07	7.17	7.21	.8	18.92	19.20	19.4
.4	9.38	9.60	9.64	.9	21.42	21.56	21.8
.5	11.75	12.01	12.14	1.0	23.78*	23.99	24.3

* Berkeley and Hartley's data (*v.infra*) give 13.4 and 22.9, resp.

$C_6H_{11}O_6CH_3$, α-Methyl Glucoside (7)

M/1000	1	2	3	4
Atm., 0°C	25.0	53.8	86.4	120.2

$C_6H_{12}O_6$, Galactose (6)

g/l	250	380	500
Atm., 0°C	35.5	62.8	95.8

$C_6H_{12}O_6$, Glucose (6)

g/l	99.8	199.5	319.2	448.6	548.6
Atm., 0°C	13.2	29.2	53.2	87.9	121.2

$C_6H_{14}O_6$, Mannitol (6)

g/l	100	110	125
Atm., 0°C	13.1	14.6	16.7

$C_6H_{14}O_6$, Isodulcitol, M/1000 = 2, $P_{osm.}$ (0°C) = 54.8 atm. (7).

C_6H_6O, Phenol, 94.06, 30°C (24)

M/1000	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
P_{osm}	1.46	2.84	3.93	5.12	6.40	7.62	8.82	10.05	11.28

Substance	Formula	M/1000	t, °C	Atm.	Lit.
Amygdalin	$C_{20}H_{27}NO_{11}$	0.0219	0	0.474	(21)
Antipyrine	$C_{11}H_{12}N_2O$	0.0530	0	1.18	(21)
Resorcinol	$C_6H_6O_2$	0.0097	11	0.207	(31)
		0.0100	16	0.206	
Saccharin	$C_7H_5NO_3S$	0.0029	17	0.075	(31)

Osmotic Pressure of Colloids

Substance	Wt. %	t, °C	mm Hg	Lit.
Dextrin	1	15.9	166	(43)
Gum arabic	1	15.2	69	(43)
	6	15.5	259	
	18	15.6	1193	
Egg albumen	1.25	room	22.4	(50)
Gelatin	1.5	room	8.2	(50)
Horse hemoglobin	5.27	room	58.75	(50)
Cow hemoglobin	10.8	room	109.0	(50)
Sodium caseinogenate	3.23	25	313	(5)
	8.0*	11	334	(38)
Hemoglobins				(1)

* Solutions nearly neutral.

Gelatin, t = 20°; Collodion Membrane (11)

Gelatin	Wt. %	mm Hg
Dhéré and Gorgolewski	0.152	1.00
Sadikoff	0.169	2.30
Moerner	0.232	7.9

Gelatin.—(*Continued*)

Gelatin	Wt. %	mm Hg
Faust	0.17	2.28
Dryplate Sleussner	0.17	2.86
Technical 1	0.174	1.61
2	0.157	2.07
3	0.145	3.07
4	0.123	3.16
5	0.118	3.58

β-Dextrin, t = 25°; Collodion Membrane (13)

Solubility 1.76% at 22°

Wt. %	0.0452	0.0818	0.158	0.321	0.513
mm Hg	5.70	8.24	12.7	15.8	18.7

Dextrin (Kahlbaum Purified), t = 25°; Collodion Membrane (14)

Wt. %	0.076	0.125	0.268	0.445	0.663	1.02	1.675
mm Hg	3.47	5.75	8.1	10.4	12.3	13.1	15.0

For other dextrins, *see* (38).

Congo Red, M. W., 696.5

t = 25° (15)		t = 25° (5)		t = 17° (18)	
M/1000 l	mm Hg	M/1000 l	mm Hg	M/1000 l	mm Hg
0.306	7.07	1.12	24	4.97	88.7
0.619	13.5	2.23	45	5.13	89.0
0.907	17.3	4.46	106	6.15	106.0
1.25	27.6	8.93	176	7.05	120
1.59	33.2	17.86	326	8.10	145
1.87	42.1	35.7	625	10.05	171.7
Initially against pure water; collodion membrane.		55.6	1020	18.3	310
		71.4	1220	37.5	603
				72.0	1139
				86.6	1363
		Parchment membrane. Against pure water			

Osmotic pressure of a solution of congo red at 28.5°, 123 mm Hg; at 62°, 138 mm Hg, parchment membrane (5)

Chicago Blue, 25°; parchment				
	M/1000 l	2.84	0.997	Lit.
	$P_{osm.}$ mm Hg	93	35	(5)

25°C, initially against pure water, collodion (12)

Tuchrot G. A.		Brilliantkongo		Chicago Blue 6 B		Kongoreinblau	
Wt. %	mm Hg	Wt. %	mm Hg	Wt. %	mm Hg	Wt. %	mm Hg
0.013	3.3	0.027	6.1	0.023	7.8	0.028	8.6
0.0275	6.0	0.050	15.7	0.043	14.8	0.045	15.0
0.029	7.1	0.0475	18.4	0.045	15.6	0.073	26.5
0.0325	8.5	0.063	22.8	0.066	23.2	0.087	29.2
0.082	21.3	0.076	29.9	0.078	27.3		
0.105	22.5						

For results on benzopurpurine, primuline, and commercial dyes, *see* (5) and (12). For the effect of electrolytes on the osmotic pressure of dyestuffs, *see* (5, 12, 15, 18).

$Fe_2Cl_6{\cdot}140Fe_2O_3$ Iron Hydroxide Sol. (19)

Wt. %	0.15	0.20	0.40	0.80	1.84
mm H_2O	2.0	5.5	20	70	220

Thorium Hydroxide Sol.

Wt. %	0.40	0.56	0.97	1.75	2.70	4.03
mm H_2O	2.5	13	47	115	240	430

Data are also given for copper ferrocyanide, prussian blue, gum arabic and dialyzed caramel.

OSMOTIC PRESSURE OF ELECTROLYTES WITH COPPER FERROCYANIDE MEMBRANE

0°C (8, 9)

M/1000	Atm.
Ca ferrocyanide	
0.1024	2.54
0.2422	5.34
0.4182	9.20
0.6030	14.65
0.7470	20.33
1.075	41.22
1.353	70.84
1.469	87.09
1.617	112.84
1.711	130.66
Mg ferrocyanide	
0.2343	6.20
0.3241	8.70
K ferrocyanide	
0.0412	2.93
0.0824	5.41
0.1529	9.19
0.2416	13.52
0.3688	19.25
Na ferrocyanide	
0.0745	5.33
0.1163	7.83
0.1667	10.69
0.2305	14.23
0.2950	17.69
Sr ferrocyanide	
0.1596	3.40
0.3361	6.18
0.4642	8.59
0.6197	12.04
α-Tetramethylammonium ferrocyanide	
0.2686	5.96
2.152	52.32
K ferricyanide	
0.1215*	7.58
0.5894*	32.39
0.8509*	47.61
Ca ferricyanide	
0.0365	2.56
0.0483	3.23
0.1232	8.68
0.1863	14.33

15°C (2)

M /1000 l H_2O	Atm.
K_2SO_4	
25.0	1.09
50.0	2.01
KNO_3	
25.0	0.93
50.0	1.60
200.0	4.50
KI	
25.0	0.92
50.0	1.80
100.0	3.37

15°C (2)

M/1000 l H_2O	Atm.
$KHCO_3$	
25.0	0.63
50.0	1.17
100.0	2.03
$KClO_3$	
50.0	1.73
$KC_2H_3O_2$	
50.0	1.26
$K_2C_2O_4$	
25.0	1.31
50.0	2.26
$KHSO_3$	
25.0	0.79
$K_2C_4H_4O_6$	
25.0	1.17
50.0	2.30
$K(SbO)C_4H_4O_6$	
25.0	0.75
50.0	1.35
$KAl(SO_4)_2.12H_2O$	
12.5	1.08
25.0	2.04
$KCr(SO_4)_2.12H_2O$	
12.5	1.10
25.0	2.27
$K_4Fe(CN)_6$	
12.5	0.93
50.0	3.47
$K_6Co_2(CN)_{12}$	
12.5	1.76
25.0	3.0
K formate	
50.0	1.25
K acetate	
50.0	1.54
K propionate	
50.0	1.62
K benzoate	
50.0	1.95
K oxalate	
50.0	2.26
$NaNO_3$	
25.0	0.60
50.0	1.69
100.0	3.11
$Na_2S_2O_3$	
50.0	2.21
Na_2HPO_4	
25.0	1.50
50.0	1.82
Na citrate	
25.0	2.12
50.0	4.32
$(NH_4)_2SO_4$	
25.0	1.30
50.0	2.64

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* g-mol per l.

MOLECULAR WEIGHTS (M. W.) CALCULATED FROM OSMOTIC PRESSURES AT VARIOUS DILUTIONS (l/M) (22)

KCl (74.5)	Dil.	1	2	4	6	12	24
	M. W.	240	105	97.5	88.9	84.6	82.7
$CuSO_4$ (159)	Dil.	1	2.49	4.15	8.30	16.60	
	M. W.	274	192	176	163	160	
$BaCl_2$ (208.3)	Dil.	1	5	10	20	40	
	M. W.	226	240	323	321	323	
K_2SO_4 (174.4)	Dil.	2	10	20	40	80	
	M. W.	160	97.3	68.5	64.5	61.7	

For the osmotic pressure of salt solutions, K and Na salts, nitrates, sulfates, salts of organic acids, alums, etc., *see* Adie (2), König and Hasenbaumer (30) and Pfeffer (43); for camphorates, naphthionates, benzenesulfonates, *o*-nitrobenzoates, silicofluorides, cobalticyanides and other salts, *see* Berkeley and Hartley (7). Adie's and Pfeffer's results are uncertain by several %; deviations between similar experiments often occur of the order of 10%. Those of Berkeley and Hartley (6, 7) show variations of 1–2%.

ADDITIONAL DATA

Aqueous Solutions of Non-colloids.—Antipyrine (42); electrolytes (25, 30); glycerol (42); mannitol (42); membranes of chemically inert substances (10); salicin (42); sucrose (3, 44, 48).

Colloidal Solutions.—Arsenious sulfide (33); gelatin (37); gums (37); hemoglobins (1, 26, 45); influence of electrolytes on osmotic pressure of colloids (32); proteins (34, 36, 47); serum proteins (46); starch (37).

OSMOTIC PRESSURES IN PYRIDINE, 25°, CAOUTCHOUC MEMBRANE (29)

Values of theoretical (calc.) and observed osmotic pressures in cm Hg

	M/l	0.200	0.150	0.125	0.100	0.075	0.050	0.025
	Calc.	372	279	232	186	139	93	46
Obs.	Sucrose		252	213	189	119	59	26
	$AgNO_3$		236	167	136	114		
	LiCl	176	117		82	76	50	17

NITROCELLULOSE IN ACETONE, 25°, COLLODION MEMBRANE (20)

g/l	1.16	3.65	8.33	18.8	46.2	67.2	106.3	141
cm H_2O	0.62	2.68	8.0	25.4	105	210	502	963

OTHER NON-AQUEOUS SOLVENTS

Ether, water and glycerol mixtures (27).

Lithium chloride in ethyl alcohol with gutta percha membrane (4).

Pyridine solutions and caoutchouc membranes (17, 28, 49).

Rubber solutions (16).

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(For a key to the periodicals see end of volume)

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THE PROPERTIES OF SURFACES: SURFACE TENSION, SURFACE ENERGY AND RELATED PROPERTIES

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THE PROPERTIES OF SURFACES: SURFACE TENSION, SURFACE ENERGY AND RELATED PROPERTIES

SURFACE TENSION AND CAPILLARITY: SYMBOLS AND ABBREVIATIONS

Cgs Units Are Used Throughout	Partout usage des unités cgs	Das Cgs System wird durchwegs benützt	Vengono sempre usate le unità cgs
γ Surface tension (or free surface energy).*	γ Tension superficielle (ou énergie superficielle libre).*	γ Oberflächenspannung (oder freie Oberflächenenergie).*	γ Tensione superficiale (o energia libera superficiale).*
γ_i Interfacial tension between two non-gaseous phases.	γ_i Tension intersuperficielle entre deux phases non-gazeuses.	γ_i Grenzflächenspannung zwischen zwei nicht gasförmigen Phasen.	γ_i Tensione alla superficie di contatto tra due fasi non gassose.
$\Delta\gamma$ (γ for a solution) − (γ for the pure solvent).	$\Delta\gamma$ (γ pour une solution) − (γ pour le solvant pur).	$\Delta\gamma$ (γ für eine Lösung) − (γ für ein reines Lösungsmittel).	$\Delta\gamma$ (γ per la soluzione) − (γ per il solvente puro).
γ_M Molecular free surface energy.	γ_M Énergie superficielle libre moléculaire.	γ_M Molekulare freie Oberflächenenergie.	γ_M Energia libera molecolare di superficie.
a^2 Capillary constant or "specific cohesion."	a^2 Constante capillaire ou "cohésion spécifique."	a^2 Kapillaritätskonstante oder "spezifische Kohäsion."	a^2 Costante di capillarità o coesione specifica.
d_l (resp. d_v) Density of the liquid (resp. of the saturated vapor).	d_l (resp. d_v) Densité du liquide (resp. de la vapeur saturée).	d_l (bezw. d_v) Dichte der Flüssigkeit (bezw. des gesättigten Dampfes).	d_l (o d_v) Densità del liquido (o del vapore saturo).
g Acceleration or intensity of gravity at place of observation.	g Accélération ou intensité de la pesanteur au lieu de l'observation.	g Beschleunigung oder Intensität der Schwerkraft am Standort der Beobachtung.	g Accelerazione o intensità della gravità nel luogo di osservazione.
h Effective height of capillary rise.	h Hauteur effective de l'ascension capillaire.	h Effektive Steighöhe.	h Altezza effettiva dell'ascensione capillare.
k_E The Eötvös constant.	k_E Constante d'Eötvös.	k_E Konstante nach Eötvös.	k_E Costante di Eötvös.
M Molecular weight, O = 16.	M Poids moléculaire, O = 16.	M Molekulargewicht, O = 16.	M Peso molecolare, O = 16.
n The van der Waals constant.	n Constante de van der Waals.	n van der Waals-Konstante.	n Costante di van der Waals.
r Internal effective radius of capillary.	r Rayon interne effectif du tube capillaire.	r Effektiver Innenradius der Kapillare.	r Raggio interno del capillare.
t_c (resp. T_c) Critical temperature.	t_c (resp. T_c) Température critique.	t_c (bezw. T_c) Kritische Temperatur.	t_c (o T_c) Temperatura critica.
x_A Mole fraction of substance A.	x_A Fraction moléculaire de substance A.	x_A Molenbruch des Stoffes A.	x_A Frazione di grammimolecola della sostanza A.

EXPERIMENTAL METHODS

Symbol	Methods	Symboles	Méthodes	Zeichen	Methoden	Simbolo	Metodi
(I)	Method of capillary height or pressure.	(I)	Ascension ou pression capillaire.	(I)	Steighöhe oder Kapillardruck.	(I)	Innalzamento oppure pressione capillare.
(II)	Drop-weight method.	(II)	Poids de la goutte.	(II)	Tropfengewicht.	(II)	Peso della goccia.
(III)	Method of maximum bubble pressure.	(III)	Pression maximum de la bulle.	(III)	Maximaldruck für Blasen.	(III)	Pressione massima della bolla.
(IV)	Method of capillary waves.	(IV)	Ondes capillaires.	(IV)	Kapillarwellen.	(IV)	Onde capillari.
(V)	Method of vibrating jet.	(V)	Jet vibrant.	(V)	Vibration.	(V)	Getto capillare.
(VI)	Drop-height method.	(VI)	Hauteur de la goutte.	(VI)	Tropfenhöhe.	(VI)	Altezza della goccia.
(VII)	Drop-shape method.	(VII)	Forme de la goutte.	(VII)	Tropfengestalt.	(VII)	Forma della goccia.
(VIII)	Method of maximum pressure in drops.	(VIII)	Pression maximum dans les gouttes.	(VIII)	Maximaldruck in Tropfen.	(VIII)	Massimo di pressione della goccia.
(IX)	Method of Sentis.	(IX)	Méthode de Sentis.	(IX)	Methode nach Sentis.	(IX)	Metodo di Sentis.

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* γ alone means that the liquid or solution was studied in the presence of its own vapor only. γ (air) means that air was present above the surface of the liquid and that, therefore, the liquid surface was in contact with air, saturated, of course, with the vapor of the liquid. γ (air or vapor) means that some measurements were made under each of the above conditions and that the values given are for either within the limits prescribed. γ (H_2), resp. (N_2), states the medium in which measurements were made, while γ (?) indicates that the medium was not stated.

EQUATIONS

Formula for capillary rise:

$$\gamma = \tfrac{1}{2}(d_l - d_g)ghr \text{ (\textit{v. further} p. 435)} \qquad (1)$$

Formula for capillary constant:

$$a^2 = \frac{\gamma}{\tfrac{1}{2}(d_l - d_g)g} \text{ (}=hr\text{ for capillary rise)} \qquad (2)$$

Formula of Eötvös:

$$\gamma_M = \gamma\left(\frac{M}{d_l}\right)^{2/3} = A_C - k_E t \text{(resp. } A_K - k_E T) \qquad (3)$$

A_C (resp. A_K) is a constant evaluated from the experimental data. For normal liquids this linear relation holds up to $t \ngtr t_c - 35°$. $A_C = k_E(t_c - 6)$ approximately, a relation which has found application as a means of computing t_c; $k_E = -\frac{d\gamma_M}{dt}$

Formula of van der Waals: $\gamma = \alpha\left(1 - \frac{T}{T_C}\right)^n$ (4)

α and n are constants evaluated from the experimental data.

Formula of Macleod: $\gamma = K(d_l - d_v)^4$, where the constant K is nearly independent of T for normal liquids.

Formula of Sugden: $P = \frac{M}{d_l - d_v}\gamma^{1/4}$

$P = 0.78V_C$ approx. for certain normal liquids.

V_C = molecular volume in cm³ at the critical temperature.

TENSILE STRENGTH AND ANGLE OF CONTACT

T. Fraser Young and William D. Harkins

TENSILE STRENGTH AND TENSILE ENERGY

The free tensile energy of a liquid is defined as equal to 2γ. It is the reversible work done on the system (increase of free energy) to rupture a bar of liquid of one cm² cross section to form two plane surfaces of 1 cm² area each. The total tensile energy (e_t) per cm² is given by the relation: $e_t = 2(\gamma + l) = 2h$, (l = latent heat, h = surface energy of unit surface).

It has not been found possible to measure the tensile strength of a liquid, since the rupture does not occur simultaneously over more than a minute area. The maximum value of the pull which has thus far been attained, is given below:

Maximum negative pressure in megabaryes (13): H_2O = 34 at 24.4°C; C_2H_5OH = 40 at 22.5°C; $(C_2H_5)_2O$ = 73 at 17.7°C.

The pull necessary to rupture a film of various liquids between two flat steel surfaces of contact, 4.5 cm² in area, has been found to be as large as 3–4 megabaryes, but this is probably much lower than that corresponding to the true tensile strength of the liquid (4).

ANGLE OF CONTACT

The angle of contact (θ) between the surface of a liquid and that of a solid is highly dependent upon the nature of the surfaces, and is in general different for contaminated surfaces from what it is for clean surfaces. In few of the experiments in which θ has been determined has cleanliness of the surface of the liquid been demonstrated, and the difficulty of cleaning the surface of a solid is so great that no experiments with what may be called pure surfaces have been carried out with solids.

By use of various optical methods it has been shown (Table 1) that θ between glass and a small number of liquids is zero provided the glass is already covered by a film of the liquid. θ may be greater than zero provided the liquid is evaporating (14), or the glass surface has become dry (15).

Table 1.—Angle of Contact (θ) between Liquid and Glass Covered with a Film of the Liquid at Room Temperature as Determined by Various Optical Methods

Liquid	θ	Lit.
Water	0	(1, 3, 14, 15)
Ethyl alcohol	0	(14)
Benzene	0	(14)
Carbon tetrachloride	0	(14)
Chloroform	0	(14)
Acetic acid	0	(3)
Aqueous solutions of various salts	0	(15)
Glycerol	0	(1)
Ethyl ether	0	(3, 14)
Turpentine	0	(1, 3)
Olive oil	0	(1)
Hydrogen peroxide	0	(12)

That θ for liquid-to-glass is zero within the limits of error of the methods employed is indicated in the case of about 100 other liquids by the data used in compiling these tables, which show that the surface tension determined by the capillary-height method on the basis of the assumption that θ is zero, is the same for each of these liquids as the value obtained by the drop-weight method by the use of the corrections of Harkins and Brown or by the bubble-pressure method by the use of the corrections of Sugden. In addition Volkmann (16) found a^2 for H_2O = constant ± 0.0002 at 20.2°C for seven different kinds of glass and Carver and Hovorka (5) found a^2 for H_2O = constant ± 0.0002 at 20° for glass, zinc, copper and silver.

Table 2.—Angle of Contact Greater than Zero

Interface	t, °C	θ, °arc	Lit.
H_2O—azobenzene	14	77°	(3)
H_2O—paraffin	14	106° 43′	(3)
Hg—glass	4.4	144.48°	(2)
	3	148.28°	
	4	147.71°	
	3	140.00°	
	9	139.41°	(2)
	16	>139°	(1)
	18	128°	(8)
H_2O—various plates coated with oleic acid			(11)
H_2O—plates coated with 65 different organic compounds			(18)

For angle of contact of a lens of H_2O on CCl_4, *v.* (6).

It should be noted that in cases where the last terms of the Laplace-Poisson equation (*v.* (2), p. 8)

$$h = a\sqrt{2}\sin\frac{\theta}{2} - \frac{a^2}{\mu} + \frac{a^2}{3r'\sin\frac{\theta}{2}}\left(1 - \cos^3\frac{\theta}{2}\right)$$

are not used, the values of θ given are often 5 or more degrees in error; $r' = r + (\sqrt{2} - 1)a$; h is approximate thickness of a drop of liquid of horizontal radius r which lies on a horizontal plane plate; μ is its radius of curvature.

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METHODS OF MEASURING SURFACE TENSION

T. Fraser Young and William D. Harkins

For critical discussion of various methods, their sources of error, corrections, precautions, etc., *see* especially (3, 4, 5, 6, 14); *cf.* (7) and the references cited below.

The *Capillary-Height Method.*

$$2\pi r\gamma = V(d_1 - d_2)g/\cos\theta,$$

in which d_1 is the density of the fluid of greater density and d_2 is the density of the other fluid; V is the volume which lies inside a capillary tube of uniform bore, between the small meniscus and the level of a horizontal plane which lies in the surface of the (extremely) large meniscus.

$$V = \pi r^2 h,$$

in which h may be considered as the average vertical distance between the two surfaces. If h_0 is the vertical distance between the plane of the large meniscus and a horizontal plane tangent to the small meniscus, then for capillary tubes of very small diameter (< 1 mm for H_2O):

$$h = h_0 + \frac{r}{3} - 0.1288\frac{r^2}{h_0} + 0.1312\frac{r^3}{h_0^2} \text{ (Poisson, Rayleigh)}$$

or approximately

$$h = h_0 + \frac{a^2 r}{3a^2 + r^2} \text{ (Hagen and Desains)}$$

This expression is not equivalent to that given by Rayleigh.

For tubes of considerably larger diameter $\left(\frac{r}{a} > 4.3\right)$,

$$1.4142\frac{r}{a} - \log_e\frac{a}{h_0} = 0.6648 + 0.19785\frac{a}{r} + \frac{1}{2}\log_e\frac{r}{a} \text{ (Rayleigh)}$$

For tubes of intermediate diameters neither equation is accurate and the tables of Bashforth and Adams (1) should be used to obtain h. *See further* (2, 5, 11, 12, 15).

Drop-Weight Method.

$$\gamma = \frac{mg}{r} \times F,$$

m is the mass of a slowly formed drop which falls from a horizontal tip of circular cross-section (radius = r) and sharp edge. F is a function of V/r^3, where V is the volume of the drop, and its value may be interpolated from the following table (for theory, *v.* (9)).

Experimental Values for Drop Weight Corrections (5)

V/r^3	F	± %	V/r^3	F	± %
∞	0.159		2.3414	0.26350	0.1
5000	0.172		2.0929	0.26452	0.05
250	0.198		1.8839	0.26522	0.05
58.1	0.215		1.7062	0.26562	0.05
24.6	0.2256		1.5545	0.26566	0.05
17.7	0.2305	0.3	1.4235	0.26544	0.05
13.28	0.23522	0.25	1.3096	0.26495	0.1
10.29	0.23976	0.2	1.2109	0.26407	0.1
8.190	0.24398	0.15	1.124	0.2632	0.15
6.662	0.24786	0.15	1.048	0.2617	0.15
5.522	0.25135	0.15	0.980	0.2602	0.15
4.653	0.25419	0.15	.912	0.2585	0.15
3.975	0.25661	0.15	.865	0.2570	0.2
3.433	0.25874	0.15	.816	0.2550	
2.995	0.26065	0.15	.771	0.2534	
2.637	0.26224	0.1	.729	0.2517	
0.692	0.2499		0.541	0.2430	
.658	0.2482		.512	0.2441	
.626	0.2464		.483	0.2460	
.597	0.2445		.455	0.2491	
.570	0.2430		.428	0.2526	
			.403	0.2559	

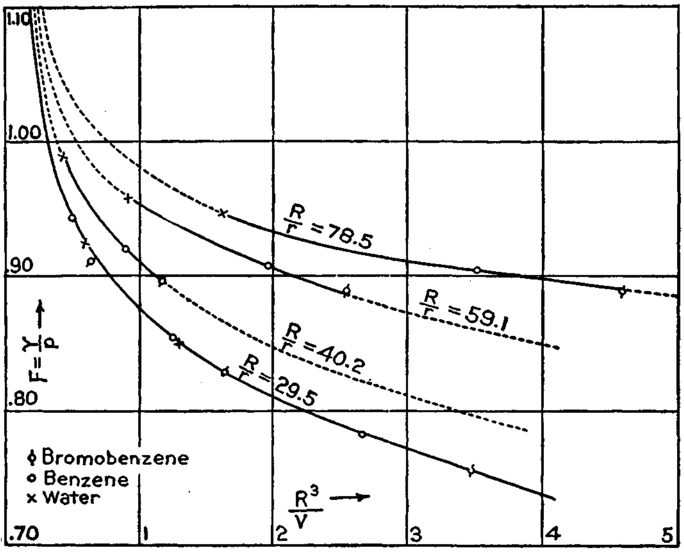

Fig. 1.

Method of Maximum Pull on a Ring.—When a circular ring of radius R (center of ring to center of wire) is pulled from the surface of a not-too-viscous liquid into the gas phase above, the surface tension is given by

$$\gamma = p \times F,$$

where p is the pull in dyne/cm and F is a function of R^3/V whose value may be interpolated from Fig. 1 for any ring of radius R constructed from a wire of radius r. V, the volume of the liquid lifted by the ring $\equiv \frac{p}{g(d_l - d_g)}$, where d_l is the density of the liquid and d_g that of the gas above it (8, 10, 13).

Other Methods.—*v.* (3, 4, 7, 14).

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INTERFACIAL TENSION FOR SOLID-LIQUID AND LIQUID-LIQUID INTERFACES

T. FRASER YOUNG AND WILLIAM D. HARKINS

CONTENTS

INTERFACE, SOLID—LIQUID

Free surface energy at the interface solid—liquid

No method has as yet been discovered for the determination of the free interfacial energy between a solid and a liquid. For values calculated from the Ostwald-Freundlich equation, *v.* (5, 25). *See further* (1, 2, 7, 9, 25, 26, 34).

INTERFACE, LIQUID—LIQUID

Abbreviations; *see also* p. 433

γ_i Interfacial tension, cgs.

γ Surface tension of organic liquid, cgs.

d_p (resp. d_o and d_w) Density of pure organic liquid (resp. the organic phase, and the aqueous phase), g/cm³.

Except where otherwise noted all values recorded below were obtained by the drop-weight method.

Accuracy.—No attempt has been made to estimate accuracy except in cases where independent determinations with different samples are available. The attainable precision by the drop-weight method appears to be about 0.1 % at a water interface and 1 % at a mercury interface. Other methods have thus far yielded considerably less accurate results.

The interfacial tension at the phase boundary liquid—liquid is in general varied much more by impurities than the surface tension at the liquid—gas interface. It is not yet known how well the drop-weight method applies to the determination of γ_i at the liquid—liquid interface since the corrections were determined under the somewhat different conditions existing at the liquid—gas interface.

Interface, Water—Organic Liquid: ℭ-Table, The ℭ-Arrangement

Formula	Name	γ_i	γ (air)	d_p	d_o	d_w	t, °C	Lit.
CCl_4	Carbon tetrachloride*	45.0±1.0	26.66	1.590	1.5846	0.9972	20	(12)
CS_2	Carbon disulfide	48.36	31.38	1.261	1.2596	0.9972	20	(12)
$CHBr_3$	Bromoform	40.85	41.53	2.8854	2.8818	1.0004	20	(16)
$CHCl_3$	Chloroform	32.80±0.2	27.13	1.485	1.4831	1.0002	20	(12, 19)
CH_2Cl_2	Methylene chloride	28.31	26.52	1.3478	1.3286	1.0018	20	(12)
CH_2I_2	Methylene iodide	48.50	50.76	3.3190	3.3180	0.99908	20	(16)
CH_3NO_2	Nitromethane	9.66	36.82	1.1385	1.1288	1.0184	20	(12)
C_2Cl_4	Tetrachloroethylene	47.48	31.74	1.6216	1.6219	0.99844	20	(16)
$C_2H_2Br_4$	Acetylene tetrabromide	38.82	49.67	2.9620	2.9588	0.9986	20	(12)
$C_2H_4Br_2$	Ethylene dibromide*	36.54	38.71	2.178	2.1773	0.9991	20	(12)
C_2H_5Br	Ethyl bromide	31.20	24.16	1.441	1.4460	1.0001	20	(12)
C_2H_5I	Ethyl iodide	40.0	29.9				16	(8, 10)
C_2H_6S	Ethylmercaptan	26.12	21.82			0.9982	20	(12)
$C_3H_4Cl_2O$	1, 1-Dichloroacetone	14.43	31.91	1.236		1.0170	20	(12)
$C_3H_5Br_3$	1, 2, 3-Tribromopropane	38.50	45.36	2.4171	2.4152	0.99892	20	(16)
C_3H_5ClO	Chloroacetone	7.11	35.27	1.170	1.1581	1.0029	20	(12)
C_4H_7N	Butyronitrile	10.38	28.06	0.79040	0.99426	0.99201	20	(12)
$C_4H_8Cl_2S$	β, β′-Dichloroethyl sulfide	28.36	42.82	1.2732			20	(14)
C_4H_9Cl	Isobutyl chloride	24.43	21.94	0.8754	0.8766	0.9973	20	(12)
C_4H_9Cl	*tert.*-Butyl chloride	23.75	19.59	0.8422	0.8423	0.9990	20	(12)
$C_4H_{10}O$	Isobutyl alcohol	2.1			0.8424	0.9834	18	(1.5)
$C_4H_{10}O$	Ethyl ether	10.70±0.2	17.10		0.7174	0.9868	20	(12)
C_5H_9N	Isovaleronitrile	14.14	26.03	0.79106	0.79294	0.99622	20	(12)
C_5H_{10}	Trimethylethylene	36.69	17.26				20	(12)
$C_5H_{10}O$	Methyl propyl ketone	6.28	24.15	0.8067	0.8125	0.9897	20	(12)
$C_5H_{10}O_2$	Isovaleric acid	2.73	25.33	0.9295	0.9457	0.9998	20	(12)
$C_5H_{10}O_3$	Diethyl carbonate	12.86	26.31		0.97513	0.99905	20	(12)
$C_5H_{11}Cl$	Isoamyl chloride	15.44	23.48	0.86962	0.87146	0.9955	20	(12)
C_5H_{12}	Isopentane	49.64	13.72	0.6200	0.6198	0.9982	20	(12)
$C_5H_{12}O$	Amyl alcohol (inactive mixt.) (I)	4.9±2.0			0.804		30	(33)
$C_5H_{12}O$	Isoamyl alcohol	5.0			0.8291	0.9952	18	(1.5)
C_6H_5Br	Bromobenzene	39.82	36.26	1.5016	1.5013	0.99862	20	(16)
C_6H_5Cl	Chlorobenzene	37.41	33.08	1.053	1.1047	0.9972	20	(12)
C_6H_5I	Iodobenzene	45.67	40.35				16.8	(8, 10, 16)
		41.84	39.70	1.8258	1.8255	0.99832	20	
$C_6H_5NO_2$	Nitrobenzene	25.66	43.38		1.2012	0.9976	20	(12)
C_6H_6	Benzene*	35.00±0.05	28.86		0.8788	0.9980	20	(10, 11, 12, 13, 22)
C_6H_7N	Aniline	5.77	42.58	1.022	1.216	0.9990	20	(12)
$C_6H_{12}O$	Cyclohexanol	3.92	34.23				16.2	(8, 10)
$C_6H_{12}O$	Ethyl propyl ketone	13.58	25.39	0.8152	0.8152	0.9964	20	(12)

Formula	Name	γ_i	γ (air)	d_p	d_o	d_w	t, °C	Lit.
$C_6H_{12}O$	Methyl butyl ketone	9.73	25.49	0.8124	0.8160	0.9956	20	(12)
$C_6H_{12}O$	Methyl *tert.*-butyl ketone	10.81	23.43	0.8055	0.8090	0.9954	20	(12)
C_6H_{14}	*n*-Hexane*	51.10 ± 0.2	18.43	0.6595	0.6597	0.9972	20	(12)
$C_6H_{15}N$	Dipropylamine	1.66	22.54	0.73853	0.81620	0.98844	20	(12)
C_7H_5NS	Phenyl isothiocyanate	39.04	41.44	1.1326	1.1331	0.99795	20	(16)
C_7H_6O	Benzaldehyde	15.51	40.04	1.0504	1.0445	0.9981	20	(12)
C_7H_7Br	*o*-Bromotoluene	41.15	35.85	1.4218	1.4318	0.99823	20	(16)
$C_7H_7NO_2$	*o*-Nitrotoluene	27.19	41.46	1.168	1.1599	0.9972	20	(12)
$C_7H_7NO_2$	*m*-Nitrotoluene	27.68	40.99	1.168	1.1547	0.9971	20	(12)
C_7H_8	Toluene	36.1					25	(37)
C_7H_8O	Anisole	25.82	35.22	0.99327	0.99270	0.99715	20	(12)
C_7H_8O	Benzyl alcohol	4.75	39.71				22.5	(8, 10)
$C_7H_{14}O_2$	Heptylic acid*	7.00 ± 0.5	28.31				20	(11, 12)
$C_7H_{14}O_2$	Ethyl isovalerate	18.39	23.68	0.8648	0.8658	0.9971	20	(12)
C_8H_8	Styrene	35.48	32.14				19.0	(8, 10)
C_8H_{10}	Ethylbenzene	31.35	29.62				17.5	(8, 10)
C_8H_{10}	*o*-Xylene	36.06	29.89	0.87810	0.87806	0.99707	20	(12)
C_8H_{10}	*p*-Xylene	37.77	28.33	0.86444	0.86494	0.99680	20	(12)
$C_8H_{10}O$	Phenetole	29.40	32.74	0.96474	0.96474	0.99820	20	(12)
$C_8H_{16}O$	Methyl hexyl ketone	14.09	26.79	0.8192	0.8205	0.9980	20	(12)
$C_8H_{16}O_2$	Caprylic acid	8.217	28.82				18.1	(8, 10)
$C_8H_{16}O_2$	Ethyl caproate*	19.80 ± 2	25.81		0.8705	0.9978	20	(19)
C_8H_{18}	*n*-Octane*	50.81 ± 0.1	21.77	0.7022	0.7021	0.9971	20	(12)
$C_8H_{18}O$	*n*-Octyl alcohol*	8.52 ± 0.2	27.53	0.8252	0.8301	0.9981	20	(12)
$C_8H_{18}O$	Methylhexyl carbinol	9.42 ± 0.2	26.52	0.8211	0.8257	0.9974	20	(12)
$C_8H_{19}N$	Diisobutylamine	10.28	22.05	0.74428	0.74763	0.99680	20	(12)
C_9H_{12}	Mesitylene	38.70	28.51	0.86124	0.86140	0.99717	20	(12)
$C_9H_{18}O_2$	Isoamyl butyrate	23.00	25.19	0.86272	0.86280	0.99672	20	(12)
$C_{10}H_7Br$	α-Bromonaphthalene	42.07	44.59	1.4836	1.4739	0.99828	20	(16)
$C_{10}H_7Cl$	α-Chloronaphthalene	40.74	41.80	1.1706	1.1700	0.9982	20	(16)
$C_{10}H_{14}$	*p*-Cymene	34.61	28.09	0.85618	0.85630	0.99702	20	(12)
		39.41	28.75				13.50	(8, 10)
$C_{10}H_{22}$	Diisoamyl	46.80	22.24	0.72216	0.72253	0.99696	20	(12)
$C_{10}H_{23}N$	Diisoamylamine	13.51			0.77628	0.99815	20	(19)
$C_{11}H_{12}O_2$	Ethyl cinnamate	21.36	38.42				19.5	(8, 10)
$C_{11}H_{14}O_2$	Ethyl hydrocinnamate	20.19	35.08				21.5	(8, 10)
$C_{11}H_{20}O_2$	Undecylenic acid	10.14	30.64	0.90604	0.90762	0.99610	25	(12)
$C_{11}H_{22}O_2$	Ethyl nonylate	23.88	28.04				20	(12)
$C_{12}H_{14}O_4$	Diethyl phthalate	16.27	37.34				20.5	(8, 10)
$C_{18}H_{34}O_2$	Oleic acid	15.59 ± 0.2	32.50				20	(10, 12*)
		15.68†	32.50	0.8910	0.8908	0.9982	20	
$C_{18}H_{34}O_3$	Ricinoleic acid	14.25	35.81				16	(8, 10)
$C_{20}H_{38}O_2$	Ethyl oleate‡	21.34			0.87601		20	(19)

* Between 10 and 40°C, the γ_i temperature coefficients of the following liquids are approximately constant: $d\gamma_i/dt$ for $CCl_4 = -0.098$; for $C_2H_4Br_2 = -0.108$; for $C_6H_6 = -0.058$; for $C_6H_{14} = -0.026$; for $C_7H_{14}O_2 = -0.037$; for $C_8H_{18} = -0.048$; for $C_5H_{18}O = +0.039$; for *sec.*-$C_8H_{18}O = +0.041$ (11). For ethyl caproate and heptaldehyde, *v.* (11).

† The oleic acid and water were mixed with each other but were not mutually saturated (12).

‡ A sample of Kahlbaum's ethyl oleate gave $\gamma_i = 18.7$ at 20°, but contained an amount of free acid equivalent to 1.65 % oleic acid.

Interface, Aqueous Solution—Organic Liquid

CCl_4; 22 ± 2°C (28)

Salt	C*	$\Delta\gamma_i$†	Method	Salt	C*	$\Delta\gamma_i$†	Method
$FeCl_3$	0.1	0.9	I	KBr	0.1	0.8	II
	1.0	−0.1	I		1.0	1.7	II
$MgSO_4$	0.1	−1.2	I	KI	0.1	1.1	II
	1.0	−2.4	I		1.0	0.8	II
$CaCl_2$	0.1	0.4	I	K_2SO_4	0.1	0.6	II
	1.0	2.3	I		0.5	0.9	II
NaCl	0.1	1.0	I		1.0	1.5	II
	1.0	2.3	I		0.1	0.2	I
NaBr	0.1	0.5	II		1.0	0.1	I
	1.0	0.8	II	KCNS	0.1	0.9	II
KCl	0.1	0.5	I		1.0	−0.8	II
	1.0	2.1	I				
	0.1	0.1	II				
	1.0	1.5	II				

Also γ_i for aqueous H_2SO_4, and for mixtures of KCl and KCNS in water.

$CHCl_3$; 22 ± 2°C (28)

Salt	C*	$\Delta\gamma_i$†	Method	Salt	C*	$\Delta\gamma_i$†	Method
$FeCl_3$	0.1	2.9	I	KBr	0.1	1.4	II
	1.0	3.5	I		1.0	1.3	II
$MgSO_4$	0.1	3.2	I	KI	0.1	1.1	II
	1.0	2.6	I		1.0	0.2	II
$CaCl_2$	0.1	2.5	I	K_2SO_4	0.1	3.2	I, II
	1.0	2.6	I		1.0	1.4	I
NaCl	0.1	2.8	I		0.1	3.2	II
	1.0	3.6	I		0.5	4.7	II
NaBr	0.1	1.1	II		0.75	3.2	II
	1.0	0.0	II		1.0	2.4	I, II
KCl	0.1	3.0	I	KCNS	0.1	1.2	II
	1.0	4.0	I		1.0	−0.4	II
	0.1	1.6	II				
	1.0	1.8	II				

* C = M/l_s. † ± 2.

$C_4H_{10}O$, Ethyl ether; 22 ± 2° (28)

Salt	M/l_s	$\Delta\gamma_i$ ±2	Method
H_2SO_4	0.2	0.2	II
	2.0	0.4	II
$FeCl_3$	0.1	0.7	II
	1.0	1.2	II
$MgSO_4$	0.1	0.8	II
	1.0	1.6	II
$CaCl_2$	0.1	0.8	II
	1.0	2.2	II
NaCl	0.1	0.2	I
	0.5	0.8	I
	1.0	1.0	I
NaBr	0.1	0.2	II
	1.0	1.5	II
KCl	0.1	0.7	I
		0.4	II
	1.0	1.4	I
		1.7	II
KBr	0.1	0.3	II
	1.0	1.4	II
KI	0.1	−0.7	II
	1.0	−1.5	II
K_2SO_4	0.1	0.3	II
	1.0	1.3	II
KCNS	0.1	−0.6	II
	1.0	−1.8	II

$C_6H_5NO_2$, Nitrobenzene; 22 ± 2° (28)

Salt	M/l_s	$\Delta\gamma_i$ ±2	Method
H_2SO_4	0.1	0.2	II
	0.2	0.1	II
	0.5	0.1	II
	1.0	−0.1	II
	2.0	−0.4	II
$FeCl_3$	0.1	0.6	I
	1.0	0.9	I
$MgSO_4$	0.1	0.4	I
	1.0	0.4	I
$CaCl_2$	0.1	0.5	I
	1.0	1.1	I
NaCl	0.1	0.0	I
	1.0	1.9	I
NaBr	0.1	0.0	II
	1.0	0.3	II
KCl	0.1	0.7	I
	1.0	1.7	I
	0.1	0.2	II
	1.0	0.8	II
KBr	0.1	0.3	II
	1.0	0.2	II
KI	0.1	0.1	II
	1.0	−1.6	II
K_2SO_4	0.1	1.1	I
	1.0	1.1	I
	0.1	0.1	II
	1.0	0.2	II
KCNS	0.1	−0.3	II
	1.0	3.1	II
$C_2H_3Cl_3O_2$, Chloral-hydrate	0.5*	−0.9	I
	1.0*	−2.9	I
	2.0*	−4.0	I

* Wt. %.

$C_4H_8Cl_2S$, β, β′-Dichloroethyl sulfide; 20°C; d_4^{20} = 1.2732 (I) (14). Phases not mutually saturated.

	d_w	γ_i
Vapor		42.82
Water	0.9982	28.36
0.1*N* HCl	1.0001	28.90
0.1*N* NaOH	1.0032	12.78
0.1*N* Na_2CO_3	1.0025	18.82

$C_5H_{11}NO_3$, Isoamyl nitrate against 0.177*N* KCl (II) (12)

γ_i	γ	d_p
30.80	27.18	0.99710
d_o	d_w	t
0.99745	1.0059	20

C_6H_6, Benzene

1% aq. soln. chloral hydrate at 22 ± 2° (I), $\Delta\gamma_i = -3.6$ (28).

Aq. soln. of NaCl at 25 ± 0.01°C (II) (16.5)

M/l_s	$\Delta\gamma_i$ ± 0.2
0.3	0.63
0.5	0.86
1.0	1.56
3.0	4.04
5.0	6.59

Aq. solutions of acids: acetic (18); butyric (17.5).

Dimethylaniline + benzene or heptane, against water (31).

Interfacial tensions and distributions for the two-phase system, butyric acid + hexane + H_2O (18).

$C_8H_{18}O$, Caprylic alcohol

For the pure alcohol, γ = 26.35, relative viscosity = 3.126, d_4^{25} = 0.82026, 25° (4)

Solution	Wt. %	γ_i
Water	0.0	9.80
Sucrose	30.0	10.88
Dextrin	10.0	3.85
Starch	1.0	10.17
Gum arabic	10.0	9.24

$C_{18}H_{34}O_2$, Oleic acid against 0.116*N* HCl (II) (12)

γ_i	d_p	d_o	d_w	t
15.99	0.8910	0.8908	1.0006	20

Benzene against aqueous soap solutions (II); sodium oleate (13); effects of oleic acid and of NaOH (22); *see further* final index under Soaps.

Effect of Hydrogen Ion Concentration on Tension at the Interface Aqueous Phase—Organic Phase

Inorganic acids and bases at concentrations up to 0.2 normal have only a very slight effect (≯ *ca.* 1%) upon the interfacial tension at the phase boundary benzene—aqueous solution, and have in general a marked effect at low concentrations only in case they react with the organic phase. Thus with esters the presence of a base in the aqueous phase accelerates the hydrolysis. For example, the interfacial tension, ethyl oleate—water, is lowered very rapidly as the concentration of strong base in the aqueous phase is increased, since the rapidity at which sodium oleate is produced at the surface increases with the concentration of the base. Since the chemical composition of the interfacial region changes in such a case with the time, no equilibrium values can be obtained, but in many cases somewhat definite values are obtained provided the liquids are left in contact only about one-half hour.

For numerical data see the literature cited below: Ethyl oleate (19); ethyl caproate (19); chloropicrin (20); diisoamylamine (19); *sec.*-octyl alcohol (19); dichloroethyl sulfide (14); benzene (13).

For aqueous solutions buffered by borate or phosphate against benzene solutions of organic acids and esters, *v.* (23).

Interfacial Tensions of Liquid Metals against Non-metallic Liquid Phases

γ_i (resp. γ_{Hg}, γ_l) = interfacial tension, resp. surface tension of Hg, resp. surface tension of the second liquid.

MERCURY AGAINST A PURE LIQUID

H_2O, Water (II) (17)

γ_i	γ_l	t, °C
375	72.8	20

CS_2, Carbon disulfide (II) (17)

γ_i	γ_l	t, °C
336	31.4	20

CH_2Cl_2, Methylene chloride (II) (15)

γ_i	γ_l	t, °C
342.5	26.5	20

CH_3I, Methyl iodide (II) (15)

γ_i	γ_l	t, °C
304	35.0	20

$C_2H_4Br_2$, Ethylene bromide (II) (15)

γ_i	γ_l	t, °C
326	38.7	20

$C_2H_4Cl_2$, 1, 1-Dichloroethane (II) (15)

γ_i	γ_l	t, °C
337	25.7	20

$C_2H_5NO_2$, Nitroethane (II) (17)

γ_i	γ_l	t, °C
378	34.9	20

C_2H_6O, Ethyl alcohol (II) (15)

γ_i	γ_l	t, °C
364	22.4	20

C_3H_8O, *n*-Propyl alcohol (II) (17)

γ_i	γ_l	t, °C
368	23.7	20

$C_4H_{10}O$, Ethyl ether (II) (17)

γ_i	γ_l	t, °C
379	21.8	20

$C_4H_{10}O$, Isobutyl alcohol (II) (17)

γ_i	γ_l	γ_{Hg}	t, °C
349.1	24.3	480	0
345.6	23.5	478	10
342.7	22.7	476	20
341.0	22.0	474	30
340.2	21.3	471	40
339.3	20.5	469	50

$C_5H_{12}O$, Iso(?)-amyl alcohol (III) (3)

γ_i	γ_l	t, °C
261.6		25

$C_6H_5NO_2$, Nitrobenzene (II) (15)

γ_i	γ_l	t, °C
350.5	43.4	20

C_6H_6, Benzene (II) (17)

γ_i	γ_l	γ_{Hg}	t, °C
361.3	30.4	478	10
357.2	28.9	476	20
353.7	27.6	474	30
351.4	26.3	471	40
349.8	24.9	469	50
348.8	23.6	467	60

C_6H_7N, Aniline (II) (17)

γ_i	γ_l	t, °C
341	42.6	20

C_6H_{14}, *n*-Hexane (II) (17)

γ_i	γ_l	t, °C
378	18.4	20

C_7H_8, Toluene (II) (17)

γ_i	γ_l	t, °C
359	29.0	20

C_8H_{10}, *o*-Xylene (II) (17)

γ_i	γ_l	t, °C
359	29.0	20

C_8H_{10}, *m*-Xylene (II) (17)

γ_i	γ_l	t, °C
357	29.0	20

C_8H_{10}, *p*-Xylene (II) (17)

361	27.0	20

C_8H_{18}, *n*-Octane (II) (17)

γ_i	γ_l	γ_{Hg}	t, °C
377.2	23.7	480	0
375.8	22.7	478	10
374.7	21.8	476	20
373.4	20.8	474	30
372.6	19.8	471	40
371.3	18.8	469	50
371.1	17.9	467	60

$C_8H_{18}O$, *sec.*-Octyl alcohol (II) (17)

365.4	27.9	480	0
361.7	27.2	478	10
359.0	26.3	476	20
357.3	25.5	474	30
355.0	24.7	471	40
353.6	23.8	469	50

$C_{10}H_{23}N$, Diamylamine (II) (17)

γ	γ_l	t, °C
371	24.6	20

$C_{11}H_{20}O_2$, Undecylenic acid (II) (17)

353	30.6	20

$C_{18}H_{34}O_2$, Oleic acid (II) (17)

322	32.5	20

MERCURY AGAINST AQUEOUS SOLUTIONS

d = density of aqueous solution, t°/4°
N = normality of aqueous soln.

HCl (VI) (27)

d (or *N*)	γ_i	t
1.004	362.8	19–20
1.032	356.1	
1.122	342.4	
1.190	335.7	

H_2SO_4 (VI, VII) (27, 32)

1.015	337.5	19.$_5$

H_2SO_4.—(*Continued*)

d (or *N*)	γ_i	t
1.071	319.7	19.$_5$
1.0559	316	20

C_2H_6O, Ethyl alcohol (IV, VI) (27, 36)

0.969	363.2	19.$_5$
0.927	361.1	19.$_5$
0.825	366.6*	0
0.795	364.0	19.$_5$

* Value determined by Method VI.

$C_2H_4O_2$, Acetic acid (VII) (32)

1.006	344	20.0

$Pb(C_2H_3O_2)_2$ (VII) (6)

2*N*	348	2$_0$
2*N**	338	2$_0$

* $+0.28 \times 10^{-3}N$ $Hg_2(CH_3COO)_2$.

$ZnCl_2$ (VI) (27)

1.094	359.0	19.$_5$
1.426	328.7	19.$_5$
1.683	304.7	19.$_5$

$ZnSO_4$ (VII) (6)

2*N*	334	2$_0$
2*N**	258	2$_0$

* $+2.53 \times 10^{-3}N$ Hg_2SO_4.

$CdSO_4$ (VII) (6)

2*N*	324	2$_0$
2*N**	283	2$_0$

* $+1.66 \times 10^{-3}N$ Hg_2SO_4.

$CuSO_4$ (VI) (27)

1.012	343.2	19.$_5$
1.067	334.9	19.$_5$
1.103	331.7	19.$_5$

Li_2SO_4 (VII) (6)

1*N*	365	2$_0$

NaOH (VI) (27)

1.006	407.1	19.$_5$
1.079	423.0	19.$_5$
1.296	429.4	19.$_5$

Na_2SO_4 (VI, VII) (6, 27)

1.010	371.8	19.$_5$
1.057	371.0	19.$_5$
1.098	377.3	19.$_5$
1*N*	333	2$_0$
1*N**	288	2$_0$

* $+2.8 \times 10^{-3}N$ Hg_2SO_4.

$NaC_2H_3O_2$ (VI) (27)

d (or *N*)	γ_i	t
1.014	379.0	19.$_5$

K_2SO_4 (VII) (6)

1*N*	354	2$_0$

$K_2C_2O_4$ (VI) (27)

1.029	352.3	19.$_5$
1.145	353.6	19.$_5$

Rb_2SO_4 (VII) (6)

0.1*N*	362	2$_0$

LEAD AGAINST FUSED SALT MIXTURES

Equimolar mixture of KCl + $PbCl_2$ (I) (29)		KCl + $PbCl_2$ (I), t = 555 – 603° (29)	
t	γ_i	Wt. % KCl	γ_i
450	23$_2$	0	16$_8$
550	21$_6$	10	18$_5$
590	21$_0$	20	20$_5$

Interface, Organic Liquid—Organic Liquid

CS_2 AGAINST CH_4O, METHYL ALCOHOL

γ_i	*d*,CS_2 phase	*d*,CH_4O phase	Method	t	Lit.
1.1	1.1333	0.7466	II	18	(1.5)

Effect of Pressure on Interfacial Tension at 25° (I) (30)

Values of $10^3\frac{1}{\gamma}\frac{\Delta\gamma}{\Delta P}$; unit of *P* is one dyne/cm²

Phases		$10^{-6}P$: 69	138	207	276	345	413
Hg	H_2O + 3 % HNO_3.......	1.8 1.5	3.2 3.0	4.6 4.8	6.5 5.7	7.9 6.9	9.3 8.6
	Ether + 3% HNO_3.......	3.3	5.7	7.6	10.2	12.3	
H_2O	Ether.........	−40.7	−81.9	−123.9	−165.9	−207.3	
	$CHCl_3$........	− 0.4	− 2.4	− 4.8	− 5.5	− 7.3	
	CS_2...........	2.7	9.3	15.2	23.7		

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(For a key to the periodicals see end of volume)

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(10) Harkins, Brown and Davies, *1*, **39**: 354; 17. (11) Harkins and Cheng, *1*, **43**: 35; 21. (12) Harkins, Clark and Roberts, *1*, **42**: 700; 20. (13) Harkins, Davies and Clark, *1*, **39**: 541; 17. (14) Harkins and Ewing, *1*, **41**: 1977; 19. (15) Harkins and Ewing, *1*, **42**: 2539; 20. (16) Harkins and Feldman, *1*, **44**: 2665; 22. (16.5) Harkins and Ginsberg, *O.* (17) Harkins and Grafton, *1*, **42**: 2534; 20. (17.5) Harkins and King, *1*, **41**: 970; 19. (18) Harkins and McLaughlin, *1*, **47**: 1610; 25. (19) Harkins and Mulliken, *O.*

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SURFACE TENSION OF METALS

W. ROSENHAIN, SPECIAL EDITOR

C. BENEDICKS (CB), L. L. BIRCUMSHAW (LLB) C. H. DESCH (CHD), O. F. HUDSON (OFH) AND T. K. ROSE (TKR)

Metal	Gas	t, °C	γ	a^2	Method (*v.* p. 433)	Cooperating experts	Lit.
Ag‡	Air	970	80$_0$	0.172	I, II, VII	TKR	(3, 11, 18)
Au	Air	1070	580–1000		I, II, VII	TKR	(6, 11, 18)
Bi	H_2	320–472	$\gamma = 378 - 0.063(t - 269)$ $a^2 = 0.0765 - 0.0_533(t - 269)$		VIII	OFH	(7)
Bi	H_2	583	354		III		(17)
	H_2	300	388		III	LLB	(24)
		300–962	$\Delta\gamma/\Delta t = -0.073$		III	LLB	
	CO	700–800	346		I		(11)
Cd	H_2	421–544	$\gamma = 630 - 0.065(t - 320)$ $a^2 = 0.160_4 + 0.0_555(t - 320)$		VIII		(7)

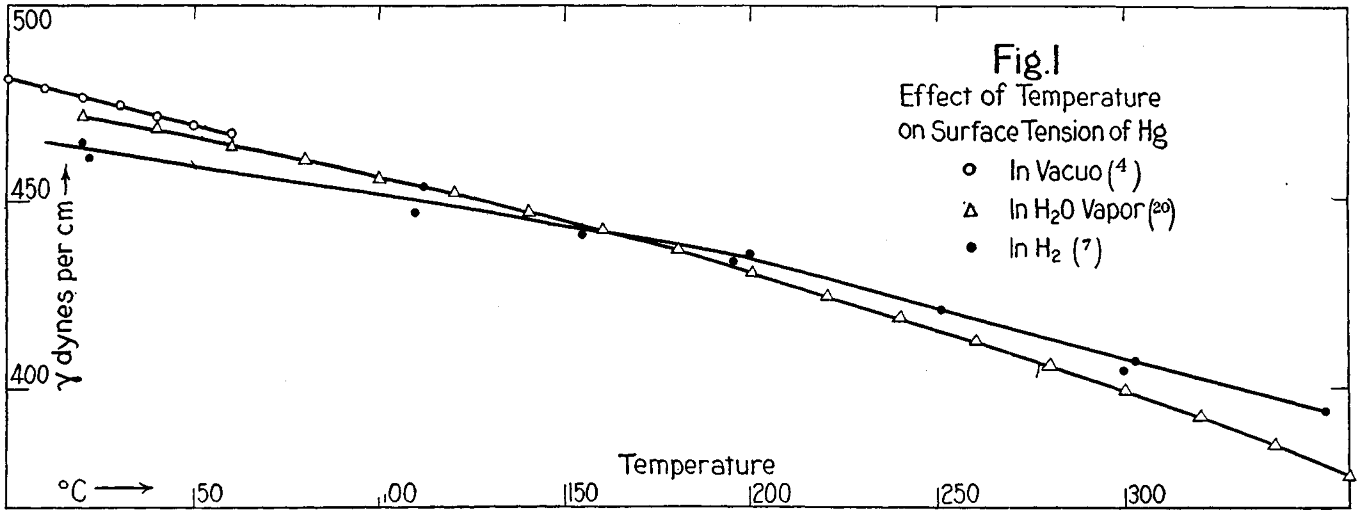

Fig. 1
Effect of Temperature on Surface Tension of Hg

Metal	Gas	t, °C	γ	a^2	Method (v. p. 433)	Cooperating experts	Lit.
Cu†	Vac.	MP–1400		0.304 ± 2 %	I		(8)
	H_2	1131	1103		III	LLB	(17)
		1131–1215	$d\gamma/dt = 0.74$		III	LLB	
Ga	CO_2	30	358	0.120	VI	CHD	(16)
Hg*	Vac.	0	47_0	0.070_5	II	TKR	(2, 4)
	Vac.	0	480.3	0.0721	II		(4)
	Vac.	60	467.1	0.0709	II		(4)
	Vac.	v. *also* Fig. 1					
	Air	15	48_7	0.073_2	II, V, VII		(5, 9, 10, 19)
	Air	For effect of time, v. Fig. 2					
	H_2	20	46_6	0.070_2	III, VII		(7, 19)
	H_2	19	470		III	LLB	(24)
	H_2	For effect of temperature, v. Fig. 1					
	N_2	15	49_6	0.074_6	V, VII		(9, 19)
	O_2	15	48_7	0.073_2	V, VII		(9, 19)
	O_2	For effect of time, v. Fig. 2					
	H_2O	v. Fig. 1					
	SO_2	15	43_7 (Initial) 36_5 (10 min) 33_7 (24 hr)		VII		(9, 16, 19)
	NH_3	15	45_0 (Initial) 42_1 (10 min) 41_6 (1 hr) 38_9 (24 hr)		VII		(9, 16, 19)
	CO_2	15	46_5		V, VII		
K	CO_2	62	411		II	CHD	(12)
Na	CO_2	90	294		II	CHD	(12)
	Vac.	100	222		VII	Ed.	(22)
	Vac.	250	211		VII	Ed.	(22)
Pb†	H_2	366–522	$\left\{\begin{array}{c}\gamma = 444 - \\ 0.077(t - 327) \\ a^2 = 0.0846 - \\ 0.0_537(t - 327)\end{array}\right\}$		VIII	OFH	(7)
	H_2	350	453		III	LLB	(24)
	H_2	350–982	$\Delta\gamma/\Delta t = -0.062$		III	LLB	(24)
	H_2	750	423		III	LLB	(17)
	H_2	750–1036	$d\gamma/dt = -0.096$		III	LLB	(17)
	CO	770–780	425		I		(18)
Pt	Air	2000	181_9		II	TKR	(11)
Sb†	H_2	640	350		III	LLB	(24)
	H_2	640–970	$\Delta\gamma/\Delta t = -0.025$		III	LLB	(24)
	H_2	750	368		III	LLB	(17)
	H_2	750–1100	$d\gamma/dt = -0.063$		III	LLB	(17)
	CO	840–850	274		I	OFH	(18)
Sn†	H_2	319–396	$\left\{\begin{array}{c}\gamma = 531 - \\ 0.080(t - 232) \\ a^2 = 0.154_5 - \\ 0.0_571(t - 232)\end{array}\right\}$		VIII	OFH	(7)
	H_2	253	526		III	LLB	(24)
	H_2	253–964	$\Delta\gamma/\Delta t = -0.018$		III	LLB	(24)
	H_2	878	508		III	LLB	(17)
	H_2	878–1050	$d\gamma/dt = -0.089$		III	LLB	(17)

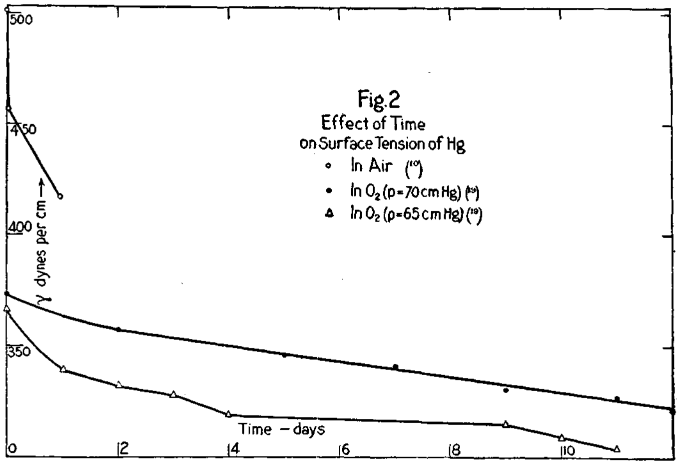

Fig. 2
Effect of Time on Surface Tension of Hg

Metal	Gas	t, °C	γ	a^2	Method (v. p. 433)	Cooperating experts	Lit.
Sn†	CO	750–910	480		I		(18)
Zn	H_2	477	753 ± 10	0.235_4	VIII	CB	(7)
		543	747 ± 10	0.235_6			
	Air	590	708 ± 40	0.22_4	I		(18)

* For a discussion of the discordant data on Hg, v. (21).

† For recent data on Sn, Pb, Sb and Cu, by Method (III), v. (25).

‡ Recent values of a^2, as given for Ag by (26) (I) in vacuum:

t, °C	a^2	t, °C	a^2
1000	0.201	1214	1.184
1060	0.193	1272	0.180
1122	0.187	1327	0.178

Alloys

Pb-Sn (23). Bi-Sn, Bi-Pb, Cu-Sn, Cu-Sb (17, 25). Cast iron (25)

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(For a key to the periodicals see end of volume)

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SURFACE TENSION AND RELATED PROPERTIES FOR TEMPERATURES BELOW 0°C*

J. E. Verschaffelt

Unless otherwise stated, $g = 980$ and the liquid is in contact with its own vapor. For abbreviations and equations, *v.* p. 433, 434.

A-Table.—Elementary Substances and Atmospheric Air

A, Argon (1) (I). $A_K = 292$; $\alpha = 39$; $n = 1.31$; $k_E = 2.0$

T, °K	a^2	$\gamma \pm 1\%$	γ_M
85.0	0.0190	13.2	122
90.0	0.0177	11.9	112

Cl_2, Chlorine†‡ (8) (I). $A_C = 263$; $\alpha = 69$; $k_E = 2.1$; $n = 1.13$

t, °C	a^2	$\gamma \pm 1\%$	γ_M
−30	0.0336	25.4	327
−35	.0345	26.4	337
−40	.0355	27.3	347
−45	.0364	28.3	358
−50	.0373	29.2	368
−55	.0383	30.2	379
−60	.0392	31.2	389

H_2, Hydrogen (9) (I, $g = 981.2$). $\alpha = 5.52$; $A_K = 45.53$; $k_E = 1.36$; $n = 1.11$

T, °K ± 0.02°	a^2	$\gamma \pm 0.1\%$	γ_M
20.40	0.05612	1.912	17.83
18.70	.06238	2.197	20.14
17.99	.06500	2.318	21.11
16.16	.07186	2.633	23.60
14.68	.07700	2.882	25.53

He, Helium (13) (I). $A_K = 5.2$; $k_E = 1.0$ (from 4.2 to 2.4°K); $\alpha = 0.63$; $n = 1.13$ (from 4.2 to 3.0°K)

T, °K ± 0.02°	a^2	$\gamma \pm 1\%$	γ_M
4.20	0.00181	0.098	0.98
4.00	.00211	.120	1.19
3.50	.00280	.177	1.68
3.00	.00350	.239	2.19
2.50	.00419	.296	2.69
2.00	.00477	.339	3.08
1.50	.00496	.353	3.22

N_2, Nitrogen† (1) (I). $A_K = 249$; $\alpha = 27.5$; $k_E = 2.00$; $n = 1.215$

T, °K	a^2	$\gamma \pm 1\%$	γ_M
70.0	0.0255	10.53	108.7
75.0	.0234	9.39	98.7
80.0	.0213	8.27	88.7
85.0	.0192	7.20	78.7
90.0	.0171	6.16	68.7

Ne, Neon (14) (I). $A_K = 85.5$; $k_E = 2.0$; $\alpha = 14.7$; $n = 1.20$

24	0.0095	5.90	37.5
25	.0091	5.50	35.5
26	.0086	5.15	33.5
27	.0082	4.80	31.5
28	.0077	4.45	29.5

O_2, Oxygen† (1) (I). $A_K = 295$; $\alpha = 37.7$; $k_E = 1.92$; $n = 1.205$

70.0	0.0302	18.3	160
75.0	.0286	17.0	151
80.0	.0269	15.7	141
85.0	.0253	14.5	132
90.0	.0237	13.2	122

Liquid Air, 65% O_2 (in contact with the atmosphere)† (12) (III)

t, °C	a^2	$\gamma \pm 1\%$
−190.5 (B. P.)	0.0243	12.2

B-Table.—Chemical Compounds, Standard Arrangement

NOCl, Nitrosyl chloride (2) (I). $A_C = 392$; $\alpha = 68$; $k_E = 1.46$; $n = 0.86$

t, °C ± 0.1°	a^2	$\gamma \pm 1\%$	γ_M
−33.0	0.049	34.5	441
−22.0	.047	33	424
− 5.5	.046	30	400

CO, Carbon monoxide (1) (I). $A_K = 265$; $\alpha = 30.0$; $k_E = 2.00$; $n = 1.225$

T, °K	a^2	$\gamma \pm 1\%$	γ_M
70.0	0.0292	12.11	124.7
75.0	.0271	10.96	114.7
80.0	.0249	9.83	104.7
85.0	.0228	8.74	94.7

CO_2, *v.* p. 447.

C_2H_2, Acetylene (11) (I). $A_C = 35$; $\alpha = 82$; $k_E = 2.40$; $n = 1.51$

t, °C	a^2	$\gamma \pm 1\%$	γ_M
−77.4	0.0604	18.0	220
−75.7	.0599	17.7	218
−70.5	.0566	16.4	204
−69.0	.0557	16.0	200
−67.0	.0548	15.6	196
−64.0	.0531	15.0	190
−62.4	.0517	14.4	184

$(CH_3)_2O$, Methyl ether (10) (I). $A_C = 244$; $\alpha = 63$; $k_E = 2.00$; $n = 1.27$

−40.0	0.0565	21.0	324
−30.0	.0535	19.4	304
−20.0	.0505	17.9	284
−10.0	.0475	16.4	264

$(CH_2)_2O$, Ethylene oxide (10) (I). $A_C = 370$; $\alpha = 74$; $k_E = 1.80$; $n = 1.13$

−50.0	0.0760	35.8	460
−40.0	.0732	34.2	442
−30.0	.0704	32.5	424
−20.0	.0676	30.8	406
−10.0	.0648	29.2	388
0.0	.0620	27.6	370
+10.0	.0592	25.9	352
20.0	.0564	24.3	334

CH_3NH_2, Methylamine (7) (III). $A_C = 267$; $k_E = 1.2$
Nitrogen atmosphere

−70	0.0785	29.2	347
−49	.0749	27.0	327
−20	.0681	23.6	294
−18	.0672	23.1	290
−12	.0649	22.2	280

$(CH_3)_2NH$, Dimethylamine (7) (III). $A_C = 296$; $k_E = 1.10$
Nitrogen atmosphere

−78	0.0680	25.2	384
−50	.0625	22.4	350
−23	.0584	20.2	323
0	.0543	18.1	296
+ 5	.0529	17.5	286

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* Except metals, for which *see* p. 439; and except organic compounds which are liquid at 0° and 1 atm., for which *see* p. 448. † *See also* p. 442. ‡ *See also* p. 447.

$(CH_3)_3N$, Trimethylamine (7) (III). $A_C = 33_3$; $k_E = 1.6_5$
Nitrogen atmosphere

t, °C	a^2	$\gamma \pm 1\%$	γ_M
−73	0.067_6	$24._8$	45_7
−52	$.062_0$	$22._2$	41_7
−32	$.058_8$	$20._2$	38_8
−19	$.055_7$	$18._7$	36_3
− 4	$.052_4$	$17._4$	33_9

$C_2H_5NH_2$, Ethylamine (7) (III). $A_C = 33_9$; $k_E = 1.2_5$
Nitrogen atmosphere

t, °C	a^2	$\gamma \pm 1\%$	γ_M
−74	0.075_1	$28._9$	43_0
−33	$.066_8$	$24._3$	37_6
$-21._5$	$.065_0$	$23._2$	36_3
0	$.061_4$	$21._3$	33_9
$+9._9$	$.059_4$	$20._3$	32_7

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(For a key to the periodicals see end of volume)

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METHOD IV

Substance	t, °C	a^2	$\gamma \pm 1\%$	γ_M	k_E*	Lit.
Cl_2	− 72	0.041_0	$33._0$	40_7	1.8_9	(4)
N_2	$-196._0$	0.021_9	8.7	93	1.9_0	(7)
O_2	$-182._9$	0.023_5	$13._2$	12_2	1.9_1	(7)
SO_2	− 25	0.044_2	$32._6$	39_7	2.1_8	(4)
N_2O	$-89._3$	0.043_8	$26._3$	28_6	2.2_8	(6)
NH_3	− 29	0.12_5	$41._2$	35_6	2.2_1	(4)
Air	$-190._3$	0.023_5	Approx. independent of composition †			(5)
Pictet's liquid	− 33	0.047	35	Composition		(4)
	− 60	0.049	38	1 mole CO_2 + 1 mole SO_2		

* Assuming γ_M to vary linearly with T up to T_c.

† γ at the B. P. for liquid air of any composition may be calculated by substituting values of d_l and d_v in equation (2), p. 434.

SURFACE TENSIONS OF FUSED SALTS ABOVE 200°C AND LIQUIDS ABOVE 360°C*

Allan Ferguson

𝔅-Table.—Chemical Compounds, Standard Arrangement

For abbreviations and symbols, *v.* p. 433

S: In air (4) (I)

t, °C	d_4^t	γ	γ_M
445.0	1.605	38.97	456

$BiCl_3$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
271	3.811	66.2	1254
304	3.735	61.8	1187
331	3.682	58.1	1127
353	3.621	55.3	1084
382	3.554	52.0	1032

$BiBr_3$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
250	4.598	66.5	1408
281	4.525	63.6	1361
299	4.471	61.6	1328
320	4.416	59.5	1294
346	4.348	56.7	1246
370	4.286	53.8	1191
389	4.237	52.0	1162
417	4.164	48.9	1106
442	4.099	46.2	1056

$SnCl_2$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
307	3.289	97.0	1449
328	3.263	96.2	1445
361	3.222	93.9	1422
377	3.202	92.0	1402
405	3.166	89.0	1364
430	3.135	86.4	1333
452	3.108	83.9	1302
480	3.072	81.6	1277

$PbCl_2$: In air (5) (I)

t, °C	γ	t, °C	γ
490	138	541	130
500	137	552	129
518	135	571	128
526	134	590	127
539	131	614	126

$TlNO_3$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
210	4.899	117.3	1682
245	4.838	115.2	1666
264	4.806	113.8	1653
285	4.768	112.0	1635
312	4.721	109.8	1614
339	4.674	107.4	1589
364	4.630	105.2	1566
389	4.586	102.8	1540
430	4.515	99.5	1507

AgCl: In air (7) (I)

t, °C	γ	t, °C	γ
452	125.5	517	119.6
468	124.3	532	116.3
472	123.6	558	114.3
488	122.4	568	113.4
494	121.6	573	112.8

AgBr: In air (2)

t, °C	d_4^t	γ	γ_M
M. P.		121.4	

$CaCl_2$: In air (8) (II)

t, °C	d_4^t	γ	γ_M
M. P.		152	

$BaCl_2$: In air (8) (II)

t, °C	d_4^t	γ	γ_M
M. P.		171	

LiF: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
868.5	1.789	249.5	1485
897.6	1.775	248.0	1484
944	1.753	242.3	1462
985	1.734	238.3	1449
1029	1.713	233.5	1431
1065	1.696	229.8	1418
1117	1.672	222.7	1387
1156	1.653	217.4	1364
1208	1.629	210.6	1335
1270	1.599	201.1	1290

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* Except metals, for which *see* p. 439; organic subtances, *see* p. 448; industrial materials, *see* Vol. II; and fused salts melting below 200°C, *see* p. 447.

LiCl: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
614	1.496	137.8	1282
640	1.483	135.4	1267
680	1.466	132.9	1263
735	1.443	128.8	1256
776	1.425	125.8	1237
814	1.409	123.2	1193
860	1.389	119.9	1172
915	1.365	116.1	1148
968	1.342	112.6	1126
1022	1.319	108.5	1098
1075	1.296	104.8	1073
Li_2SO_4: In N_2 (3) (III)			
860	2.004	223.8	3231
874	1.999	223.1	3227
897	1.989	221.8	3219
923	1.978	220.2	3207
963	1.962	217.4	3183
977	1.956	216.4	3175
1001	1.947	214.8	3161
1039	1.932	212.3	3141
1057	1.924	211.0	3130
1074	1.917	209.8	3120
1090	1.911	208.8	3111
1112	1.901	207.3	3100
1157	1.884	204.2	3072
1168	1.879	203.4	3066
1184	1.873	202.4	3057
1192	1.869	201.8	3052
1214	1.860	200.3	3039
$LiNO_3$: In N_2 (3) (III)			
359	1.723	111.5	1305
403	1.699	109.1	1288
418	1.690	108.4	1285
445	1.676	106.0	1264
493	1.650	102.3	1232
555	1.616	99.0	1209
609	1.586	96.2	1189
Li_2SiO_3: In N_2 (3) (III)			
t, °C	γ	t, °C	γ
1254	374.6	1479	352.8
1380	358.2	1550	348.7
1421	356.2	1601	346.6
$LiBO_2$: In N_2 (3) (III)			
879	261.8	1198	239.7
922	259.7	1249	234.2
968	256.2	1309	225.8
1012	253.1	1355	220.7
1055	250.3	1408	212.7
1097	247.7	1457	203.1
1150	243.6	1520	192.4
NaF: In N_2 (3) (III)			
t, °C	d_4^t	γ	γ_M
1010	1.936	199.5	1552
1053	1.912	195.5	1533
1097	1.887	191.2	1513
1147	1.859	185.8	1485
1189	1.835	180.5	1455
1234	1.810	176.4	1435
1263	1.794	173.1	1417
1313	1.766	167.5	1385
1357	1.741	162.9	1360

NaF.—*(Continued)*

t, °C	d_4^t	γ	γ_M
1405	1.714	157.8	1331
1456	1.685	152.5	1301
1497	1.662	148.7	1281
1546	1.634	143.5	1250
NaCl: In N_2 (3) (III)			
803	1.547	113.8	1282
811	1.542	113.5	1281
821	1.536	112.9	1278
832	1.529	111.9	1270
859	1.512	109.9	1257
883	1.497	108.2	1245
908	1.482	106.4	1233
931	1.467	104.5	1219
961	1.449	102.7	1208
996	1.427	99.7	1185
1037	1.401	97.0	1167
1080	1.374	94.0	1146
1122	1.347	91.3	1128
1172	1.316	88.0	1104
M. P.		113.3*	
NaBr: In N_2 (3) (III)			
761	2.320	105.8	1326
810	2.284	102.9	1303
852	2.250	99.6	1274
897	2.211	96.2	1245
942	2.169	92.9	1218
985	2.125	90.0	1196
1029	2.078	86.2	1163
1074	2.026	84.0	1152
1116	1.974	81.1	1131
1166	1.912	78.0	1112
M. P.		102.8*	
NaI: In N_2 (3) (III)			
706	2.692	85.6	1248
746	2.649	83.9	1237
816	2.575	80.5	1209
861	2.527	77.6	1180
M. P.		93.9*	
Na_2SO_4: In N_2 (3) (III)			
900	2.061	194.8	3275
945	2.039	189.3	3205
990	2.017	188.2	3210
1032	1.997	186.5	3202
1077	1.971	184.7	3199
$NaNO_3$: In N_2 (3) (III)			
322	1.900	119.7	1509
355	1.877	118.1	1501
397	1.850	115.9	1487
427	1.829	114.2	1476
466	1.803	111.8	1459
513	1.771	108.9	1438
559	1.740	105.9	1415
602	1.711	103.4	1397
656	1.675	99.4	1364
693	1.650	96.8	1340
738	1.620	93.7	1313
329	1.895	110.8	In air (1)
405	1.846	106.5	

* In air (8) (II).

$NaPO_3$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
827	2.181	197.5	2565
871	2.162	194.8	2544
927	2.137	191.6	2522
1014	2.099	186.7	2487
1099	2.062	181.6	2448
1181	2.025	176.6	2409
1265	1.989	170.9	2358
1317	1.966	166.7	2318
1434	1.914	156.2	2213
1517	1.878	147.5	2116

CH_3CO_2Na: In air (8) (II)

M. P.		38.8	

Na_2MoO_4: In N_2 (3) (III)

699	2.796	214.0	3761
729	2.777	210.0	3707
751	2.763	208.1	3686
777	2.747	204.9	3644
819	2.720	202.4	3623
859	2.695	199.0	3584
904	2.667	195.4	3544
948	2.639	191.4	3496
990	2.613	187.7	3451
1035	2.584	184.1	3410
1079	2.557	181.2	3380
1122	2.530	178.8	3359
1172	2.499	176.1	3335
1212	2.473	174.6	3330

Na_2WO_4: In N_2 (3) (III)

710	3.893	203.3	3632
741	3.860	201.0	3612
788	3.812	198.2	3591
834	3.765	195.2	3566
879	3.721	191.5	3526
932	3.671	189.5	3521
985	3.623	184.2	3452
1039	3.576	181.4	3430
1081	3.541	178.3	3393
1133	3.499	174.6	3350
1181	3.461	172.4	3332
1232	3.424	168.0	3270
1282	3.390	163.8	3209
1332	3.355	160.6	3168
1391	3.318	155.0	3080
1450	3.282	152.0	3043
1517	3.245	147.3	2971
1559	3.224	144.0	2917
1595	3.208	142.6	2899

$NaBO_2$: In N_2 (3) (III)

t, °C	γ	t, °C	γ
1016	193.7	1234	159.7
1052	188.3	1277	150.8
1097	180.9	1323	142.9
1140	174.7	1372	135.1
1192	166.1	1441	126.2

KF: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
913	1.869	138.4	1368
962	1.837	135.2	1352
1015	1.801	131.0	1328
1062	1.770	127.4	1306
1097	1.749	124.5	1287
1147	1.713	119.9	1256
1185	1.689	116.1	1228
1234	1.654	112.3	1205
1275	1.627	108.6	1178
1310	1.604	104.9	1148

KCl: In N_2 (3) (III)

800	1.509	95.8	1290
827	1.492	94.0	1275
862	1.470	91.3	1251
885	1.456	89.7	1237
909	1.442	88.0	1221
941	1.421	85.8	1203
986	1.396	82.2	1166
1029	1.370	79.1	1136
1054	1.355	77.2	1117
1088	1.335	75.2	1099
1104	1.326	73.7	1082
1125	1.313	72.5	1070
1167	1.287	69.6	1042
M. P.		98.4*	

KBr: In N_2 (3) (III)

775	2.086	85.7	1270
798	2.068	83.8	1249
826	2.045	82.0	1231
859	2.019	79.5	1204
887	1.997	77.8	1187
920	1.970	75.4	1161
M. P.		91.0*	

KI: In N_2 (3) (III)

737	2.392	75.2	1270
764	2.364	72.1	1227
812	2.314	69.2	1195
866	2.257	66.8	1173
873	2.250	66.5	1170
M. P.		83.5*	

K_2SO_4: In N_2 (3) (III)

1070	1.888	143.7	2935
1103	1.870	142.6	2931
1145	1.848	140.6	2913
1199	1.818	136.7	2863
1247	1.792	132.7	2806
1306	1.760	128.8	2757
1347	1.737	126.2	2725
1372	1.724	124.6	2704
1400	1.709	122.4	2672
1440	1.687	119.8	2637
1463	1.674	118.1	2613
1490	1.660	116.1	2584
1530	1.637	114.1	2563
1586	1.607	110.7	2517
1656	1.569	106.8	2468

KNO_3: In N_2 (3) (III)

380	1.837	110.4	1597
436	1.794	106.0	1558
480	1.760	102.8	1531
534	1.719	98.5	1489
578	1.685	95.2	1459
628	1.647	91.6	1426
675	1.611	87.9	1389
722	1.575	84.0	1349
772	1.537	80.2	1307
349	1.869	106.4	In air (1) (I)
414	1.764	100.7	

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* In air (8) (II).

KPO_3: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
897	2.069	155.5	2304
942	2.049	151.8	2264
996	2.027	149.0	2238
1036	2.010	146.1	2207
1082	1.983	143.0	2180
1120	1.973	140.3	2146
1167	1.953	136.8	2106
1205	1.938	133.5	2066
1250	1.918	130.2	2029
1288	1.901	126.3	1980
1345	1.877	122.5	1937
1372	1.865	118.5	1882
1413	1.848	114.7	1832
1497	1.812	105.5	1708
1536	1.795	100.3	1634

KCN: In air (8) (II)

M. P.		96.1	

$PbCl_2.KCl$: In air (6) (I)

t, °C	γ	t, °C	γ
471	105	555	97.9
502	103	582	95.1
522	102	592	94.7
529	101	602	94.4
538	100	616	94.4
547	99.2		

$PbCl_2.KCl$: In liquid Pb (6) (I)

t, °C	γ	t, °C	γ
453	230	531	216
467	228	542	214
494	223	546	212
509	219	599	199
526	220		

$K_2Cr_2O_7$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
420	2.271	140.1	
454	2.248	139.4	3593
480	2.229	138.4	3588
504	2.213	137.0	3568
535	2.191	135.0	3540

K_2MoO_4: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
931	2.362	150.5	3261
977	2.334	147.3	3217
1021	2.307	145.2	3196
1105	2.255	140.7	3144
1143	2.230	138.6	3120
1189	2.200	135.5	3078
1273	2.144	130.0	3004
1356	2.087	123.6	2908
1438	2.029	118.0	2829
1453	2.018	116.9	2813
1522	1.959	112.5	2761

K_2WO_4: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
925	3.175	161.0	3531
969	3.139	154.1	3406
1013	3.103	150.2	3346
1052	3.071	145.9	3275
1097	3.035	141.9	3207
1139	3.002	138.0	3143
1183	2.968	134.1	3076
1230	2.933	130.3	3013
1284	2.893	124.6	2908
1322	2.866	120.9	2839
1367	2.834	118.4	2802
1409	2.805	114.3	2723
1458	2.771	110.0	2642
1489	2.751	107.9	2605
1520	2.730	105.6	2560

KBO_2: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
992		123.5	
1036		112.3	
1091		103.0	
1142		96.6	

RbF: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
803	2.894	127.2	1389
847	2.851	121.3	1338
887	2.812	116.7	1299
936	2.763	113.0	1273
986	2.711	108.9	1242
1037	2.657	105.2	1216
1085	2.605	102.2	1197

RbCl: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
750	2.088	95.7	1433
770	2.072	94.2	1417
828	2.024	89.0	1360
880	1.981	84.5	1310
923	1.946	81.1	1272
933	1.937	79.9	1257
962	1.914	77.3	1226
994	1.887	74.7	1196
1037	1.852	71.3	1156
1089	1.809	66.7	1099
1150	1.759	61.4	1035

RbBr: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
729	2.656	87.7	1378
779	2.601	84.1	1340
831	2.542	80.7	1305
884	2.486	77.2	1267
944	2.421	73.1	1222
986	2.375	70.2	1188
1041	2.318	66.7	1147
1121	2.226	60.6	1071

RbI: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
673	2.827	79.4	1414
722	2.774	75.8	1367
772	2.719	72.2	1319
822	2.663	68.5	1269
869	2.611	65.1	1222
918	2.557	61.6	1173
968	2.501	58.3	1126
1016	2.448	55.4	1086

Rb_2SO_4: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
1086	2.538	132.5	2953
1112	2.521	129.7	2903
1145	2.499	127.3	2866
1195	2.466	124.2	2821
1235	2.440	121.8	2786
1289	2.403	118.9	2748
1344	2.367	116.0	2708
1397	2.331	113.8	2684
1415	2.319	113.1	2676
1482	2.275	110.9	2658
1545	2.233	108.9	2643

$RbNO_3$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
327	2.467	107.5	1643
376	2.419	104.0	1611
428	2.368	99.8	1568
480	2.318	96.1	1531
527	2.272	92.5	1494
578	2.222	88.9	1457
625	2.177	85.6	1422
676	2.127	81.4	1373
726	2.078	77.7	1332

CsF: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
723	3.583	104.5	1270
769	3.526	101.0	1241
826	3.456	96.4	1200
877	3.392	92.3	1164
930	3.327	88.1	1125
985	3.259	84.3	1091
1042	3.189	81.3	1068
1100	3.117	78.9	1052

CsCl: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
664	2.772	89.2	1378
717	2.714	85.9	1346
771	2.655	81.9	1302
830	2.592	77.7	1255
881	2.537	73.7	1208
934	2.479	69.7	1160
979	2.421	66.4	1123
1035	2.370	61.6	1056
1080	2.332	56.3	976

CsBr: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
658	3.116	81.8	1366
694	3.066	78.9	1333
753	2.990	74.9	1286
808	2.915	71.6	1250
858	2.846	68.5	1216
916	2.769	65.5	1184
971	2.695	62.7	1154

CsI: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
654	3.158	73.1	1383
713	3.086	68.8	1321
768	3.018	65.7	1281
821	2.953	62.5	1236
879	2.883	59.2	1187
926	2.826	56.6	1153
980	2.760	53.8	1113
1030	2.699	51.1	1073

Cs_2SO_4: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
1036	3.037	111.3	2694
1063	3.018	108.2	2630
1105	2.988	105.0	2570
1165	2.937	100.8	2495
1221	2.889	97.3	2435
1275	2.841	94.7	2397
1331	2.787	91.7	2351
1372	2.743	89.8	2326
1423	2.690	87.4	2294
1470	2.636	85.5	2275
1530	2.566	83.0	2248

$CsNO_3$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
426	2.796	91.8	1554
460	2.758	88.2	1507
511	2.700	83.7	1451
577	2.627	79.2	1398
602	2.599	76.3	1356
686	2.505	72.5	1321

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bottomley, *4*, **83**: 1421; 03. (2) Gradenwitz, *8*, **67**: 467; 99. (3) Jaeger, *93*, **101**: 1; 17. (4) Kellas, *4*, **113**: 903; 18. (5) Lorenz and Kaufler, *25*, **41**: 3727; 08. (6) Lorenz and Liebmann, *7*, **83**: 459; 13. (7) Lorenz, Liebmann and Höchberg, *93*, **94**: 301; 16. (8) Motylewski, *93*, **38**: 410; 04.

SURFACE-TENSION DATA FOR CERTAIN PURE LIQUIDS BETWEEN 0 AND 360°C AND FOR ALL TYPES OF SOLUTIONS AT ALL TEMPERATURES

T. FRASER YOUNG AND WILLIAM D. HARKINS*

LIQUID—GAS INTERFACE

For abbreviations and symbols, *v.* p. 433

The greater part of the surface-tension values listed in the following tables have been corrected, in so far as possible, to agree with certain "standard" values for water and for benzene (C_6H_6) as determined by the capillary-height method. As the primary standard, the value of γ for water is taken as equal to 72.75 ± 0.05 dyne/cm at 20° in the presence of air at ordinary pressure. The values used in selecting this standard are those of Richards and Coombs, 1915, corrected 1921 (64) 72.72; Harkins and Brown, 1919 (40) 72.80; Richards and Carver, 1921 (63) 72.73; and Young and Gross (for these tables) 72.80. So far as is known all of these values have been determined with about the same degree of precision, and also with the same order of accuracy with respect to known errors.

The "standard" value for benzene in air at 20° is 28.88 ± 0.03, and is based on the work of Richards and Coombs (64), Richards and Carver (63) and Harkins and Brown (40).

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$RbNO_3$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
327	2.467	107.5	1643
376	2.419	104.0	1611
428	2.368	99.8	1568
480	2.318	96.1	1531
527	2.272	92.5	1494
578	2.222	88.9	1457
625	2.177	85.6	1422
676	2.127	81.4	1373
726	2.078	77.7	1332

CsF: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
723	3.583	104.5	1270
769	3.526	101.0	1241
826	3.456	96.4	1200
877	3.392	92.3	1164
930	3.327	88.1	1125
985	3.259	84.3	1091
1042	3.189	81.3	1068
1100	3.117	78.9	1052

CsCl: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
664	2.772	89.2	1378
717	2.714	85.9	1346
771	2.655	81.9	1302
830	2.592	77.7	1255
881	2.537	73.7	1208
934	2.479	69.7	1160
979	2.421	66.4	1123
1035	2.370	61.6	1056
1080	2.332	56.3	976

CsBr: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
658	3.116	81.8	1366
694	3.066	78.9	1333
753	2.990	74.9	1286
808	2.915	71.6	1250
858	2.846	68.5	1216
916	2.769	65.5	1184
971	2.695	62.7	1154

CsI: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
654	3.158	73.1	1383
713	3.086	68.8	1321
768	3.018	65.7	1281
821	2.953	62.5	1236
879	2.883	59.2	1187
926	2.826	56.6	1153
980	2.760	53.8	1113
1030	2.699	51.1	1073

Cs_2SO_4: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
1036	3.037	111.3	2694
1063	3.018	108.2	2630
1105	2.988	105.0	2570
1165	2.937	100.8	2495
1221	2.889	97.3	2435
1275	2.841	94.7	2397
1331	2.787	91.7	2351
1372	2.743	89.8	2326
1423	2.690	87.4	2294
1470	2.636	85.5	2275
1530	2.566	83.0	2248

$CsNO_3$: In N_2 (3) (III)

t, °C	d_4^t	γ	γ_M
426	2.796	91.8	1554
460	2.758	88.2	1507
511	2.700	83.7	1451
577	2.627	79.2	1398
602	2.599	76.3	1356
686	2.505	72.5	1321

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bottomley, *4*, **83**: 1421; 03. (2) Gradenwitz, *8*, **67**: 467; 99. (3) Jaeger, *93*, **101**: 1; 17. (4) Kellas, *4*, **113**: 903; 18. (5) Lorenz and Kaufler, *25*, **41**: 3727; 08. (6) Lorenz and Liebmann, *7*, **83**: 459; 13. (7) Lorenz, Liebmann and Höchberg, *93*, **94**: 301; 16. (8) Motylewski, *93*, **38**: 410; 04.

SURFACE-TENSION DATA FOR CERTAIN PURE LIQUIDS BETWEEN 0 AND 360°C AND FOR ALL TYPES OF SOLUTIONS AT ALL TEMPERATURES

T. Fraser Young and William D. Harkins*

LIQUID—GAS INTERFACE

For abbreviations and symbols, *v.* p. 433

The greater part of the surface-tension values listed in the following tables have been corrected, in so far as possible, to agree with certain "standard" values for water and for benzene (C_6H_6) as determined by the capillary-height method. As the primary standard, the value of γ for water is taken as equal to 72.75 ± 0.05 dyne/cm at 20° in the presence of air at ordinary pressure. The values used in selecting this standard are those of Richards and Coombs, 1915, corrected 1921 (64) 72.72; Harkins and Brown, 1919 (40) 72.80; Richards and Carver, 1921 (63) 72.73; and Young and Gross (for these tables) 72.80. So far as is known all of these values have been determined with about the same degree of precision, and also with the same order of accuracy with respect to known errors.

The "standard" value for benzene in air at 20° is 28.88 ± 0.03, and is based on the work of Richards and Coombs (64), Richards and Carver (63) and Harkins and Brown (40).

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* Assisted by P. L. K. Gross, Ben. H. Nicolet, Leslie Hellerman, B. R. Mortimer, David M. Gans, L. H. Chêng, O. G. Vogel, A. W. Meyer, W. E. Vaughan, B. Ginsberg, E. H. Robinson, and C. M. Marberg.

𝔄-𝔅 Table

H_2O (I, II, III, IX) (19, 45, 61, 63, 64, 66, 75, 77, 78, 97, 98, 99, 100, 101)

t, °C	γ (air)	a^2 (air)
−8	76.96 ± 0.3	0.1574
−5	76.42 ± 0.2	.1562
0	75.64 ± 0.1	.15448
+5	74.92 ± 0.1	.15299
10	74.22 ± 0.05	.15160
11	74.07 ± 0.05	.15131
12	73.93 ± 0.05	.15103
13	73.78 ± 0.05	.15075
14	73.64 ± 0.05	.15048
15	73.49 ± 0.05	.15019
16	73.34 ± 0.05	.14991
17	73.19 ± 0.05	.14963
18	73.05 ± 0.05	.14937
19	72.90 ± 0.05	.14909
20	72.75 ± 0.05	.14881
21	72.59 ± 0.05	.14852
22	72.44 ± 0.05	.14824
23	72.28 ± 0.05	.14795
24	72.13 ± 0.05	.14768
25	71.97 ± 0.05	.14738
26	71.82 ± 0.05	.14711
27	71.66 ± 0.05	.14683
28	71.50 ± 0.05	.14654
29	71.35 ± 0.05	.14627
30	71.18 ± 0.05	.14597
35	70.38 ± 0.05	.14456
40	69.56 ± 0.05	.14313
45	68.74 ± 0.05	.14173
50	67.91 ± 0.05	.14032
55	67.05 ± 0.05	.13887
60	66.18 ± 0.05	.13741
70	64.42 ± 0.1	.13449
80	62.61 ± 0.1	.1315
90	60.75 ± 0.2	.1284
100	58.85 ± 0.2	.1253
	γ (vapor)	
110	56.89 ± 0.2	k_E
120	54.89 ± 0.2	1.27
130	52.84 ± 0.3	
25		1.03
70		1.07
100		1.18

H_2O_2 (I) (33)

t, °C	γ (air) ± *ca.* 0.5
0.2	78.9
6.2	77.9
11.0	77.7
13.9	76.6
18.2	76.1

Br_2 (I, II) k_E = 2.0 (22, 40, 57, 73)

t, °C	γ (air or vapor) ±0.7
0	45.0
20	41.5
50	36.2

Cl_2 (I) (35); *v. also* p. 441

t, °C	γ††
0	21.7
10	20.0
20	18.4
30	16.7
40	15.1
50	13.4

$\gamma = 72(1 - T/T_C)^{1.13}$

SO_3 (I) (68); *cf.* (5)

t, °C	γ‡‡
17.5	33.1
35.3	30.3
60.4	25.7
78.3	22.3
100.0	17.8

S_2Cl_2 (I) k_E = 2.2 (61)

t, °C	γ ±1.0
15.5	43.8
46.3	39.3
78.3	35.0

SCl_2O (I, III) (61, 82)

t, °C	γ (air or vapor) ±1.5
20	33.1
50	28.8

SCl_2O_2 (III) (82)

t, °C	γ (air)*
13	35.26
23.5	32.92
47.5	28.40

* The results of (61) are 2 to 5 dyne/cm lower.

$SOBr_2$ (I) (36)

t, °C	γ (?)††
17	45.0
25	44.4

Se (II) (57)

t, °C	γ (air)
217	92.4 ± 20

N_2O (I) (84)

t, °C	γ§
−25	10.10
+10	3.37
15	2.52
20	1.75
25	1.07

$$\gamma = 86\left(1 - \frac{T}{T_C}\right)^{1.33}$$

N_2O_4 (I) k_E = 2.2 (61)

t, °C	γ ±1.0
1.6	30.6
19.8	27.5

NH_3 (I) k_E = 1.3 (4)

t, °C	γ ± 2.0
11.1	23.4
34.1	18.1
59.0	13.0

For notes †-§§ *see* p. 475.

P_2O_3 (I) k_E = 2.3 (71)

t, °C	γ‡‡
34.3	36.6
60.25	33.2
78.95	31.4
109.4	27.8

PCl_3 (I, II) k_E = 2.2 (14, 40, 61, 73)

t, °C	γ (air or vapor) ±0.5
15	29.7
20	29.1
50	25.2
75	22.0

PCl_5 (I) γ (vapor) (95)

$POCl_3$ (I, III) k_E = 2.2 (61, 73, 82)

t, °C	γ ±0.3 (air)	γ ±0.5 (vapor)
10	33.4	33.4
20	32.2	32.2
30	30.9	30.9
50	28.4	28.4
65	26.5	26.5
85	24.1	24.1

PBr_3 (III) (82)

t, °C	γ (air) ±1§§
24	45.8
33	44.1
59.5	38.4
72	37.1

PI_3 (III) (30)

t, °C	γ (N_2) ±2†
75.3	56.5
121.4	53.6
150	51.4

$PSCl_3$ (I) (73)

$a^2 = 4.4496 - 0.01199t$; at 125°C, γ = 21.1

t, °C	a^2 ±2%
9.0	0.04341
61.7	.03710
65.8	.03660
72.0	.03586

$AsCl_3$ (III) (30)

t, °C	γ (N_2) ±2†
−21	43.8
+50.2	36.6
110	31.0

$AsBr_3$ (III) (30)

t, °C	γ (N_2) ±2†
49.6	49.6
121	41.0
179.7	36.1

$SbCl_3$ (III) (95)

t, °C	γ (air) +1.0§§
109.5	44.51
127.5	41.84
148.5	39.43
166.5	37.38

$SbCl_5$ (III) γ (air) (95)

CO_2 (I) (84, 85)

t, °C	γ§
−25	9.13
0	4.49
+10	2.73
15	1.90
20	1.16
25	0.52
30	0.06

$$\gamma = 75\left(1 - \frac{T}{T_C}\right)^{1.25}$$

CCl_4 (I, II) (18, 19, 21, 23, 51, 58, 60, 63, 89)

t, °C	γ (air)	γ (vapor)
10	28.00±0.1	28.22±0.2
20	26.77±0.1	26.95±0.1
30	25.53±0.1	25.70±0.2
50	23.14±0.2	23.22±0.2
75	20.19±0.2	20.20±0.2
100		17.26±0.2
150		11.66±0.2
200		6.53±0.2
250		2.11±0.2
270		0.68±0.2

γ (vapor) $= 67.671\left(1 - \frac{T}{556.25}\right)^{1.23}$ ±0.2, 10 to 270°C, k_E = 2.21 from 10 to 100°C; = 2.2 from 10 to 220°C. At 20°C, a^2 (air) = 0.03426. γ (vapor) − γ (air) = 0.18.

CCl_2O (I) k_E = 2.1 (54)

t, °C	γ††
16.7	20.1
34.5	17.6
46.1	15.9

CS_2 (I, II, III, IX) k_E = 2.1 (40, 51, 58, 59, 73, 75, 91, 94)

t, °C	γ (air or vapor) ±0.3
0	35.28
10	33.81
20	32.33
45	28.66
60	26.45

CCl_3NO_2, Chloropicrin (I, II) (26, 73)

t, °C	γ (air or vapor) ±0.6
10	33.7
20	32.3
95	22.4

For other C-compounds, *v.* p. 448.

$SiCl_4$, Silicon tetrachloride (I) k_E = 2.1 (61)

t, °C	γ ±1.0
18.9	16.9
45.5	14.1

C_4O_4Ni, Nickel tetracarbonyl (I) k_E = 2.4 (61)

t, °C	γ ±1.0
19.8	14.7
45.9	11.8

$\mathfrak{C}$-Table, the $\mathfrak{C}$-Arrangement

For abbreviations and symbols, *v.* p. 433

CHBrCl$_2$, Dichlorobromomethane (I) $k_E = 2.1$ (90)

t, °C	γ (air) ±0.3
22.5	32.25
44.0	29.36
61.5	27.11
84.5	24.22

CHBr$_3$, Bromoform (I, II) (14, 25)

t, °C	a^2 (air) ±0.001
55	0.0265
120	0.0211
t, °C	γ (air) ±0.3
20	41.53

CHCl$_3$, Chloroform (I, II, III) $k_E = 2.1$ (23, 51, 58, 59, 63, 72, 91)

t, °C	γ	γ (air)
10	28.60 ±0.2	28.50 ±0.2
20*	27.24 ±0.1	27.14 ±0.1
60	21.73 ±0.2	21.73 ±0.2
77.5	19.40 ±0.3	

* At 20°C, a^2 (air) = 0.0372$_2$; γ(vapor) − γ(air) = +0.10.

HCN, Hydrogen cyanide (I, II) $k_E = 1.1$ (8)

t, °C	γ (air)††
10	19.1
17	18.2
25	17.2

CH$_2$BrNO$_2$, Bromonitromethane (III) (30)

t, °C	γ (N$_2$) ±2†
−18.5	48.3
+80	36.4
135.8	28.6

CH$_2$Cl$_2$, Methylene chloride (II) (23)

At 20°C, γ (air) = 26.52 ± 0.2

CH$_2$I$_2$, Methylene iodide (II) (25)

At 20°C, γ (air) = 50.76 ± 0.3

CH$_2$O$_2$, Formic acid (I, II) $k_E = 0.9$ (30, 31, 46, 50, 61, 73)

t, °C	γ (air)
10	38.7 ±0.5
20	37.6 ±0.5
50	34.4 ±0.5
100	29.0 ±1.0

CH$_3$Cl, Methyl chloride (I) (86)

t, °C	γ§
0	19.5
10	17.8
20	16.2

$$\gamma = 72\left(1 - \frac{T}{T_C}\right)^{1.22}$$

CH$_3$I, Methyl iodide (I) (73)

At 2.5°C, a^2 (air) = 0.02960 ± 2%; at 43.5°C, a^2 (air) = 0.02532 ± 2%, γ (air) = 25.8

CH$_3$NO, Formamide (I, II) $k_E = 0.7$ (50, 83, 87)

t, °C	γ (air) ±0.4
0	59.9
20	58.2
50	55.7
75	53.3

CH$_3$NO$_2$, Nitromethane (I, II) (23, 50, 73)

t, °C	γ (air)
0	39.8 ±0.2
20	36.82 ±0.1
45	33.4 ±0.2
100	26.1 ±0.3

CH$_4$O, Methyl alcohol (I, II) (45, 46, 48, 60, 64)

t, °C	γ (air)
0	24.49 ±0.2
20	22.61 ±0.1
30	21.75 ±0.2
50	20.14 ±0.2

t, °C	γ ±0.2	k_E
70	18.51	0.9
100	15.67	1.0
150	10.42	1.3
200	4.41	1.7
235	0.34	

From 70 to 235°C,

$$\gamma = 173.245\left(1 - \frac{T}{513.1}\right)^{1.33} - 243.042\left(1 - \frac{T}{513.1}\right)^{2} + 146.344\left(1 - \frac{T}{513.1}\right)^{3}, \pm 0.2.$$

At 20°C, d_4^{20} = 0.7918; a^2 (air) = 0.0583$_0$.

CH$_4$S, Methylmercaptan (I) $k_E = 2.1$ (6)

t, °C	γ ± < 1.5
9.8	26.44
33.3	22.42
43.5	20.73

CH$_5$N, Methylamine (III) (30)

t, °C	γ (N$_2$) ±2†
−70	29.2
−20	23.0
−12	21.7

C$_2$Cl$_4$, Tetrachloroethylene (I, II) (25, 73)

t, °C	γ (air)
10	32.8 ±0.2
20	31.74 ±0.1
120	21.6 ±0.4

C$_2$HCl$_3$O, Chloral (I) $k_E = 2.2$

t, °C	γ (61)	t, °C	γ (73)
19.4	25.34	20.0	30.01
45.8	22.18	96.5	20.38

For notes †–§§ *see* p. 475.

C$_2$HCl$_3$O$_2$, Trichloroacetic acid (III) (30)

t, °C	γ (N$_2$) ±2†
80.2	27.8
136.5	23.4
196	17.8

C$_2$H$_2$Br$_4$, 1, 1, 2, 2-Tetrabromoethane (I, II) $k_E = 2.5$ (23, 90)

t, °C	γ (air)
20	49.67 ±0.1
45	46.54 ±0.2
75	42.87 ±0.2
100	39.78 ±0.2

C$_2$H$_2$Cl$_2$O$_2$, Dichloroacetic acid (III) (30)

t, °C	γ (N$_2$) ± 2†
25.7	35.4
80.2	30.3
176.2	21.4

C$_2$H$_2$Cl$_4$, 1, 1, 2, 2-Tetrachloroethane (I) $k_E = 2.3$ (90)

t, °C	γ (air) ±0.3
22.5	36.03
40.6	33.69
60.3	31.22
76.3	29.23
92.2	27.36

C$_2$H$_3$ClO, Acetyl chloride (I) $k_E = 2.1$ (61)

t, °C	γ ±1.0
14.8	26.7
46.2	21.9

C$_2$H$_3$ClO$_2$, Chloroacetic acid (III) (30)

t, °C	γ (N$_2$) ±2†
80.2	33.3
136.2	28.1
176.3	23.5

C$_2$H$_3$Cl$_3$, 1, 1, 2-Trichloroethane (I) (73)

t, °C	a^2 (air) ±2%	γ (air)
7.1	0.04922	
114	0.03459	22.0

C$_2$H$_3$N, Acetonitrile (I, II) $k_E = 1.5$ (12, 39, 62, 73)

t, °C	γ (air) ± 0.1	γ (vapor)
10	30.62	30.62 ±0.3
20	29.30	29.30 ±0.3
50	25.40	25.40 ±0.2
90	20.21	20.21 ±0.2

C$_2$H$_3$NS, Methyl thiocyanate (I) (73)

$a^2 = 0.07606 - 0.000186t$

t, °C	a^2 ±2%	γ
9.2	0.07435	
48.5	0.06704	
60.0	0.06490	
73.5	0.06239	
133.0	0.05132	23.3

C$_2$H$_4$Br$_2$, Ethylene bromide (I, II) $k_E = 2.2$ (14, 21, 51, 58, 59, 65, 73)

t, °C	γ (air)	γ (vapor)
10	40.05 ±0.3	40.05 ±0.5
20	38.75 ±0.1	38.75 ±0.4
30	37.45 ±0.1	37.45 ±0.4
40	36.15 ±0.1	36.15 ±0.4
50	34.87 ±0.2	34.87 ±0.4
60	33.58 ±0.2	33.58 ±0.4
100	28.40 ±0.3	28.40 ±0.4
130	24.73 ±0.4	24.73 ±0.4

C$_2$H$_4$Cl$_2$, 1, 1-Dichloroethane (I, II) (40, 72)

t, °C	γ (air) ±0.5
35.0	23.4
57.0	20.5

C$_2$H$_4$Cl$_2$, Ethylene chloride (I, II, III) (40, 65, 72, 91, 94)

t, °C	γ (air) ±0.3
10	33.6
20	32.2
40	29.5
60	26.7
80	24.0

C$_2$H$_4$O, Acetaldehyde (I) $k_E = 1.8$ (32)

t, °C	γ††
0.1	23.9
10.0	22.4
20.0	21.2
29.0	20.1
43.0	18.0
50.0	17.0

C$_2$H$_4$O$_2$, Acetic acid (I, II, III) (3, 45, 46, 48, 60, 73, 91, 94)

t, °C	γ (air)	γ (vapor)
10	28.62 ±0.2	28.8 ±0.5
20	27.63 ±0.2	27.8 ±0.5
50	24.65 ±0.2	24.8 ±0.5
75	22.18 ±0.2	22.3 ±0.5
100	19.7 ±0.3	19.8 ±0.4
118	18.1 ±0.3	18.1 ±0.3
150		15.0 ±0.3
180		12.3 ±0.3
220		8.5 ±0.3
250		5.7 ±0.3
t, °C	k_E	k'_E*
20	1.3	2.0
100	1.3	2.0_5
150	1.3_5	2.1_5
250	1.4_5	2.3

* k'_E calculated for C$_4$H$_8$O$_4$.

C$_2$H$_4$O$_2$, Methyl formate (I, II) (49, 60, 73)

t, °C	γ (vapor) ±0.2	γ (air) ±0.2
0	28.30	28.00
10	26.68	26.50
20	25.08	25.00
30	23.50	23.49
50	20.40	
100	13.04	
150	6.41	

$C_2H_4O_2$.—(*Continued*)

t, °C	γ (vapor) ±0.2	γ (air) ±0.2
200	0.99	
210	0.21	

$$\gamma = 77.83\left(1 - \frac{T}{487.1}\right)^{1.23}$$

±0.2, from 50 to 214°C; $k_E = 2.09$ from 0 to 100°C; $=2.1$ from 0 to 130°C.

C_2H_5Br, Ethyl bromide (I, II) (23, 65, 73)

t, °C	γ (air or vapor)
10	25.48±0.2
20	24.15±0.2
40	21.52±0.2

$C_2H_5Cl_2OP$, Ethoxydichlorophosphine (I) (73)

$a^2 = 0.04751 - 0.0001357t$; $\gamma = 19.8$ at 116.5°C

t, °C	a^2 ±2%
9.1	0.04627
46.7	0.04118
51.3	0.04055
60.0	0.03937
72.5	0.03767

C_2H_5I, Ethyl iodide (I, II, III) $k_E = 2.2$ (18, 61, 65, 73, 91)

t, °C	γ (air) ±1	γ (vapor) ±2
10	30.6	30.6
20	29.4	29.4
50	25.6	25.6
75	22.4	22.4

C_2H_5NO, Acetamide (I) $k_E = 1.2$ (83)

t, °C	γ (?) ±0.5
85	39.3
95	38.4
105	37.3
120	35.7

C_2H_5NO, Acetaldoxime (I) $k_E = 1.5$ (11, 92)

t, °C	γ ±0.3
35	30.1
60	27.3
80	25.1
110	21.7
145	17.8

$C_2H_5NO_2$, Nitroethane (I) $k_E = 1.7$ (61, 73)

t, °C	γ (air or vapor) ±0.5
10	33.4
20	32.2
50	28.5
100	22.5
110	21.2

$C_2H_5NO_3$, Ethyl nitrate (I, II) (50, 73)

t, °C	γ (air or vapor) ±0.7
0	31.2
20	28.7
85	20.5

$C_2H_6N_2O$, Dimethylnitrosoamine (I, II) $k_E = 1.8$ (50, 83)

t, °C	γ (air or vapor) ±0.5
20	38.9
40	36.4
75	31.8

C_2H_6O, Ethyl alcohol (I, II, IX) (45, 46, 48, 59, 60, 62, 64, 75)

t, °C	γ (air)	γ (vapor)	k_E
0	24.05±0.2		
10	23.14±0.1	23.61±0.3	
20	22.27±0.1	22.75±0.3	1.0
30	21.43±0.1	21.89±0.3	
40	20.60±0.2	21.02±0.3	
50	19.80±0.2	20.14±0.3	
60	19.01±0.2	19.24±0.3	
70	18.22±0.2	18.34±0.3	
100		15.47±0.2	1.3
150		10.16±0.2	1.7
200		4.26±0.2	2.1
240		0.13±0.2	

$$\gamma = \left[230.564\left(1 - \frac{T}{516.2}\right)^{1.45} - 304.339\left(1 - \frac{T}{516.2}\right)^{2} + 139.756\left(1 - \frac{T}{516.2}\right)^{3}\right]$$

±0.3, from 10 to 240°C. At 20°C, $d_4^{20} = 0.7892$; a^2 (air) $= 0.0576_8$.

$C_2H_6O_2$, Glycol (I, II) (52, 61)

t, °C	γ (air or vapor) ±1.5
0	49.0
20	47.7
50	45.3
80	42.3
130	36.7

$C_2H_6O_4S$, Dimethyl sulfate (III) (82)

t, °C	γ (air) ±1§§
18	40.12
36.5	37.76
55	35.46
74.5	33.25
93	31.03

C_2H_6S, Methyl sulfide (I) $k_E = 2.1$ (6)

t, °C	γ ± < 1.5
11.1	26.50
32.9	23.33
57.7	19.87

C_2H_6S, Ethylmercaptan (I, II) $k_E = 2.1$ (20, 39, 61)

t, °C	γ (air or vapor) ±0.7
0	25.4
10	24.0
20	22.5

C_2H_7N, Dimethylamine (III) (30)

t, °C	γ (N_2) ±2†
−78	25.2
−23	20.2
+ 5	17.7

For notes †–§§ *see* p. 475.

C_2H_7N, Ethylamine (III) (30)

t, °C	γ (N_2) ±2†
−74	29.1
−21.5	23.4
+ 9.9	20.4

$C_2H_8N_2O_3$, Dimethylammonium nitrate (I) $k_E = 0.6$ (88)

t, °C	γ (air) ±0.5
69.6	52.05
97.6	50.65
118.0	49.75

$C_2H_8N_2O_3$, Ethylammonium nitrate (I) $k_E = 0.5$ (88)

t, °C	γ (air) ±0.5
17.5	47.67
20.0	47.62
45.2	46.53
58.5	46.02

$C_3H_2N_2$, Malononitrile (I)

At 36°C, $a^2 = 0.09_6$; varies with time, temperature and thermal history of the sample, *v.* (89).

$C_3H_4Br_2O_2$, α, β-Dibromopropionic acid (I) (53)

t, °C	γ (?) ±3
50	87
90	56

$C_3H_4Cl_2O$, α, α-Dichloroacetone (II) (23)

At 20°C, γ (air) = 31.91 ± 0.2

C_3H_5Br, 3-Bromopropylene (I) (73)

$a^2 = 0.042869 - 0.000148t$, $\gamma = 21.35$ at 70.0°C

t, °C	a^2 ±2%
8.0	0.04170
37.5	0.03730
43.5	0.03640
55.0	0.03472

$C_3H_5Br_3$, 1, 2, 3-Tribromopropane (II) (25)

At 20°C, γ (air) = 45.36 ± 0.3

C_3H_5ClO, Chloroacetone (II) (23)

At 20°C, γ (air) = 35.27 ± 0.2

C_3H_5ClO, α-Epichlorohydrin (I, III) (73, 82.7)

t, °C	γ (air or vapor) ±0.3
10	38.5
20	37.0
50	32.9
85	28.2

$C_3H_5ClO_2$, Ethyl chloroformate (I) $k_E = 2.1$ (61)

t, °C	γ ±1.0
15.1	27.5
46.5	23.5

C_3H_5I, 3-Iodopropylene (I) (73)

$a^2 = 0.03747 - 0.000110t$, $\gamma = 21.4$ at 102.0°C

t, °C	a^2 ±2%
11.1	0.03625
43.5	0.03269
45.8	0.03249
66.5	0.03016

C_3H_5N, Propionitrile (I, II) $k_E = 1.6$ (47, 61, 62, 73)

t, °C	γ (air or vapor) ±0.3¶
10	28.3
20	27.2
50	23.8
75	21.0
90	19.4

C_3H_5NO, Lactonitrile (I) $k_E = 1.3$ (83)

t, °C	γ (?) ±0.5
20	36.7
30	35.8
45	34.3
60	32.9

C_3H_5NS, Ethyl thiocyanate (I) (61, 73)

t, °C	γ
20	36.2
80	28.8
140	21.3

C_3H_5NS, Ethyl isothiocyanate

t, °C	γ (air) (II) (39)	t, °C	γ (vapor) (I) (61)
30.0	31.69	18.4	36.25
40.0	30.56	46.0	32.59
50.0	29.49	$k_E = 2.2$	

$C_3H_6Br_2$, 1, 2-Dibromopropane (I) (73)

$a^2 = 0.038869 - 0.0000950t$, $\gamma = 21.2$ at 141.5°C

t, °C	a^2 ±2%
10.0	0.03792
63.5	0.03283
71.7	0.03205

$C_3H_6Cl_2$, 1, 2-Dichloropropane (I) (73)

t, °C	a^2 (air) ±2%	γ
8	0.05246	
98	0.03889	20.0

C_3H_6O, Allyl alcohol (I, II) $k_E = 1.5$ (50, 61, 72)

t, °C	γ (air or vapor) ±0.5
0	27.6
20	25.8
50	23.2
95	19.2

C_3H_6O, Acetone (I, II, III)
$k_E = 1.9$ (12, 43, 47, 48, 61, 62, 72, 91, 94)

t, °C	γ (air or vapor) ±0.2
0	26.21
20	23.70
40	21.16
60	18.61
80	16.2 ± 0.3

$C_3H_6O_2$, Propionic acid (I, II)
$k_E = 1.5$ (50, 61, 73)

t, °C	γ (air) ±0.3	γ (vapor) ±0.6
10	27.7	27.7
20	26.7	26.7
50	23.7	23.7
80	20.8	20.8
140	15.7	15.7

$C_3H_6O_2$, Ethyl formate (I, II)
$k_E = 2.1$ (43, 49, 58, 72)

t, °C	γ (air or vapor) ±0.3
0	26.2
20	23.6
50	19.8
80	16.0
130	10.0
185	4.0
210	1.9

$C_3H_6O_2$, Methyl acetate (I, II)
$k_E = 2.2$ (49, 58, 65, 72)

t, °C	γ (air or vapor) ±0.3
0	27.4
20	24.6
50	20.6
80	16.6
130	10.3
180	4.5
215	1.2

C_3H_7Br, Propyl bromide (I) (73)
$a^2 = 0.04184 - 0.0001428t$, $\gamma = 19.65$ at 71.0°C

t, °C	a^2 ±2%
10.0	0.04041
45.2	0.03539
68.5	0.03206

C_3H_7Br, Isopropyl bromide (I) (73)
$a^2 = 0.04002 - 0.000145t$, $\gamma = 19.05$ at 60.5°C

t, °C	a^2 ±2%
10.5	0.03849
26.0	0.03625
38.3	0.03447
52.5	0.03241

C_3H_7Cl, *n*-Propyl chloride (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
5.6	0.0533	
47	0.0436	18.3

$C_3H_7ClO_2$, Monochlorohydrin (I) $k_E = 1.5$ (89)

t, °C	γ (air) ±0.3
17.0	49.19
35.0	47.43
57.8	45.17
80.2	42.97
98.5	41.19

C_3H_7I, *n*-Propyl iodide (I) (73)
$a^2 = 0.03645 - 0.0001045t$, $\gamma = 20.0$ at 102.5°C

t, °C	a^2 ±2%
14.0	0.03499
40.0	0.03227
70.0	0.02914
85.3	0.02754

C_3H_7I, Isopropyl iodide (I) (73)
$a^2 = 0.034596 - 0.0001045t$, $\gamma = 19.5$ at 89.0°C

t°, C	a^2 ±2%
7.0	0.03386
49.5	0.02942
70.0	0.02727
77.0	0.02654

C_3H_7N, Allylamine (I) (73)

t, °C	a^2 (air) ±2%	γ (air)
11.0	0.06786	
56	0.05907	21.2

C_3H_7NO, Acetoxime (I) $k_E = 1.7$ (11)

t, °C	γ ±0.4
63.26	26.15
76.10	24.61
98.50	22.25
113.40	20.79
117.70	20.68

C_3H_7NO, *n*-Propionaldoxime (I)
$k_E = 1.4$ (11)

t, °C	γ ±0.4
23.45	29.01
54.70	25.99
97.84	22.05

C_3H_7NO, Propionamide (I)
$k_E = 1.3$ (83)

t, °C	γ (?) ±0.5
80	32.1
90	31.2
105	29.8
120	28.4

$C_3H_7NO_2$, Lactamide (I) $k_E = 1.1$ (83)

t, °C	γ (?) ±0.5
80	44.6
90	43.8
105	42.6
120	41.3

C_3H_8O, *n*-Propyl alcohol (I, II)
$k_E = 1.3$ (47, 61, 62, 65, 72)

t, °C	γ (air)*
− 5.0	25.9 ±0.2
+20.0	23.8 ±0.2
40.0	22.1_5 ±0.2
60.0	20.5 ±0.2
80.0	18.8_5 ±0.3
95.0	17.6 ±0.3

* γ (vapor) = same +0.6 to −0.3.

C_3H_8O, Isopropyl alcohol (I)
$k_E = 1.1$ (61, 72)

t, °C	γ (air or vapor) ±0.3
5	22.8
20	21.7
50	19.3
80	17.0

C_3H_8O, Methyl ethyl ether (I)
$k_E = 2.2$ (6)

t, °C	γ ± <1.5
7.9	17.54
33.5	14.10
45.5	12.60

$C_3H_8O_2$, Methylal (III) (91)
At 18.0°C, γ (air) = 21.4 ± 0.3

$C_3H_8O_3$, Glycerol (I) (10, 15, 30, 90.5)

t, °C	γ (air) ±3.0
20	$63._4$
90	$58._6$
150	$51._9$

C_3H_9N, *n*-Propylamine (I)
$k_E = 1.9$ (73, 83)

t, °C	γ (air) ±0.3
10	23.5
20	22.4
30	21.2
45	19.4

C_3H_9N, Isopropylamine (III) (30)

t, °C	γ (N_2) ±2†
−72	28.1
0	19.4
+25.2	16.8

C_3H_9N, Trimethylamine (III) (30)

t, °C	γ (N_2) ±2†
−73	24.8
−32	20.0
− 4	17.3

$C_4H_4Cl_2O_2$, Succinyl chloride (III) γ (air) (96)

$C_4H_4N_2$, Succinonitrile (I)
$k_E = 0.6$ (87)

t, °C	γ (air) ±0.3
80.1	35.45
99.5	33.79
118.2	32.17

C_4H_4S, Thiophene (I) (74)

t, °C	γ (air) ±0.3
0	36.2
20	33.1
40	30.1
60	27.1
80	24.3

For notes †-§§ *see* p. 475.

$C_4H_5Cl_3O_2$, Ethyl trichloroacetate (I) (31, 73)

t, °C	γ (air) ±0.4
10	32.3
20	31.2
50	28.1
70	25.9
165	15.9

$C_4H_5NO_2$, Methyl cyanoacetate (III) (30)

t, °C	γ (N_2) ±2†
−16	43.9
+90	31.7
197	20.1

C_4H_5NS, Allyl isothiocyanate (I, II) $k_E = 2.1$ (39, 73)

t, °C	γ (air or vapor)
0	36.8 ± 0.3
20	34.5 ± 0.3
60	29.8 ± 0.3
90	26.5 ± 0.4
150	20.6 ± 0.4

$C_4H_6Cl_2O_2$, Ethyl dichloroacetate (I) (73)

t, °C	a^2 (air) ±2%	γ (air)
7.3	0.05183	
158	0.03143	16.8

$C_4H_6O_3$, Acetic anhydride (I)
$k_E = 2.2$ (61, 73)

t, °C	γ ±0.3
15	33.3
20	32.7
50	29.2
140	18.6

$C_4H_7ClO_2$, Ethyl chloroacetate (I) (73)

t, °C	a^2 (air) ±2%	γ (air)
7	0.05731	
144.5	0.03643	17.3

C_4H_7N, *n*-Butyronitrile (I, II)
$k_E = 1.7$ (23, 39, 62, 83)

t, °C	γ (air) ±0.4¶
10	28.7
20	27.6
50	24.5
75	21.9
110	18.2

$C_4H_8Cl_2S$, β, β′-Dichloroethyl sulfide (II) (24)
At 20°C, γ (air) = 42.82 ± 0.5

C_4H_8O, Methyl ethyl ketone (I, II) (13, 47)

t, °C	γ (air or vapor) ±0.2
0	26.9
20	24.6
40	22.3
75	18.4

$C_4H_8O_2$, *n*-Butyric acid (I, II) $k_E = 1.6$ (**50, 61, 73**)

t, °C	γ (air) ±0.3*
0	28.8
20	26.8
50	24.0
100	19.5
160	14.5

* γ (vapor) = same +0.3 ±0.5.

$C_4H_8O_2$, Isobutyric acid (I, II) $k_E = 1.6$ (**50, 61, 73**)

t °C	γ (air or vapor)
0	27.1±0.3
20	25.2±0.3
50	22.4±0.4
100	17.9±0.5
150	13.8±0.5

$C_4H_8O_2$, Ethyl acetate (I, II, III) $k_E = 2.3$ (**17, 49, 60, 62, 65, 72, 91**)

t, °C	γ (vapor)	γ (air) ±0.3
0	26.9 ±0.4	26.5
20	24.3 ±0.4	23.9
50	20.4 ±0.4	20.2
75	17.4 ±0.3	17.4
100	14.4 ±0.3	
150	8.7 ±0.3	
200	3.7 ±0.3	
240	0.5 ±0.3	
245	0.15±0.3	

$C_4H_8O_2$, Methyl propionate (I, II) $k_E = 2.2$ (**43, 49, 58, 72**)

t, °C	γ (air or vapor) ±0.3
10	26.1
20	24.9
40	22.4_5
80	17.6
130	11.8
180	6.4
237	1.2

$C_4H_8O_2$, *n*-Propyl formate (I, II) $k_E = 2.2$ (**49, 58, 65, 72**)

t, °C	γ (air or vapor) ±0.3
0	26.8
20	24.5
50	21.1
100	15.5
130	12.1
190	5.9
240	1.5

C_4H_9Br, Isobutyl bromide (I) (**73**)

$a^2 = 0.04386 - 0.000141t$, $\gamma = 17.6$ at 91.0°C

t, °C	a^2 ±2%
10.1	0.04244
58.0	0.03710
69.5	0.03407

C_4H_9Cl, Isobutyl chloride (I, II) (**23, 73**)

t, °C	γ (air)
10	23.1 ±0.2
20	21.9_4±0.1
70	16.2 ±0.2

C_4H_9Cl, *tert.*-Butyl chloride (II) (**23**)

At 20°C γ (air) = 19.59 ± 0.2

C_4H_9I, Isobutyl iodide (I) (**73**)

$a^2 = 0.03786 - 0.0001032t$, $\gamma = 17.9$ at 119.5°C

t, °C	a^2 ±2%
6.5	0.03719
48.5	0.03286
70.2	0.03062
74.5	0.03017

C_4H_9NO, Methyl ethyl ketoxime (I) (**17**)

t, °C	γ ±0.3
13.8	30.38
150.4	16.64

$C_4H_9NO_2$, *n*-Butyl nitrite (III) (**82**)

t, °C	γ ±1 (air)§§
13	22.25
28.5	20.48
42.5	19.12
56.5	17.58

$C_4H_9NO_2$, Methylurethane (I) (**17**)

t, °C	γ ±0.3
55.9	38.88
101.2	33.39
150.9	27.69

$C_4H_{10}N_2O$, Diethylnitrosoamine (I) $k_E = 1.9$ (**83**)

t, °C	γ (?) ±0.5
20	33.1
30	32.1
45	30.6
60	29.0
75	27.4

$C_4H_{10}O$, *n*-Butyl alcohol (I, II) (**50, 61, 65**)

t, °C	γ (air or vapor) ±0.4
0	26.2
20	24.6
50	22.1
100	17.8
130	15.1

$C_4H_{10}O$, Isobutyl alcohol (I, II) (**20, 50, 61, 62, 64, 72**)

At 20°C, a^2 (air) = 0.0582_1; $d_4^{20} = 0.8019$

t, °C	γ (air)	γ (vapor) ±0.3
0	24.4±0.2	
20	22.8±0.1	23.0
30	22.1±0.1	22.3
50	20.5±0.2	22.7
75	18.5±0.3	18.6
105	15.9±0.3	15.9
130		13.7

$C_4H_{10}O$, *d-sec.*-Butyl alcohol (I) (**76**)

t, °C	γ‡‡	k_E
10	23.5	1.4
80	17.4	1.5

$C_4H_{10}O$, *dl-sec.*-Butyl alcohol (I) (**76**)

t, °C	γ‡‡	k_E
10	23.5	1.4
80	17.4	1.5

$C_4H_{10}O$, *tert.*-Butyl alcohol (I) (**2, 65**)

t, °C	γ (air or vapor) ±0.5
20	20.7
80	14.6

$C_4H_{10}O$, Ethyl ether (I, II) (**20, 34, 51, 60, 63, 72**)

t, °C	γ ±0.2
20	17.01
50	13.47
100	7.97
150	3.12
190	0.15

γ (vapor) = $57.358\left(1 - \frac{T}{466.9}\right)^{1.23}$ ±0.2, from 20 to 193°C. γ (air) ±0.2 = 16.96 at 20°C; $k_E = 2.2_5$ from 0 to 100°C. At 20°C, $d_4^{20} = 0.713_3$; a^2 (air) = 0.0486_5; γ (vapor) − γ (air) = +0.05.

$C_4H_{10}O_2$, Dimethylacetal (I) (**73**)

$a^2 = 0.05676 - 0.000217t$, $\gamma = 17.13$ at 63.3°C

t, °C	a^2 ±2%
7.5	0.05514
29.5	0.05036
45.0	0.04700
60.0	0.04353

$C_4H_{10}O_3S$, *sym.*-Diethyl sulfite (I, II) $k_E = 2.2$ (**44, 89**)

t, °C	γ (air)
10	30.4
20	29.4
50	26.3
90	22.2

$C_4H_{10}O_3S$, Ethyl ethylsulfonate (I) $k_E = 2.0$ (**89**)

t, °C	γ (air) ±0.3
17.6	36.31
49.7	32.99
71.5	30.80
96.5	28.30

For notes †–§§ *see* p. 475.

$C_4H_{10}O_4S$, Diethyl sulfate (III) (**82**)

t, °C	γ (air) ±1§§
13	34.61
32.5	32.54
48	30.86
70	28.60

$C_4H_{10}S$, Ethyl sulfide (I) (**73**)

t, °C	γ ±0.4
10	26.5
50	21.9
90	17.3

$C_4H_{11}N$, *n*-Butylamine (III) (**30**)

t, °C	γ (N_2) ±2†
−21	26.1
+41	19.7
70.8	17.4

$C_4H_{11}N$, Isobutylamine (I) (**73**)

t, °C	a^2 (air) ±2%	γ (air)
12.3	0.06371	
68	0.05218	17.6

$C_4H_{11}N$, *tert.*-Butylamine (III) (**30**)

t, °C	γ (N_2) ±2†
−30	22.5
−10	18.4
40.5	15.3

$C_4H_{11}N$, Diethylamine (I) (**73**)

t, °C	a^2 (air) ±2%	γ (air)
10.2	0.06069	
56	0.04986	16.4

$C_4H_{12}N_2O_3$, Diethylammonium nitrate (I) $k_E = 0.8$ (**88**)

t, °C	γ (air) ±0.4
99.6	40.31
100.0	40.30
109.0	39.84
114.8	39.51

$C_5H_4O_2$, Furfural (I, II) (**50, 73**)

t, °C	γ (air or vapor) ±0.4
20	43.5
30	42.2
40	40.9
160	25.4

C_5H_5N, Pyridine (I, II) $k_E = 2.3$ (**40, 49, 51, 61, 62, 73, 94**)

t, °C	γ (air)*
0	40.8±1.0
20	38.0±1.0
40	35.0±0.8
60	32.1±0.7
80	29.3±0.6
100	26.4±0.5
115	24.2±0.5

* γ (vapor) = same +2.0 to −0.5.

C_5H_6, Cyclopentadiene (I) $k_E = 1.5$ (92)

t, °C	γ ±0.4
40.4	31.5
101.1	25.2
139.9	21.0

$C_5H_7NO_2$, Ethyl cyanoacetate (I) $k_E = 1.9$ (89)

t, °C	γ (air) ±0.3
17.5	36.07
31.3	34.53
61.0	31.33
83.9	29.07
101.3	27.32

$C_5H_8O_2$, Acetylacetone (I, II) (39, 69, 92)

t, °C	γ (air or vapor)
0	33.3±0.2
20	31.2±0.2
50	28.0±0.2
100	23.0±0.3
145	18.6±0.3

$C_5H_8O_2$, β, β-Dimethylacrylic acid (I) $k_E = 1.8$ (16)

t, °C	γ (air) ±*ca.* 1.5
85	27.9
110	25.7
137	23.0
155	21.6
177	19.4

$C_5H_8O_2$, Allyl acetate (I) (73)

t, °C	a^2 (air) ±2%	γ (air)
4.5	0.06118	
103	0.04106	16.5

$C_5H_8O_3$, Levulinic acid (III) (30)

t, °C	γ (N_2) ±2†
25.5	39.7
81.5	35.5
115	32.9

$C_5H_8O_4$, Dimethyl malonate (II) (39)

t, °C	γ (air) ±0.4
10	38.33
30	35.82
50	33.30

C_5H_9N, Isovaleronitrile (I, II) (23, 39, 73)

t, °C	γ (air)
10	27.0 ±0.2
20	26.03±0.1
50	23.3 ±0.2
130	16.0 ±0.5

C_5H_9NS, *n*-Butyl isothiocyanate (I) $k_E = 2.2$ (7)

t, °C	γ ±0.3
11.2	31.78
55.2	27.21
108.5	21.87

For notes †-§§ *see* p. 475.

C_5H_{10}, Trimethylethylene (I, II) (20, 72)

t, °C	γ (air)
7	18.9 ±0.3
20	17.26±0.1
37	15.1 ±0.3

$C_5H_{10}O$, Isovaleraldehyde (I) (73)

$a^2 = 0.06425 - 0.000195t$; $\gamma = 16.3$ at 93.0°C

t, °C	a^2 ±2%
10.0	0.06230
53.5	0.05382
68.0	0.05099
78.7	0.04890

$C_5H_{10}O$, Diethyl ketone (II) (47)

t, °C	γ (air) ±0.3
0	26.90
15	25.33
30.1	23.73
45	22.20

$C_5H_{10}O$, Methyl propyl ketone (I, II) $k_E = 2.0$ (50, 61, 62)

t, °C	γ (air) ±0.5	γ (vapor) ±0.8
0	27.3	
20	25.2	26.1
50	21.9	22.6
90	17.7	

$C_5H_{10}O_2$, Ethyl propionate (I, II) $k_E = 2.3$ (43, 49, 58, 72)

t, °C	γ (air or vapor) ±0.3
5	25.9
20	24.2
50	20.9
100	15.5
130	12.4
180	7.3
238	2.2

$C_5H_{10}O_2$, Isovaleric acid (I, II) $k_E = 1.7$ (20, 50, 61, 65, 73)

t, °C	γ (air)	γ (vapor) ±1
15	26.16±0.1	26.16
20	25.33±0.1	25.33
40	23.67±0.1	23.67
80	20.4 ±0.3	20.4
175	12.6 ±0.5	12.6

$C_5H_{10}O_2$, Isobutyl formate (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
5.2	0.05871	
98.5	0.04149	15.8

$C_5H_{10}O_2$, Methyl *n*-butyrate (I, II) $k_E = 2.3$ (43, 49, 58, 72)

t, °C	γ (air or vapor)
10	26.15±0.2
20	25.00±0.2
40	22.73±0.2
60	20.43±0.2
100	16.1±0.2
132.5	12.5±0.5
185.0	7.3±0.5
210.0	5.0±0.5
238.0	2.7±0.5

$C_5H_{10}O_2$, Methyl isobutyrate (I, II) $k_E = 2.3$ (49, 58, 62, 65, 72)

t, °C	γ (vapor) ±0.3	γ (air) ±0.2
10	24.9	24.92
20	23.8	23.79
50	20.4	20.40
75	17.6	17.60
100	14.9	
125	12.2	
150	9.6	
175	7.2	
200	4.8	
237	1.8	

$C_5H_{10}O_2$, *n*-Propyl acetate (I, II) $k_E = 2.3$ (43, 49, 58, 72)

t, °C	γ (air or vapor) ±0.3
0	26.6
20	24.3
50	21.0
100	15.6
130	12.4
190	6.5
240	2.2

$C_5H_{10}O_3$, Diethyl carbonate (II, III) (20, 82)

t, °C	γ (air)
13	27.2 ±0.2
20	26.31±0.1
40	24.0 ±0.2
65	21.1 ±0.2

$C_5H_{10}O_3$, *dl*-Ethyl lactate (I, II) $k_E = 2.1$ (29, 43, 44)

t, °C	γ (air or vapor) ±0.3
0	31.9
20	29.9
50	26.8
80	23.7
110	20.7

$C_5H_{10}O_4$, Glyceryl acetate (I) $k_E = 1.7$ (89)

t, °C	γ (air)
17.0	43.5
37.5	41.6
70.0	38.6
(II) (39)	
10.0	41.3
37.5	38.6

$C_5H_{11}Br$, Isoamyl bromide (I) (73)

$a^2 = 0.04650 - 0.000134t$, $\gamma = 16.3$ at 118.5°C

t, °C	a^2 ±2%
15.1	0.0445
47.0	0.0402
69.5	0.0372
87.5	0.0348

$C_5H_{11}Cl$, Isoamyl chloride (I, II) (23, 73)

t, °C	γ (air)
10	24.4 ±0.3
20	23.48±0.1
100	15.7 ±0.3

$C_5H_{11}I$, Isoamyl iodide (I) (14, 73)

t, °C	a^2 ±2%
5	0.0400
20	0.0384
40	0.0363
70	0.0332
145	0.0253

$C_5H_{11}N$, Piperidine (I, II) $k_E = 2.1$ (47, 58, 61, 73)

t, °C	γ (air) ±0.2*
0	32.65
20	30.20
30	28.95
50	26.6
75	23.7
105	20.4
130	17.5

* γ (vapor) = same +0.2 ±0.3.

$C_5H_{11}NO$, Methyl propyl ketoxime (I) $k_E = 1.9$ (11, 62)

t, °C	γ (air) ±0.3
10	30.0
20	29.1
50	26.3
100	21.7
145	17.6

$C_5H_{11}NO$, Isovaleraldoxime (I) $k_E = 1.7$ (11, 17)

t, °C	γ ±0.3
20	27.8
50	25.0
100	20.6
150	16.4

$C_5H_{11}NO_2$, Isoamyl nitrite (III) (82)

t, °C	γ (air) ±1§§
14	22.04
35	20.35
56	18.06
73	16.28

$C_5H_{11}NO_2$, Ethylurethane (I) $k_E = 1.5$ (17, 83)

t, °C	γ ±0.3
60	31.8
80	29.9
100	27.9
150	22.9

$C_5H_{11}NO_3$, Isoamyl nitrate (I, II) (23, 73)

t, °C	γ (air)
20	27.18±0.1
143	20.0 ±0.4

C_5H_{12}, Isopentane (II) (23)
At 20°C, γ (air) = 13.72 ±0.2

$C_5H_{12}O$, Isoamyl alcohol (I, II, III) (42, 46, 62, 65, 72, 91)

t, °C	γ (air) ±0.5
0	25.3
10	24.6
20	23.8
50	21.5
100	17.7
130	15.1

$C_5H_{12}O$, *tert.*-Amyl alcohol (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
3.9	0.05949	
120	0.04283	15.2

$C_5H_{12}O$, Ethyl propyl ether (II) (50)

t, °C	γ (air) ±0.3
0	21.69
20	19.46

$C_5H_{13}N$, *n*-Amylamine (III) (30)

t, °C	γ (N_2) ±2†
−21	25.9
+41.2	20.4
99.8	15.6

$C_5H_{13}N$, Isoamylamine (I) k_E = 2.0 (73, 83)

t, °C	γ (air) ±0.4
10	24.6
20	23.6
50	20.75
75	18.35
95	16.4

$C_5H_{13}N$, *tert.*-Amylamine (III) (30)

t, °C	γ (N_2) ±2†
−70	27.6
+29.3	19.7
70	15.5

$C_6H_3BrN_2O_4$, 4-Bromo-1, 2-dinitrobenzene (I) (53)

t, °C	γ (?) ±3
40	13
80	12

$C_6H_3ClN_2O_4$, 1-Chloro-2, 4-dinitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
60.4	45.5
136	38.3
204.2	31.5

$C_6H_3ClN_2O_4$, 4-Chloro-1, 2-dinitrobenzene (I) (53)

t, °C	γ (?) ±3
30	14
70	12

$C_6H_3Cl_2NO_2$, 1, 2-Dichloro-4-nitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
46	40.2
136	32.0
204	25.6

$C_6H_3Cl_2NO_2$, 1, 3-Dichloro-4-nitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
35	41.3
114.9	33.3
204	24.4

$C_6H_3Cl_2NO_2$, 1, 4-Dichloro-2-nitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
60.5	38.3
136	31.5
204	25.0

$C_6H_3Cl_3O$, 2, 4, 6-Trichlorophenol (III) (30)

t, °C	γ (N_2) ±2†
70.2	36.3
156	28.6
196.5	24.1

C_6H_4BrCl, *p*-Chlorobromobenzene (III) (81)

t, °C	γ (air) ±1§§
70	33.15
102	29.81
106	29.41
132	26.75
164	23.54
194	20.60

$$\gamma\text{ (air)} = 71.83\left(1 - \frac{T}{722}\right)^{1.2}$$

C_6H_4BrF, *p*-Fluorobromobenzene (III) (30)

t, °C	γ (N_2) ±*ca.* 2†
−21	39.8
+70	29.4
138	22.4

$C_6H_4BrNO_2$, *o*-Bromonitrobenzene (III) (82.6)

t, °C	γ (air) ±1§§
55.5	43.44
67.5	42.12
80	40.56
94.5	38.94

$C_6H_4BrNO_2$, *m*-Bromonitrobenzene (III) (82.6)

t, °C	γ (air) ±1§§
63	42.45
71.5	41.36
83	40.10
91	38.94

$C_6H_4BrNO_2$, *p*-Bromonitrobenzene (III) (82.6)

t, °C	γ (air) ±1§§
132	34.58
145	33.12
159.5	31.78
170	30.63

C_6H_4ClI, *p*-Chloroiodobenzene (III) (81)

t, °C	γ (air) ±1§§
61	37.57
88	34.78
113	32.22
127	30.80

For notes †–§§ see p. 475.

C_6H_4ClI.—(*Continued*)

t, °C	γ (air) ±1§§
167	26.82

$$\gamma\text{ (air)} = 74.71\left(1 - \frac{T}{767}\right)^{1.2}$$

$C_6H_4ClNO_2$, *o*-Chloronitrobenzene (III) (82.6)

t, °C	γ (air) ±1§§
50.5	42.29
70.5	39.80
91.5	37.23
121	34.04

$C_6H_4ClNO_2$, *m*-Chloronitrobenzene (III) (82.6)

t, °C	γ (air) ±1§§
60.5	41.79
74.5	38.76
90.5	36.27
129	31.77

$C_6H_4ClNO_2$, *p*-Chloronitrobenzene (III) (81)

t, °C	γ (air) ±1§§
97	35.73
111	34.23
127	32.52
141	31.05
156	29.48
179	27.19
186	26.38

$$\gamma\text{ (air)} = 78.68\left(1 - \frac{T}{768}\right)^{1.2}$$

$C_6H_4Cl_2$, *m*-Dichlorobenzene (III) (30)

t, °C	γ (N_2) ±2†
−22	41.6
+90.7	28.6
160	22.8

$C_6H_4Cl_2$, *p*-Dichlorobenzene (III) (81)

t, °C	γ (air) ±1§§
68	30.72
96	27.65
117	25.39
139	23.06
150	21.84
166	20.24
170	19.84

$$\gamma\text{ (air)} = 71.45\left(1 - \frac{T}{675}\right)^{1.2}$$

$C_6H_4FNO_2$, *m*-Fluoronitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
0	40.1
104.5	29.7
196	21.4

$C_6H_4FNO_2$, *p*-Fluoronitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
24.5	38.4
89.3	31.3
194.1	20.3

$C_6H_4INO_2$, *o*-Iodonitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
61	43.1
136	35.8
205	29.5

$C_6H_4INO_2$, *m*-Iodonitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
25.7	47.3
156.1	33.7
216	28.6

$C_6H_4N_2O_4$, *o*-Dinitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
126	38.4
176	33.6
209.1	30.9

$C_6H_4N_2O_4$, *m*-Dinitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
94.8	42.3
155	36.1
204.5	31.8

$C_6H_4N_2O_4$, *p*-Dinitrobenzene (III) (30)

t, °C	γ (N_2) ±2†
176.2	34.4
210	31.5
226	30.4

$C_6H_4N_2O_5$, 2, 4-Dinitrophenol (III) (30)

t, °C	γ (N_2) ±2†
125.4	41.1
170	37.3
215	32.9

$C_6H_4O_2$, *p*-Benzoquinone (III) γ (air) (96)

C_6H_5Br, Bromobenzene (I, II, III) (25, 40, 73, 81)

t, °C	γ (air) ±0.5
10	37.7
20	36.5
50	33.0
100	27.2
150	21.7

C_6H_5BrO, *m*-Bromophenol (I) k_E = 1.8 (28)

t, °C	γ ±0.4
44.5	42.87
69.5	40.51
100.1	37.40

C_6H_5BrO, *p*-Bromophenol (I) k_E = 1.9 (28)

t, °C	γ ±0.4
74.4	42.36
99.9	39.54

C_6H_5Cl, Chlorobenzene (I, II, III) (23, 43, 51, 58, 59, 60, 62, 73, 80, 89)

t, °C	γ (air)	γ (vapor) ±0.2
10	34.40 ±0.2	34.78
20	33.19 ±0.1	33.56
30	31.98 ±0.2	32.35
40	30.79 ±0.2	31.15
50	29.63 ±0.2	29.95
75	26.77 ±0.2	27.00
100	24.00 ±0.2	24.11

C_6H_5Cl.—(*Continued*)

t, °C	γ (air)	γ (vapor) ±0.2
130	20.71±0.2	20.72
150		18.52
200		13.24
250		8.33
300		3.92
330		1.64

γ (vapor) $= 72.20\left(1 - \frac{T}{632.3}\right)^{1.23} \pm 0.2$, from 10 to 333°C. $k_E = 2.21$ from 10 to 100°C; $=2.2$ from 10 to 250°C.

C_6H_5ClO, *o*-Chlorophenol (I)

$k_E = 2.2$ (**28**)

t, °C	γ ±0.4
12.7	42.25
45.2	38.17
73.3	34.20

C_6H_5ClO, *m*-Chlorophenol (I)

$k_E = 1.9$ (**28**)

t, °C	γ ±0.4
33.0	41.72
78.6	37.23
138.5	30.73

C_6H_5ClO, *p*-Chlorophenol (I)

$k_E = 2.0$ (**28**)

t, °C	γ ±0.4
51.6	41.09
72.4	39.08
99.8	35.70

C_6H_5F, Fluorobenzene (II) (**40**)

t, °C	γ (air) ±0.3
9.3	28.49
34.5	25.15

C_6H_5I, Iodobenzene (I, II, III) (**18, 25, 40, 73, 81**)

t, °C	γ (air)
15	40.3±0.3
20	39.7±0.2
60	35.2±0.3
100	30.6±0.5
150	25.0±0.7
189	10.8±1.0

$C_6H_5NO_2$, Nitrobenzene (I, II, III, IX) $k_E = 2.2$ (**17, 23, 47, 61, 73, 75, 81**)

t, °C	γ (air or vapor) ±0.5
0	46.4
20	43.9
50	40.2
75	37.3
100	34.4
150	29.0
195	24.1

$C_6H_5NO_3$, *o*-Nitrophenol (I)

$k_E = 2.5$ (**28**)

t, °C	γ ±0.4
53.2	37.73
79.7	34.50

$C_6H_5NO_3$, *m*-Nitrophenol (I)

$k_E = 1.7$ (**28**)

t, °C	γ*
116.0	48.01
147.0	44.92

* The results of (**30**) are about 8 dyne/cm smaller.

$C_6H_5NO_3$, *p*-Nitrophenol (I)

$k_E = 1.9$ (**28**)

t, °C	γ*
129.7	45.66
162.5	42.17

* The results of (**30**) are about 4.5 dyne/cm smaller.

$C_6H_5NO_4$, 2-Nitroresorcinol (III) (**30**)

t, °C	γ (N_2) ±2†
90.7	39.5
140	34.0
185.5	29.1

C_6H_6, Benzene (I, II, III, IX) (**19, 21, 58, 59, 60, 61, 62, 63, 64, 66, 75, 77, 78, 80, 87, 89, 94**); *v. also* p. 446

t, °C	γ (air)	γ (vapor)
0.0	31.58±0.2	31.70±0.15
10.0	30.22±0.05	
20.0	28.88±0.03	29.02±0.03
30.0	27.56±0.05	27.70
40.0	26.26±0.05	
50.0	24.98±0.1	25.08±0.10
60.0	23.72±0.1	
70.0	22.48±0.1	22.52±0.15
80.0	21.26±0.15	
100.0		18.78±0.2
150.0		12.86±0.2
200.0		7.41±0.2
250.0		2.66±0.2
270.0		1.08±0.15
280.0		0.42±0.1
285.0		0.14
288.5		0.00

γ (air) $= 31.58 - 0.137t + 0.0001t^2 \pm 0.2$, from 0°C to boiling point; γ (vapor) $= 71.926\left(1 - \frac{T}{561.6}\right)^{1.28} \pm 0.2$, from 0°C to T_C. $k_E = 2.22$, 0 to 100°C $= 2.2$, 0 to 220°C. At 20°C, $d_4^{20} = 0.8788$; a^2 (air) $= 0.06713$, γ (vapor) $- \gamma$ (air) $= 0.14$.

C_6H_6ClN, *o*-Chloroaniline (III) (**30**)

t, °C	γ (N_2) ±2†
−19	45.7
+80.9	35.1
196.5	26.1

C_6H_6ClN, *p*-Chloroaniline (III) (**81**)

t, °C	γ (air) ±1§§
81	39.72
117	35.79
133	34.06
153	31.93
185	28.57

$$\gamma \text{ (air)} = 81.37\left(1 - \frac{T}{787}\right)^{1.2}$$

$C_6H_6N_2O_2$, *m*-Nitroaniline (III) (**30**)

t, °C	γ (N_2) ±2†
124.2	42.7
170	38.5
201.3	35.6

$C_6H_6N_2O_2$, *p*-Nitroaniline (III) (**30**)

t, °C	γ (N_2) ±2†
151	46.7
171.5	44.8
184.5	43.6

C_6H_6O, Phenol (I, II)

$k_E = 1.85$ (**1, 7, 28, 41, 42, 48, 93**)

t, °C	γ (air or vapor)
0	43.1 ±0.4
20	40.9 ±0.3
30	39.88±0.2
50	37.70±0.2
80	34.42±0.2
100	32.24±0.2
150	26.8 ±0.3
180	23.6 ±0.4

C_6H_6S, Thiophenol (I, II)

$k_E = 2.0$ (**39, 89**)

t, °C	γ (air) ±0.5
10	41.0
20	39.8
45	36.7
75	33.1
90	31.3

$C_6H_7ClO_4$, Dimethyl chloromaleate (I) $k_E = 2.7$ (**89**)

t, °C	γ (air) ±0.3
20.3	37.56
52.6	33.58
75.5	30.84
100.3	27.99

$C_6H_7ClO_4$, Dimethyl chlorofumarate (I, II) $k_E = 2.7$ (**44, 89**)

t, °C	γ (air)
20	39.0±0.4
50	35.4±0.4
100	29.3±0.3

C_6H_7N, Aniline (I, II, III)

$k_E = 2.1$ (**23, 40, 51, 62, 73, 81**)

t, °C	γ (air) ±0.4¶
10	44.0
20	42.9
50	39.4
100	33.7
150	27.9
180	24.4

C_6H_7N, α-Picoline (III) (**30**)

t, °C	γ (N_2) ±2†
−70	47.4
+46	31.3
126	22.5

C_6H_8ClN, Aniline hydrochloride (I) $k_E = 1.7$ (**56**)

t, °C	γ ±*ca.* 1
211.8	39.3
232.5	37.6

For notes †-§§ *see* p. 475.

$C_6H_8N_2$, Phenylhydrazine

(I) (**83**)

t, °C	γ (?)
20	46.1
30	44.8
50	42.1
60	40.8

(II) (**39**)

t, °C	γ (air)
30	43.5
50	42.2

$C_6H_8O_4$, Dimethyl fumarate (III) (**82.4**)

t, °C	γ (air) ±1§§
106	25.67
123	23.77
132	22.75
146	21.20
163	19.18

$C_6H_8O_4$, Dimethyl maleate (III) (**82.4**)

t, °C	γ (air) ±1§§
24	37.31
51	34.12
113	26.85
143	23.42

$C_6H_8O_6$, Triformin (III) (**30**)

t, °C	γ (N_2) ±2†
0	49.6
91.2	39.6
184.8	28.8

$C_6H_9NO_2$, Propyl cyanoacetate (III) (**30**)

t, °C	γ (N_2) ±2†
−16	37.5
+71	29.1
201	17.5

C_6H_{10}, 1, 5-Hexadiene (I) (**72**)

t, °C	a^2 (air) ±1.5%	γ (air)
4.1	0.05935	
58.4	0.04627	14.7

$C_6H_{10}O$, Mesityl oxide (I) (**14, 16**)

t, °C	γ (air)
24	28.3±0.5
75	22.8±0.8
125	17.4±1.0

$C_6H_{10}O_2$, Methylacetylacetone (I) $k_E = 2.2$ (**92**)

t, °C	γ ±0.4
36.3	31.3
75.7	27.2
120.7	22.6

$C_6H_{10}O_3$, Ethyl acetoacetate (I, II) (**39, 61, 69, 73**)

t, °C	γ (air or vapor)
0	34.8 ±0.4
20	32.51±0.3
50	29.23±0.3
75	26.5 ±0.4
90	25.0 ±0.4
110	22.9 ±0.5
150	18.9 ±0.6

$C_6H_{10}O_3$, Methyl *α*-acetopropionate (I) (92)

t, °C	γ ±0.4
36.0	30.9
97.1	24.1
151.4	18.6

$C_6H_{10}O_3$, Methyl methylacetoacetate (III) (30)

t, °C	γ (N_2) ±2†
−71	46.5
+70.2	28.1
156	20.4

$C_6H_{10}O_4$, Dimethyl succinate (III) (30)

t, °C	γ (N_2) ±2†
25.2	34.1
95	26.4
176.2	17.5

$C_6H_{10}O_4$, Diethyl oxalate (I, II) (39, 73)

t, °C	γ (air or vapor) ±0.3
10	33.2
20	32.0
50	28.7
70	26.6

$C_6H_{10}O_6$, Dimethyl *d*-tartrate (I) k_E = 2.0 (37)

t, °C	γ‡‡
62.0	39.0
135.1	32.2

$C_6H_{10}O_6$, Dimethyl *dl*-tartrate (I) k_E = 2.0 (37)

t, °C	γ‡‡
89.6	35.2
159.2	28.8

$C_6H_{11}N$, Isoamyl cyanide (I) k_E = 1.9 (73, 83)

t, °C	γ
20	26.8±0.3
60	23.2±0.3
154	15.6±0.4

$C_6H_{11}NO$, Mesityl oxide oxime (I) k_E = 2.1 (11)

t, °C	γ ±0.4
22.10	32.27
54.60	28.69
74.95	26.63
105.00	24.66

$C_6H_{11}NO_2$, Ethyl *β*-aminocrotonate (I) (53)

t, °C	γ (?) ±3
10	33
60	27

C_6H_{12}, Cyclohexane, (II, III) (18, 30)

t, °C	γ (air)
10	26.9±1.0
20	25.3±0.3
80	15.7±1.5

$C_6H_{12}O$, Cyclohexanol (II) (18)

At 16.2°C, γ (air) = 34.23 ± 0.3

$C_6H_{12}O$, Ethyl propyl ketone (II) (23)

At 20°C, γ (air) = 25.39 ± 0.2

$C_6H_{12}O$, Methyl *n*-butyl ketone (II) (23)

At 20°C, γ (air) = 25.49 ± 0.2

$C_6H_{12}O$, Pinacolin (I) (73)

$a^2 = 0.06440 - 0.000206t$; γ = 15.1 at 105.5°C

t, °C	a^2 ±2%
8.6	0.06263
43.4	0.05546
60.2	0.05200
79.0	0.04813

$C_6H_{12}O_2$, Isocaproic acid (I) k_E = 1.7 (61)

t, °C	γ ±1.0
17.0	26.9
46.5	24.5
78.2	21.9
132.3	17.8

$C_6H_{12}O_2$, *act.*-Amyl formate (I, II) k_E = 2.2 (29, 44)

t, °C	γ (air or vapor) ±0.4‡
0	26.5
20	24.6
60	20.8
110	16.1

$C_6H_{12}O_2$, Isoamyl formate (I) (65, 72)

t, °C	γ (air or vapor) ±0.5
5	26.1
20	24.7
123	15.0

$C_6H_{12}O_2$, Isobutyl acetate (I, II) (40, 65, 72)

t, °C	γ (air) ±0.2
5	24.7
20	23.3
60	19.5
110	14.9

$C_6H_{12}O_2$, Ethyl *n*-butyrate (I, II) (51, 64, 72)

At 20°C, a^2 (air) = 0.0570_2; d_4^{20} = 0.8789

t, °C	γ (air)
5.0	26.1 ±0.3
20.0	24.54±0.2
60.0	20.6 ±0.3
119.0	14.7 ±0.5

$C_6H_{12}O_2$, Ethyl isobutyrate (I) (65, 72)

t, °C	γ (air or vapor)
5	24.83±0.3
20	23.25±0.2
110	13.85±0.3

$C_6H_{12}O_2$, Methyl isovalerate (I) (65, 72)

t, °C	γ (air or vapor)
20	24.1±0.2
115	14.6±0.4

$C_6H_{12}O_2$, *n*-Propyl propionate (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
4.5	0.06040	
121.7	0.03804	14.3

$C_6H_{12}O_3$, Paraldehyde (I, II) k_E = 2.6 (50, 72)

t, °C	γ (air) ±0.5
5	27.5
20	25.9
50	22.6
124	14.5

$C_6H_{13}NO_2$, Isopropylurethane (I) (17)

t, °C	γ ±0.3
65.5	28.69
107.3	25.07
152.4	21.32

C_6H_{14}, *n*-Hexane (I, II) (13, 21, 23, 39, 72)

t, °C	γ (air)
0	20.52±0.2
20	18.43±0.2
40	16.3 ±0.2
68	13.4 ±0.3

$C_6H_{14}O$, Methyl isoamyl ether (I) (73)

$a^2 = 0.060369 - 0.0002145t$

At 91.0°C, γ = 13.82

t, °C	a^2 ±2%
6.5	0.05897
45.3	0.05065
72.6	0.04479
78.3	0.04357

$C_6H_{14}O_2$, Acetal (I, II) (50, 72)

t, °C	γ (air) ±0.2
5	23.2
20	21.65
40	19.6
100	13.5

$C_6H_{15}N$, Di-*n*-propylamine (I, II) k_E = 2.3 (23, 83)

t, °C	γ (air)
20	22.54±0.1
30	21.5 ±0.2
60	18.4 ±0.3

$C_6H_{15}N$, *n*-Hexylamine (III)

t, °C (30)	γ (N_2) ±2†
−18	28.0
+65	21.7
124.5	16.5

$C_6H_{15}N$, Isohexylamine (III)

t, °C (30)	γ (N_2) ±2†
−75	30.8
+60	20.3
121	15.9

$C_6H_{15}N$, Triethylamine (I, II) (41, 42, 73)

t, °C	γ (air) ±0.3
0	22.9
20	20.9
40	18.8
90	13.7

$C_6H_{15}O_4P$, Triethyl phosphate (III) (82)

t, °C	γ (air) ±1§§
15.5	30.61
38.5	28.30
69.5	25.44
87.5	23.65

C_7H_5BrO, Benzoyl bromide (I)

t, °C (14)	a^2 (air) ±2%
120	0.0439
169	0.0380

C_7H_5ClO, Benzoyl chloride (I) (73)

At 194.5°C, γ = 20.25

$a^2 = 0.06891 - 0.000150t$

t, °C	a^2 ±2%
9.8	0.06744
69.5	0.05849
81.5	0.05669
110.5	0.05234

C_7H_5N, Benzonitrile (I, II) k_E = 2.1 (17, 51, 62, 73, 83)

t, °C	γ (air or vapor) ±0.3
10	40.2
20	39.05
50	35.6
75	32.7
100	29.9
150	24.5
190	20.6

C_7H_5NS, Phenyl isothiocyanate (I, II) k_E = 2.4 (7, 25, 39, 73)

t, °C	γ (air or vapor) ±0.3
13	42.47
20	41.64
50	38.15
100	32.4
150	27.0
200	21.9
220	20.0

$C_7H_6Cl_2$, Benzal chloride (I) (73)

At 203.5°C, γ = 20.2

$a^2 = 0.06432 - 0.000122t$

t, °C	a^2 ±2%
11.5	0.06292
48.5	0.05840
76.5	0.05499
93.0	0.05297

C_7H_6O, Benzaldehyde (II) (23, 47)

t, °C	γ (air)
20	40.04±0.2
35	38.3 ±0.3
50	36.5 ±0.3

$C_7H_6O_2$, Salicyl aldehyde (III)

t, °C (30)	γ (N_2) ±2†
0	44.8
90.5	35.0
190	24.9

$C_7H_6O_2$, Toluquinone (III) γ (air) (96)

For notes †–§§ *see* p. 475.

C_7H_7Br, Benzyl bromide (I) (14)

t, °C	a^2 (air) ±2%
110	0.0472
156	0.0400

C_7H_7Br, *o*-Bromotoluene (I, II) (25, 73)

t, °C	γ (air)
20	34.85±0.2
180	18.6 ±0.5

C_7H_7Br, *p*-Bromotoluene (III) (81)

t, °C	γ (air) ±1.0§§
43	32.06
60	30.34
81	28.23
100	26.34
122	24.19
131	23.32
164	20.18

$$\gamma\ (\text{air}) = 66.46\left(1 - \frac{T}{694}\right)^{1.2}$$

C_7H_7Cl, Benzyl chloride (I) (73)

$a^2 = 0.07287 - 0.0001719t$, $\gamma = 19.5$ at 178.5°C

t, °C	a^2 ±2%
10.0	0.07115
50.0	0.06428
75.0	0.05998

C_7H_7Cl, *p*-Chlorotoluene (I, III) (73, 81)

t, °C	γ (air or vapor) ±1§§
25	32.08
50	29.38
64	27.90
79	26.31
108	23.30
120	22.08
151	18.95

$$\gamma\ (\text{air or vapor}) = 66.65\left(1 - \frac{T}{653}\right)^{1.2}$$

C_7H_7F, *m*-Fluorotoluene (III) (30)

t, °C	γ (N_2) ±2†
−71	42.1
+25.4	28.3
84.9	22.4

C_7H_7I, *p*-Iodotoluene (III) (81)

t, °C	γ (air) ±1§§
39	35.66
59	33.64
78	31.73
100	29.56
122	27.35
140	25.68
166	23.20

$$\gamma\ (\text{air}) = 69.28\left(1 - \frac{T}{734}\right)^{1.2}$$

C_7H_7NO, Benzamide (I) $k_E = 1.3$ (83)

t, °C	γ (?) ±0.5
130	38.4
140	37.8
150	37.1
160	36.4
170	35.6

C_7H_7NO, Formanilide (I) $k_E = 1.6$ (83)

t, °C	γ (?) ±0.5
60	39.4
75	38.1
90	36.8
105	35.4

$C_7H_7NO_2$, *o*-Nitrotoluene (I, II, III) (14, 23, 82.6)

t, °C	γ (air)
20	41.46±0.2
60	37.0 ±0.5
100	32.7 ±1
150	27.5 ±1.5
195	22.9 ±2

$C_7H_7NO_2$, *m*-Nitrotoluene (II, III) (23, 82.6)

t, °C	γ (air)
20	40.9±0.2
40	38.7±0.5
90	33.2±0.5
115	30.4±0.5

$C_7H_7NO_2$, *p*-Nitrotoluene (III) (81)

t, °C	γ (air) ±1§§
56	37.23
77	35.02
95	33.15
122	30.39
138	28.78
155	27.07
179	24.70
220	20.68

$$\gamma\ (\text{air}) = 74.06\left(1 - \frac{T}{754}\right)^{1.2}$$

$C_7H_7NO_2$, Salicylamide (I) $k_E = 1.4$ (83)

t, °C	γ (?) ±0.5
140	40.8
150	40.0
160	39.3
170	38.4

$C_7H_7NO_3$, *o*-Nitroanisole (III) (30)

t, °C	γ (N_2) ±2†
25.4	48.4
117	38.4
212	26.5

$C_7H_7NO_3$, *p*-Nitroanisole (III) (30)

t, °C	γ (N_2) ±2†
60.5	40.9
144.5	33.1
220	24.5

For notes †-§§ *see* p. 475.

C_7H_8, Toluene (I, II, III, IX) $k_E = 2.2$ (20, 40, 43, 58, 62, 63, 72, 75, 89, 91)

t, °C	γ (air)	γ (vapor) ±0.3
0	30.74±0.2	
10	29.60±0.1	27.7
20	28.43±0.05	28.5
30	27.30±0.1	27.4
40	26.13±0.1	26.2
50	24.99±0.2	25.0
60	23.81±0.2	23.8
80	21.53±0.2	21.5
100	19.39±0.2	19.4
130		16.3

At 20°C, a^2 (air) = 0.0670_7; $d_4^{20} = 0.8658$

$C_7H_8N_2O$, Phenylmethylnitrosoamine (I) $k_E = 2.5$ (83)

t, °C	γ (?) ±0.5
20	45.4
30	14.2
45	42.4
60	40.5
75	38.7
90	36.9

$C_7H_8N_2O_2$, 2-Methyl-4-nitroaniline (III) (30)

t, °C	γ (N_2) ±2†
142	43.0
184.5	36.3

$C_7H_8N_2O_2$, 4-Methyl-2-nitroaniline (III) (30)

t, °C	γ (N_2) ±2†
121	36.4
151	33.1
185	29.8

$C_7H_8N_2O_2$, 2-Methyl-6-nitroaniline (III) (30)

t, °C	γ (N_2) ±2†
105	39.2
151	35.2
201.2	30.7

$C_7H_8N_2O_2$, *p*-Nitromethylaniline (III) (30)

t, °C	γ (N_2) ±2†
155.2	46.3
186	43.7
210	40.1

C_7H_8O, Benzyl alcohol (I, II) $k_E = 1.6$ (18, 28, 65)

t, °C	γ (air or vapor) ±1
20	39.0
80	33.5

C_7H_8O, *o*-Cresol (I) $k_E = 2.0$ (7, 28, 62)

t, °C	γ (air or vapor) ±0.3
10	39.8
40	36.7
70	33.5
100	30.4
150	25.1
180	22.0

C_7H_8O, *m*-Cresol (I) $k_E = 1.8$ (28, 62, 65)

t, °C	γ (air or vapor) ±0.3¶
10	38.4
20	37.4
50	34.6
100	29.8
150	25.1
180	22.2

C_7H_8O, *p*-Cresol (I) $k_E = 1.7$ (28, 65)

t, °C	γ ±0.4
20	36.7
50	34.0
100	29.3

C_7H_8O, Anisole (I, II) $k_E = 2.3$ (17, 23, 51, 62, 73, 89)

t, °C	γ (air)
10	36.41±0.2
20	35.22±0.1
40	32.81±0.2
60	30.41±0.2
80	28.02±0.2
100	25.66±0.3
125	22.7 ±0.3
150	19.8 ±0.3

$C_7H_8O_2$, Guaiacol (I) $k_E = 2.2$ (61)

t, °C	γ
19.6	38.66
46.0	35.66
78.0	31.90

(I) (14)

t, °C	γ (air)
142	28.1
179	23.9
201	21.3

$C_7H_8O_2$, Resorcinol monomethyl ether (III) (30)

t, °C	γ (N_2) ±2†
− 20	83.1
+107	37.5
206	26.8

$C_7H_8O_2$, Dimethyl-γ-pyrone (I) $k_E = 1.9$ (55)

t, °C	γ (air)‡‡
137	30.8
183	26.3

C_7H_9N, Benzylamine (I) $k_E = 2.1$(83)

t, °C	γ (?) ±0.5
20	39.5
30	38.3
45	36.5
60	34.8
75	33.1

C_7H_9N, Methylaniline (I, II) (13, 40, 65)

t, °C	γ (air or vapor)
10	40.7±0.3
20	39.6±0.3
60	35.3±0.3
195	21.0±0.5

C_7H_9N, *o*-Toluidine (I, II, III) (13, 27, 30, 31, 50, 65)

t, °C	γ (air or vapor) ±0.8
0	42.3
20	40.0
50	36.7
100	31.2
150	25.7
200	20.6

C_7H_9N, *m*-Toluidine (I) (65)

At 20°C, γ = 36.9 ± 0.3

C_7H_9N, *p*-Toluidine (I, II, III) (13, 50, 81)

t, °C	γ (air) ±0.3
50	34.6
100	29.8
150	25.0
210	19.3

$C_7H_{10}O_4$, Dimethyl citraconate (III) (82.4)

t, °C	γ (air) ±1§§
20	35.69
32	34.51
53	31.37
64	30.78
79	28.20

$C_7H_{10}O_4$, Dimethyl mesaconate (III) (82.4)

t, °C	γ (air) ±1§§
20	34.68
32	33.80
63	29.84
80	27.68

$C_7H_{11}BrO_4$, Diethyl bromomalonate (III) (30)

t, °C	γ (N_2) ±2†
−20.7	39.1
+66.6	29.3
146	24.2

$C_7H_{11}Cl_3O_2$, *act.*-Amyl trichloroacetate (I, II) (29, 44)

t, °C	γ (air or vapor) ±0.2‡
0	31.2_5
20	29.3
50	26.4_5
100	21.9
150	17.8±0.3

$C_7H_{11}NO_2$, Butyl cyanoacetate (III) (30)

t, °C	γ (N_2) ±2†
− 21.3	35.2
+114.5	24.6
213.1	17.6

$C_7H_{11}NO_2$, Isobutyl cyanoacetate (III) (30)

t, °C	γ (N_2) ±2†
−20.5	34.2
+94.5	24.9
213	15.4

$C_7H_{12}O_2$, Ethyl cyclobutanecarboxylate (III) (82.7)

t, °C	γ (air) ±1§§
19.5	29.96
47.5	26.58
70	24.10
90.5	21.68

$C_7H_{12}O_4$, Diethyl malonate (II) (39)

t, °C	γ (air) ±0.4
10	33.14
30	30.99
50	28.88

$C_7H_{14}O$, Dipropyl ketone (II) (44)

t, °C	γ (air) ±0.3
10	26.69
30	24.71
40	23.75
60	21.93

$C_7H_{14}O_2$, Heptylic acid (II) (23)

At 20°C, γ (air) = 28.31 ± 0.3

$C_7H_{14}O_2$, Ethyl isovalerate (I, II) (23, 72)

t, °C	γ (air)
20	23.68±0.1
130	13.2 ±0.4

$C_7H_{14}O_2$, Isoamyl acetate (I, II) k_E = 2.3 (47, 62, 72)

t, °C	γ (air) ±0.2
0	26.6
20	24.7
50	21.8
75	19.5
100	17.1
125	14.7
139	13.4

$C_7H_{14}O_2$, Isobutyl propionate (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
7.2	0.05906	
137	0.03544	13.0

$C_7H_{14}O_2$, Propyl butyrate (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
5.8	0.06117	
143.5	0.03621	13.2

$C_7H_{14}O_2$, Propyl isobutyrate (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
5.7	0.05906	
134.8	0.03544	12.9

$C_7H_{15}NO$, Oenanthaldoxime (I) k_E = 1.6 (11)

t, °C	γ ±0.4
54.60	26.38
76.78	24.78
107.15	22.41

$C_7H_{17}N$, *n*-Heptylamine (III) (30)

t, °C	γ (N_2) ±2†
−18.5	27.5
+70.9	20.3
145.5	14.4

$C_8H_4Cl_2O_2$, *sym.*-Phthalyl chloride (III) γ (air) (96)

$C_8H_4Cl_2O_2$, *unsym.*-Phthalyl chloride (96)

C_8H_7N, Benzyl cyanide (I, II) k_E = 2.2 (47, 83)

t, °C	γ (air) ±0.3
20	41.8
45	39.0
60	37.3

C_8H_7N, *o*-Tolunitrile (I, II, III) (39, 82.6, 83)

t, °C	γ (air) ±0.5
20	38.2
40	36.0
75	32.1
100	29.5
116	28.0

C_8H_7N, *m*-Tolunitrile (I, II, III) (39, 82.6, 83)

t, °C	γ (air) ±0.5
0	39.8
20	37.7
40	35.5
85	30.7

C_8H_7N, *p*-Tolunitrile (I, II, III) (39, 82.6, 83)

t, °C	γ (air) ±0.2
30	36.8
40	35.7
70	32.3
96	29.7

C_8H_7NO, Mandelonitrile (I) k_E = 1.9 (83)

t, °C	γ (?) ±0.5
20	44.3
30	43.4
45	41.9
60	40.4

C_8H_8, Styrene (II) (18)

At 19°C, γ (air) = 32.14 ± 0.3

$C_8H_8N_2O_6$, 4, 5-Dinitro-1, 2-dimethoxybenzene (III) (30)

t, °C	γ (N_2) ±2†
130.8	41.0
182	35.7
208	31.5

C_8H_8O, Acetophenone (I, II) k_E = 2.2 (13, 14, 50)

t, °C	γ (air or vapor) ±0.3
20	39.8
50	36.2
75	33.3
125	27.8
175	22.8

$C_8H_8O_2$, *p*-Methoxybenzaldehyde (III) (30)

t, °C	γ (N_2) ±2†
0	44.9
101	33.7
210	22.9

$C_8H_8O_2$, Methyl benzoate (I) k_E = 2.4 (62, 73)

t, °C	γ (air or vapor)
10	38.8±0.2
20	37.6±0.2
50	34.2±0.3
75	31.2±0.3
100	28.4±0.3
150	23.0±0.3
200	17.6±0.3

$C_8H_8O_3$, Methyl salicylate (III) (30)

t, °C	γ (N_2) ±2†
−19.8	44.2
+94	31.9
212.2	19.8

C_8H_9NO, Acetanilide (I) k_E = 1.9 (83)

t, °C	γ (?) ±0.5
120	35.6
130	34.7
145	33.3
160	32.0

C_8H_9NO, *anti*-Benzaldoxime *N*-methyl ether (III) (82)

t, °C	γ (air) ±1§§
100	40.93
122	38.62
141	36.80
163	34.53

C_8H_9NO, *anti*-Benzaldoxime *O*-methyl ether (III) (82)

t, °C	γ (air) ±1§§
16.5	37.03
33.5	34.92
55.5	32.20
73	30.13

C_8H_9NO, Phenylacetamide (I) k_E = 1.6 (83)

t, °C	γ (?) ±0.5
160	34.0
170	33.2
180	32.4

$C_8H_9NO_3$, *p*-Nitrophenetole (III) (30)

t, °C	γ (N_2) ±2†
70.2	35.3
140	29.3
220	22.6

C_8H_{10}, Ethylbenzene (I, II) (18, 40, 65, 66, 72)

t, °C	γ (air)
0	31.40±0.2
20	29.20±0.2
35	27.60±0.2
60	24.91±0.2
135	16.9 ±0.3

For notes †–§§ *see* p. 475.

C_8H_{10}, *o*-Xylene (I, II) (23, 40, 66)

t, °C	γ (air) ±0.3
0	32.27
20	30.10
40	27.90
60	25.70

C_8H_{10}, *m*-Xylene (I) k_E = 2.25 (20, 62, 65, 66, 72, 89)

t, °C	γ (air)¶	γ (vapor) ±0.4
0	31.15±0.1	31.15
20	28.90±0.1	28.90
40	26.70±0.1	26.70
60	24.57±0.1	24.57
100	20.46±0.2	20.46
135	17.18±0.3	17.18

C_8H_{10}, *p*-Xylene (II) (23, 40, 65, 66, 72)

t, °C	γ (air)
5	29.92±0.2
20	28.37±0.1
35	26.80±0.2
60	24.20±0.2
135	16.7 ±0.3

$C_8H_{10}O$, *p*-Tolyl methyl ether (I) (73)

$a^2 = 0.075037 - 0.0001838t$

t, °C	a^2 ±2%	γ
5.5	0.0740	
48.7	0.0661	
75.5	0.0612	
92.5	0.0580	
175.5	0.0428	17.4

$C_8H_{10}O$, Phenetole (I, II) k_E = 2.4 (23, 51, 62, 73)

t, °C	γ (air)
20	32.74±0.1
50	29.5 ±0.2
100	24.2 ±0.2
150	18.9 ±0.2
170	16.8 ±0.2

$C_8H_{10}O_2$, *o*-Dimethoxybenzene (III) (30)

t, °C	γ (N_2) ±2†
0.0	42.5
104.5	29.3
196	20.8

$C_8H_{10}O_2$, *m*-Dimethoxybenzene (I) (73)

$a^2 = 0.077718 - 0.0001709t$

At 215°C, γ = 17.6

t, °C	a^2 ±2%
10.6	0.0759
72.0	0.0654
87.0	0.0628

$C_8H_{10}O_2$, *p*-Dimethoxybenzene (III) (30)

t, °C	γ (N_2) ±2†
66	34.7
146	26.4
206	19.5

$C_8H_{10}O_4$, Dimethyl 3-methyl-Δ²-cyclopropene-1, 2-dicarboxylate (III) (82.7)

t, °C	γ (air) ±1§§
42	35.46
63	32.94
81	30.79
95	28.98

$C_8H_{11}ClO_4$, Diethyl chlorofumarate (I, II) k_E = 2.8 (44, 89)

t, °C	γ (air) ±0.3
15	34.8
40	32.3
60	30.2

$C_8H_{11}ClO_4$, Diethyl chloromaleate (I) k_E = 2.6 (89)

t, °C	γ (air) ±0.3
15.5	34.45
26.3	33.33
50.0	30.83
70.75	28.77
97.05	26.19

$C_8H_{11}N$, Dimethylaniline (I, II) k_E = 2.4 (20, 40, 62, 63)

At 20°C, a^2 (air) = 0.07811; γ (vapor) − γ (air) = 0.10; d_4^{20} = 0.9562

t, °C	γ (air)
10	37.70±0.1
20	36.56±0.05
50	33.20±0.1
75	30.39±0.2
100	27.6 ±0.3
150	22.4 ±0.3
175	20.0 ±0.3

$C_8H_{11}N$, Ethylaniline (I, II) (13, 31, 40, 65)

t, °C	γ (air or vapor) ±0.5
10	37.6
20	36.6
60	32.4
210	16.7

$C_8H_{11}NO_2$, Ethyl 1-cyanocyclobutane-1-carboxylate (III) (82.7)

t, °C	γ (air) ±1§§
13.5	35.68
57	30.92
84.5	27.86
126.5	23.49

$C_8H_{12}BrN$, Phenyldimethylammonium bromide (I) k_E = 1.7 (88)

t, °C	γ (air) ±0.5
82.0	51.60
97.0	50.24
113.5	48.77

$C_8H_{12}O_4$, Diethyl fumarate (I, II) k_E = 2.7 (44, 89)

t, °C	γ (air) ±0.4
20	32.4
45	29.8
75	26.6

$C_8H_{12}O_4$, Diethyl maleate (I) k_E = 2.6 (89)

t, °C	γ (air) ±0.3
19.8	33.38
41.4	31.08
79.35	27.33

$C_8H_{13}BrO_4$, Diethyl methylbromomalonate (III) (30)

t, °C	γ (N_2) ±2†
− 21	35.0
+114	22.6
197	14.7

$C_8H_{13}NO_2$, Amyl cyanoacetate (III) (30)

t, °C	γ (N_2) ±2†
−17.5	32.7
+89	25.0
201	17.8

C_8H_{14}, *n*-Hexylacetylene (I) k_E = 2.4 (90)

t, °C	γ (air) ±0.3
23.0	23.89
39.0	22.22
57.0	20.40
73.6	18.75
92.8	16.92

$C_8H_{14}O_3$, Ethyl dimethylacetoacetate (II) (39)

t, °C	γ (air) ±0.4
30	29.61
40	28.51
50	27.39

$C_8H_{14}O_3$, Ethyl ethylacetoacetate (I) k_E = 2.4 (92)

t, °C	γ ±0.4
38.8	28.1
97.8	22.3
148.3	17.6

$C_8H_{14}O_4$, Diethyl succinate (I) k_E = 2.3 (31)

t, °C	γ (?) ±2
13.0	31.9
70.6	26.5

$C_8H_{14}O_5$, Diethyl malate (II) (44)

t, °C	γ (air) ±0.3
30	35.51
40	32.55
60	30.63

$C_8H_{14}O_6$, Diethyl *d*-tartrate (III) (30)

t, °C	γ (N_2) ±2†
25	37.6
134.7	26.9
212.7	20.2

C_8H_{16}, *n*-Octylene (mixture of 1-*n*-octylene and 2-*n*-octylene) (I, II) (18, 72)

t, °C	γ (air) ±0.3
2	24.0
20	22.2
125	12.4

For notes †–§§ *see* p. 475.

$C_8H_{16}O$, Methyl hexyl ketone (II) (23, 47)

t, °C	γ (air)
0	28.6 ±0.2
20	26.79±0.1
30	25.9 ±0.2

$C_8H_{16}O_2$, Caprylic acid (II) (18)

At 18.1°C, γ (air) = 28.82 ± 0.3

$C_8H_{16}O_2$, Ethyl caproate (II) (20)

At 20°C, γ (air) = 25.81 ± 0.2

$C_8H_{16}O_2$, Isoamyl propionate (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
4.5	0.06152	
160.5	0.03459	12.4

$C_8H_{16}O_2$, Isobutyl *n*-butyrate (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
5.8	0.06046	
157	0.03361	12.0

$C_8H_{16}O_2$, Isobutyl isobutyrate (I) (72)

t, °C	a^2 (air) ±2%	γ (air)
7.9	0.0583	
149	0.0337	12.0

$C_8H_{16}O_2$, *n*-Propyl isovalerate (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
15	0.05857	
155.5	0.03459	12.4

C_8H_{18}, 2, 5-Dimethylhexane (I) (66, 72)

t, °C	γ (air)
0	21.95±0.2
30	18.97±0.2
60	16.16±0.2
110	11.5 ±0.3

C_8H_{18}, 2-Methylheptane (I) (66)

t, °C	p*	γ ±0.1
0.0	9.6	22.85
34.3	10.4	19.48
61.0	57.2	16.94

* p = pressure of air + vapor (in cm of mercury).

C_8H_{18}, *n*-Octane (I, II) k_E = 2.3 (20, 21, 61, 66)

t, °C	γ (air) ±0.1	γ (vapor) ±0.3
0	23.80	23.80
20	21.80	21.80
40	19.82	19.82
60	17.88	17.88

$C_8H_{18}O$, *dl*-Methylhexyl carbinol (II) k_E = 2.1 (9, 21, 23)

t, °C	γ (air) ±0.1
0	27.96
20	26.37
40	24.78
60	23.02

$C_8H_{18}O$, *d*-Methylhexyl carbinol (I) k_E = 2.0 (76)

t, °C	γ**
10	26.6
80	20.8

$C_8H_{18}O$, *l*-Methylhexyl carbinol (I) k_E = 1.9 (76)

t, °C	γ**
10	26.5
80	20.9

$C_8H_{18}O$, *n*-Octyl alcohol (II) (20, 21)

t, °C	γ (air) ±0.2
0.16	29.09
20.00	27.53
39.87	25.85
59.67	24.38

$C_8H_{19}N$, Diisobutylamine (II, III) (23, 30)

t, °C	γ (air)
-70	30.0 ±1.5
+20	22.05±0.2
125	12.7 ±1.5

C_9H_7N, Quinoline (I, II) k_E = 2.4 (7, 40, 45, 62, 73)

t, °C	γ (air) ±0.3
10	46.2
20	45.0
50	41.5
100	35.8
150	30.3
200	25.1
230	22.1

$C_9H_{10}O_2$, Ethyl benzoate (I, III) (30, 31, 73)

t, °C	γ ±0.5
0	37.5
20	35.5
50	32.5
75	30.0
200	17.5

$C_9H_{10}O_3$, Ethyl *m*-hydroxybenzoate (I) k_E = 2.2 (28)

t, °C	γ ±0.4
85.8	35.76
115.4	32.99
143.5	30.28

$C_9H_{10}O_3$, Ethyl *p*-hydroxybenzoate (I) k_E = 2.2 (28)

t, °C	γ ±0.4
119.7	33.71
149.3	31.01
172.8	28.80

$C_9H_{10}O_3$, Ethyl salicylate (I) k_E = 2.4 (28)

t, °C	γ ±0.4
20.5	38.33
61.1	35.06
85.6	31.37

$C_9H_{11}NO$, Methylacetanilide (I) k_E = 2.2 (83)

t, °C	γ (?) ±0.5
105	32.4
115	31.5
120	31.0
130	30.0
145	28.5

$C_9H_{11}NO_2$, Phenylurethane (I) k_E = 2.2 (17, 83)

t, °C	γ (?) ±0.4
60	36.5
80	34.5
100	32.5
150	27.6

C_9H_{12}, *p*-Ethyltoluene (I) (72)

t, °C	a^2 (air) ±1.5%	γ (air)
4.5	0.07088	
161.8	0.04184	15.2

C_9H_{12}, Mesitylene (I, II) k_E = 2.2 (23, 40, 62, 72)

t, °C	γ (air)
5	30.1 ±0.2
20	28.51±0.2
50	25.5 ±0.2
75	23.0 ±0.3
100	20.6 ±0.3
125	18.2 ±0.3
165	14.9 ±0.3

C_9H_{12}, *n*-Propylbenzene (I) (72)

t, °C	γ (air) ±0.4
4.5	30.6
158.7	15.3

C_9H_{12}, Pseudocumene (III) (30)

t, °C	γ (N_2) ±2.0†
−21	34.1
+86.5	24.0
166	16.2

$C_9H_{12}O$, *dl*-Phenylethyl carbinol (I) k_E = 2.0 (76)

t, °C	γ‡‡
10	34.9
80	28.4

$C_9H_{12}O$, *l*-Phenylethyl carbinol (I) k_E = 2.0 (76)

t, °C	γ‡‡
10	34.7
80	28.3

$C_9H_{13}N$, Dimethyl-*o*-toluidine (I) (13, 27)

t, °C	γ ±1.0
15	32.9
150	18.2

$C_9H_{14}O$, Phorone (I) (14)

t, °C	a^2 (air) ±2%
132	0.0520
160	0.0470
191	0.0418

$C_9H_{14}O_3$, Ethyl allylacetoacetate (I) k_E = 2.6 (92)

t, °C	γ ±0.4
39.2	28.5
105.7	22.2
121.2	20.8

$C_9H_{14}O_4$, Diethyl cyclopropane-1, 1-dicarboxylate (III) (82.7)

t, °C	γ (air) ±1§§
25	31.28
110	22.62
153	18.52
189	15.52

$C_9H_{14}O_4$, Diethyl cyclopropane-1, 2-dicarboxylate (III) (82.7)

t, °C	γ (air) ±1§§
11	33.41
14	33.22
54	28.92
71	27.29
90	25.17

$C_9H_{14}O_6$, Glyceryl triacetate (III) (30)

t, °C	γ (N_2) ±2†
−19	37.8
+99.8	30.1
200.3	20.4

$C_9H_{16}O_3$, Ethyl *n*-?-propylacetoacetate (III) (30)

t, °C	γ (N_2) ±2†
−76.2	43.6
+70	24.8
200.5	14.2

$C_9H_{17}BrO_2$, *act.*-Amyl α (?)-bromo-*n*-butyrate (I) k_E = 2.6 (90)

t, °C	γ (air) ±0.3‡
17.1	29.55
44.9	26.96
75.8	24.12
103.5	21.50

$C_9H_{18}O_2$, *act.*-Amyl butyrate (I, II) k_E = 2.4 (29, 44)

t, °C	γ (air or vapor) ±0.3‡
0	27.1
20	25.2
60	21.5
80	19.8
110	17.3

$C_9H_{18}O_2$, Isoamyl butyrate (II) (23)

At 20°C, γ (air) = 25.19 ± 0.2

$C_9H_{18}O_2$, Isobutyl isovalerate (I, II) k_E = 2.6 (29, 44)

t, °C	γ (air or vapor) ±0.3
0	26.1
20	24.2
60	20.6
105	16.5

C_9H_{20}, Tetraethylmethane (I) k_E = 2.2 (38)

t, °C	γ‡‡
20	22.9
40	21.2

$C_9H_{21}N$, Tri-*n*-propylamine (I) k_E = 2.7 (83)

t, °C	γ (?) ±0.5
20	23.2
30	22.3
45	20.8
60	19.4
75	18.0

$C_{10}H_7Br$, α-Bromonaphthalene (II) (25)

At 20°C, γ (air) = 44.59 ± 0.3

$C_{10}H_7Cl$, α-Chloronaphthalene (II) (25)

At 20°C, γ (air) = 41.80 ± 0.3

$C_{10}H_8$, Naphthalene (I) (13, 14)

t, °C	γ (air or vapor) ±1
127	28.8
170	24.0
190	21.8

$C_{10}H_9BrO_2$, Methyl α-bromoallocinnamate (III) (82.4)

t, °C	γ (air) ±1§§
20	43.41
30	42.30
60	38.77
81	36.10

$C_{10}H_9BrO_2$, Methyl β-bromoallocinnamate (III) (82.4)

t, °C	γ (air) ±1§§
66	36.04
71	35.23
86	33.54
94	32.70

$C_{10}H_9BrO_2$, Methyl α-bromocinnamate (III) (82.4)

t, °C	γ (air) ±1§§
20	45.59
51	41.80
81	38.22
131	31.57

$C_{10}H_9BrO_2$, Methyl β-bromocinnamate (III) (82.4)

t, °C	γ (air) ±1§§
20	44.79
32	42.36
61	39.96
77	37.49

$C_{10}H_{10}O$, Benzylideneacetone (I) k_E = 2.6 (16)

t, °C	γ (air) ±*ca.* 1.5
60.0	39.9
67.8	39.2
80.0	37.9
110.5	34.3
137.5	31.5
155.0	29.6
199.0	25.2

$C_{10}H_{10}O_2$, Methyl allocinnamate (III) (82.4)

t, °C	γ (air) ±1§§
20	40.17
41	37.53
62	34.93
78	32.88

For notes †–§§ *see* p. 475.

$C_{10}H_{10}O_2$, Methyl cinnamate (I, II, III) (39, 82.4, 89)

t, °C	γ (air) ±0.5
20	39.5
50	36.5
100	31.4

$C_{10}H_{12}O$, Anethole (I, II) $k_E = 2.3$ (50, 62)

t, °C	γ (air) ±0.5
10	37.6
20	36.5
50	33.3
100	28.4
150	23.8
200	19.6
220	18.1

$C_{10}H_{12}O$, Cumic aldehyde (I) (73)

$a^2 = 0.07397 - 0.0001505t$

At 237.0°C, γ = 14.8

t, °C	a^2 ±2%
8.8	0.07265
48.4	0.06669
70.5	0.06336
94.5	0.05975
125.5	0.05509

$C_{10}H_{12}O_3$, Methyl *d*-β-hydroxy-β-phenylpropionate (I) $k_E = 2.4$ (76)

t, °C	γ‡‡
10	40.7
80	33.3

$C_{10}H_{12}O_3$, Methyl *dl*-β-hydroxy-β-phenylpropionate (I) $k_E = 2.4$ (76)

t, °C	γ‡‡
10	40.0
80	33.1

$C_{10}H_{13}NO$, Ethylacetanilide (I) $k_E = 2.6$ (83)

t, °C	γ (?) ±0.5
60	34.6
75	33.1
90	31.5
105	29.9

$C_{10}H_{14}$, 1, 2, 4, 5-Tetramethylbenzene (I) (13)

t, °C	γ ±0.4
108.5	22.07
210.2	13.45

$C_{10}H_{14}$, *p*-Isopropyltoluene (I, II) $k_E = 2.3$ (18, 23, 40, 62, 72)

t, °C	γ (air)
5	29.5±0.2
20	28.1±0.1
50	25.3±0.2
100	20.7±0.2
150	16.1±0.3
176	13.8±0.4

$C_{10}H_{14}O$, Carvol (I) (73)

$a^2 = 0.076947 - 0.0001611t$

At 227.5°C, γ = 15.6

$C_{10}H_{14}O$.—(*Continued*)

t	a^2 ±2%
10.5	0.07525
45.7	0.06757
91.5	0.06220
137.5	0.05479

$C_{10}H_{14}O$, *dl*-β-Phenylethylmethyl carbinol (I) $k_E = 2.2$ (76)

t, °C	γ‡‡
10	36.7
80	30.1

$C_{10}H_{14}O$, *d*-β-Phenylethylmethyl carbinol (I) $k_E = 2.0$ (76)

t, °C	γ‡‡
10	36.5
80	30.3

$C_{10}H_{14}O$, *l*-β-Phenylethylmethyl carbinol (I) $k_E = 2.2$ (76)

t, °C	γ‡‡
10	36.7
80	30.2

$C_{10}H_{14}O$, Thymol (III) (30)

t, °C	γ (N_2) ±2†
0	34.2
115	25.3
211	17.9

$C_{10}H_{14}O_4$, "labile" Diethyl 3-methyl-Δ²-cyclopropene-1, 2-dicarboxylate (III) (82.7)

t, °C	γ (air) ±1§§
26	33.98
50	31.13
77	27.99

$C_{10}H_{14}O_4$, "normal" Diethyl 3-methyl-Δ²-cyclopropene-1, 2-dicarboxylate (III) (82.7)

t, °C	γ (air) ±1§§
41.5	31.42
51	30.33
62	29.12
77.5	27.52

$C_{10}H_{15}N$, Diethylaniline (I) (13, 31, 65)

t, °C	γ
15	34.7±0.3
20	34.2±0.3
50	31.1±0.3
110	24.9±0.5
210	14.7±0.7

$C_{10}H_{16}$, *dl*-Limonene (I) $k_E = 2.3$ (37)

t, °C	γ‡‡
10	28.1
90	20.8

$C_{10}H_{16}$, *d*-Limonene (I) $k_E = 2.3$ (37)

t, °C	γ‡‡
10.9	28.5
90.3	21.2

$C_{10}H_{16}$, *l*-Limonene (I) $k_E = 2.2$ (37)

t, °C	γ‡‡
6.2	28.5
95.5	20.5

$C_{10}H_{16}$, *dl*-Pinene (I) $k_E = 2.3$ (37)

t, °C	γ‡‡
10	27.0
90	19.5

$C_{10}H_{16}$, *d*-Pinene (I) $k_E = 2.4$ (37)

t, °C	γ‡‡
12.6	27.2
91.4	19.8

$C_{10}H_{16}$, *l*-Pinene (I) $k_E = 2.3$ (37)

t, °C	γ‡‡
11.4	27.3
93.8	19.6

$C_{10}H_{16}$, Sylvestrene (III) (30)

t, °C	γ (N_2) ±2†
−70	35.7
+55.5	23.2
149.5	14.6

$C_{10}H_{16}$, Terebene (III) (30)

t, °C	γ (N_2) ±2†
−74	35.8
+86.3	21.1
170	13.9

$C_{10}H_{16}O_2$, α-Campholenic acid (III) (30)

t, °C	γ (N_2) ±2†
0	37.0
117	26.4
212	18.8

$C_{10}H_{16}O_4$, Diethyl cyclobutane-1, 1-dicarboxylate (III) (82.7)

t, °C	γ (air) ±1§§
15	32.51
49	28.70
81	25.24

$C_{10}H_{18}O$, Linalool (I) $k_E = 2.3$ (62)

t, °C	γ (air) ±0.3
8.0	28.74
34.0	26.42
55.0	24.55
78.0	22.83
109.0	20.20
124.7	18.85

$C_{10}H_{18}O_2$, α-Dihydrocampholenic acid (III) (30)

t, °C	γ (N_2) ±2†
0	34.3
95	25.3
195.3	18.9

$C_{10}H_{18}O_3$, Ethyl diethylacetoacetate (II) (39)

t, °C	γ (air) ±0.4
30	28.24
40	27.25
50	26.29

For notes †–§§ *see* p. 475.

$C_{10}H_{22}$, Diisoamyl (I, II) (23, 47, 72)

t, °C	γ (air)
0	23.96±0.2
20	22.24±0.1
30	21.41±0.2
160	10.7 ±0.3

$C_{10}H_{22}O$, Isoamyl ether (I) $k_E = 2.2$ (31)

t, °C	γ (?) ±2
17.8	23.2
64.0	19.5

$C_{10}H_{23}N$, Diisoamylamine (III) (30)

t, °C	γ (N_2) ±2†
−20	26.5
+80.8	17.9
178.5	10.8

$C_{11}H_{10}O_2$, Ethyl phenylpropiolate (I) $k_E = 2.4$ (89)

t, °C	γ (air) ±0.3
15.6	39.68
35.4	37.57
66.5	34.31
81.5	32.78
99.9	30.94

$C_{11}H_{12}O$, Benzylidene methyl ethyl ketone (I) $k_E = 2.7$ (16)

t, °C	γ (air) ±*ca.* 1.5
59.5	38.5
67.0	37.5
82.0	36.1
110.5	32.9
124.0	31.6
138.0	30.3
180.0	25.7

$C_{11}H_{12}O_2$, Ethyl cinnamate (I, II) (18, 39, 89)

t, °C	$γ_1$ (air)	$γ_2$ (air)
7	39.87	
15	38.93	
20	38.37	
25	37.80	37.10
30	37.25	36.61
41	36.09	35.52
50		34.68
100		29.82

$C_{11}H_{12}O_3$, Ethyl β-hydroxy-α-phenylacrylate (I) (92)

t, °C	γ ±0.4
37.3	36.0
68.9	32.3
118.9	27.4

$C_{11}H_{14}O_2$, Ethyl hydrocinnamate (II) (18)

At 21.5°C, γ (air) = 35.08 ± 0.3

$C_{11}H_{16}$, Pentamethylbenzene (I) (13)

t, °C	γ ±0.4
108.1	24.65
207.4	16.32

$C_{11}H_{18}O_4$, Diethyl caronate (Ethyl *trans*-3, 3-dimethylcyclopropane-1, 2-dicarboxylate) (III) (82.7)

t, °C	γ (air) ±1§§
12	31.56
54	27.10
75	25.00
93.5	23.15

$C_{11}H_{18}O_6$, Diethyl *O*-propionylmalate (I) k_E = 2.9 (29)

t, °C	γ ±0.3
56.2	28.86
107.4	23.97
149.0	20.46

$C_{11}H_{20}$, *n*-Nonylacetylene (I) k_E = 2.5 (90)

t, °C	γ (air) ±0.3
20.3	28.47
36.6	26.90
55.6	25.10
75.8	23.29
92.5	21.82

$C_{11}H_{20}O_2$, Undecylenic acid (II) (23)

At 25°C, γ (air) = 30.64 ± 0.3

$C_{11}H_{20}O_3$, Ethyl isoamylacetoacetate (I) (92)

t, °C	γ ±0.4
35.6	26.8
97.5	21.6
139.0	18.1

$C_{11}H_{22}O_2$, Ethyl *n*-nonylate (II) (20)

At 20°C, γ (air) = 28.04 ± 0.2

$C_{12}H_{10}$, Acenaphthene (I) (13)

t, °C	γ ±0.4
128.6	32.3
178.7	27.4

$C_{12}H_{10}$, Diphenyl (I) (13)

t, °C	γ ±0.4
129.2	29.5
179.7	24.8

$C_{12}H_{10}N_2O$, Azoxybenzene (III) (82)

t, °C	γ (air) ±1§§
51	43.34
66.5	41.42
77.5	40.26
89	39.17

$C_{12}H_{11}N$, Diphenylamine (I, III) (14, 30, 56, 83)

t, °C	γ (air or vapor) ±1.0
80	37.7
150	30.7
200	26.0
275	19.8

$C_{12}H_{14}O_4$, Diethyl phthalate (I, II) (18, 44, 89)

t, °C	γ (air)	k_E
10	38.5±0.3	
20	37.5±0.2	3.1
50	34.5±0.3	
75	32.0±0.3	
94	30.1±0.4	2.6

$C_{12}H_{14}O_4$, *dl*-Ethyl benzoyllactate (I, II) k_E = 3.0 (29, 44)

t, °C	γ (air or vapor) ±0.3
15	37.5
20	36.9
60	32.8
110	27.6

$C_{12}H_{16}O_2$, *n*-Propyl hydrocinnamate (I) k_E = 2.8 (89)

t, °C	γ (air) ±0.3
19.0	34.50
31.7	33.15
47.9	31.52
62.1	30.05
80.5	28.31

$C_{12}H_{16}O_2$, Isopropyl hydrocinnamate (I) k_E = 2.7 (89)

t, °C	γ (air) ±0.3
18.5	33.27
42.0	30.96
51.7	30.00
71.7	28.07
100.6	25.27

$C_{12}H_{18}O_6$, Triethyl aconitate (I) k_E = 3.2 (90)

t, °C	γ (air) ±0.3
20.3	34.55
34.8	33.04
51.0	31.36
69.7	29.47
90.6	27.43

$C_{12}H_{20}O_6$, *l*-Diethyl *O*-*n*-butyrylmalate (I, II) k_E = 3.3 (29, 44)

t, °C	γ (air or vapor) ±0.3
0	33.9
20	31.8
50	28.9
100	24.1
145	20.1

$C_{12}H_{22}O_2$, Ethyl α-dihydrocampholenate (III) (30)

t, °C	γ (N_2) ±2†
−21	31.0
+95	21.5
194	13.5

$C_{12}H_{27}N$, Triisobutylamine (III) (30)

t, °C	γ (N_2) ±2†
−21	24.5
+90.3	18.0
185	11.0

$C_{13}H_6Cl_4O$, 3, 4, 3′, 4′-Tetrachlorobenzophenone (III) (30)

t, °C	γ (N_2) ±2†
154	35.1
186.5	32.1
220	29.3

$C_{13}H_6Cl_6$, 2, 4, 2′, 4′-Tetrachlorobenzophenone dichloride (III) (30)

t, °C	γ (N_2) ±2†
156	31.2
185.5	29.9
218	27.9

$C_{13}H_{10}O$, Benzophenone (I, II) k_E = 2.9 (13, 50, 89)

t, °C	γ (air or vapor) ±0.4
10	46.2
20	45.1
50	41.8
90	37.4

$C_{13}H_{10}O_3$, Diphenyl carbonate (III) (82)

t, °C	γ (air) ±1§§
101	34.28
120.5	32.19
139	30.41

$C_{13}H_{10}O_3$, Phenyl salicylate (III) (30)

t, °C	γ (N_2) ±2†
0	45.7
90.1	36.8
211.6	26.3

$C_{13}H_{12}$, Diphenylmethane (I, II) (13, 24, 40)

t, °C	γ (air)
30	37.1±0.5
60	34.9±0.5
210	24 ±2.0

$C_{13}H_{12}O$, Benzohydrol (I) k_E = 2.2 (28)

t, °C	γ ±0.4
73.55	38.65
90.9	37.06

$C_{13}H_{14}O_2$, Isobutyl phenylpropiolate (I) k_E = 2.3 (89)

t, °C	γ (air) ±0.3
16.7	35.34
34.6	33.71
62.0	31.23
93.0	28.39

$C_{13}H_{16}O$, Benzalpinacolin (I) k_E = 2.6 (16)

t, °C	γ (air) ±*ca.* 1.5
62.0	32.8
83.0	30.9
110.3	28.6
137.1	26.0
156.0	24.5
199.0	20.6

$C_{13}H_{22}O_6$, *l*-Diethyl *O*-*n*-valerylmalate (I) k_E = 3.5 (29)

t, °C	γ ±0.3
16.3	31.51
54.7	27.52
107.4	23.20
147.8	19.93

For notes †-§§ *see* p. 475.

$C_{13}H_{24}O_4$, Di-*act*.-amyl malonate (I, II) k_E = 2.8 (44, 89)

t, °C	γ (air)‡
25	27.9±0.7
60	25.1±0.6
100	21.9±0.5

$C_{14}H_{10}O_2$, Benzil (III) γ (air) (96)

$C_{14}H_{12}O_2$, Benzyl benzoate (III) (30)

t, °C	γ (N_2) ±2†
21.8	47.4
90.8	35.8
210.5	26.6

$C_{14}H_{14}$, *sym*.-Diphenylethane (I) (13)

t, °C	γ ±0.4
108.3	29.09
210.2	19.95

$C_{14}H_{14}$, 1, 1-Diphenylethane (II) (24)

t, °C	γ (air) ±0.5
20	37.67
25	37.20

$C_{14}H_{14}N_2O$, *o*, *o*′-Azoxytoluene (III) (82)

t, °C	γ (air) ±1§§
69.5	40.41
78.5	39.39
90.5	38.33
101	37.25

$C_{14}H_{14}N_2O_3$, *p*, *p*′-Azoxyanisole (I) (67)

t, °C	γ
116.3	38.62
133.3	37.27
135.1	37.01
153.3	35.60

(III) (30)

t, °C	γ (N_2)†
115	40.1
160.5	35.5
211	31.4

$C_{14}H_{15}N$, Dibenzylamine (I) k_E = 2.9 (83)

t, °C	γ (?) ±0.5
20	41.1
30	40.0
45	38.4
60	36.8
75	35.1

$C_{14}H_{20}O_2$, Amyl hydrocinnamate (II) (43)

t, °C	γ (air) ±0.3
15	32.45
40	30.30

$C_{14}H_{20}O_2$, *act*.-Amyl hydrocinnamate (I) k_E = 2.8 (89)

t, °C	γ (air) ±0.3‡
16.0	33.20
38.4	31.13
57.0	29.43
83.8	27.05
99.8	25.64

$C_{14}H_{23}ClO_4$, Di-*act.*-amyl chlorofumarate (I, II) k_E = 2.9 (44, 89)

t, °C	γ (air)‡
30	29.6 ± 0.6
60	27.2 ± 0.5
100	24.0 ± 0.5

$C_{14}H_{23}N$, Diisobutylaniline (III) (30)

t, °C	γ (N_2) ±2†
0	32.8
92.5	23.9
195.8	15.9

$C_{14}H_{24}O_4$, Di-*act.*-amyl maleate (I) k_E = 2.8 (89)

t, °C	γ (air) ±0.3‡
17.4	29.59
28.7	28.62
42.8	27.47
61.2	25.97
73.2	25.01
96.8	22.62

$C_{14}H_{24}O_6$, *l*-Diethyl *O*-caproylmalate (I) k_E = 3.1 (29, 62)

t, °C	γ (air or vapor) ±0.3
10	31.8
20	30.9
50	28.3
100	24.0
145	20.1

$C_{14}H_{26}O_4$, Di-*act.*-amyl succinate (I, II) k_E = 2.9 (44, 89)

t, °C	γ (air) ±0.7‡
20	28.9
50	26.5
100	22.6

$C_{14}H_{26}O_4$, Diethyl sebacate (I) k_E = 3.3 (90)

t, °C	γ (air) ±0.3
22.5	32.94
38.7	31.30
55.8	29.65
75.0	27.84
97.6	25.78

$C_{14}H_{26}O_5$, Diamyl malate (II) (44)

t, °C	γ (air) ±0.3
30	27.96
40	27.28
60	25.95

$C_{15}H_{16}$, 1, 1-Diphenylpropane (II) (24)

t, °C	γ (air) ±0.5
20	37.15
25	36.64

$C_{15}H_{16}$, Di-*p*-tolylmethane (II) (24)

t, °C	γ (air) ±0.5
20	35.51
25	34.80

$C_{15}H_{22}O_8$, Tetraethyl cyclopropane -1, 1, 2, 2-tetracarboxylate (III) (82.7)

$C_{15}H_{22}O_8$.—(*Continued*)

t, °C	γ (air) ±1§§
76	29.08
97	27.08
122	24.75
152	21.93

$C_{15}H_{26}O_4$, Di-*act.*-amyl citraconate (I) k_E = 2.9 (89)

t, °C	γ (air) ±0.3‡
24.8	28.78
46.5	26.91
66.6	25.29
82.6	24.00
99.9	22.65

$C_{15}H_{26}O_4$, Di-*act.*-amyl mesaconate (I) k_E = 2.9 (89)

t, °C	γ (air) ±0.3‡
27.4	29.16
42.0	27.96
60.1	26.45
74.5	25.26
101.1	23.16

$C_{15}H_{26}O_6$, Tributyrin (III) (30)

t, °C	γ (N_2) ±2†
−20.5	33.0
+99.8	25.5
200.8	18.3

$C_{15}H_{26}O_6$, *l*-Diethyl *O*-*n*-heptoylmalate (I, II) k_E = 3.2 (29, 44)

t, °C	γ (air or vapor) ±0.3
0	32.6
20	30.9
60	27.4
145	20.0

$C_{15}H_{33}N$, Triisoamylamine (I) k_E = 3.2 (83)

t, °C	γ (?) ±0.5
20	24.5
30	23.6
45	22.3
60	21.1
75	19.8

$C_{16}H_{14}O_4$, *o, o*-Dimethoxybenzil (III) γ (air) (96)

$C_{16}H_{16}NO_2$, Anisaldazine (III) (30)

t, °C	γ (N_2) ±2†
171	32.1
180.5	31.2
230.5	26.8

$C_{16}H_{18}N_2O_3$, *p*-Azoxyphenetole (I) (67)

t, °C	γ
134.9	30.77
165.1	28.44
169.4	28.06
183.8	27.01

(III) (30)

t, °C	γ (N_2)†
142.5	31.6
174.5	28.6
219	25.2

$C_{16}H_{22}O_4$, Diethyl ethylbenzylmalonate (III) (30)

t, °C	γ (N_2) ±2†
0	39.0
106	28.1
206.5	19.7

$C_{16}H_{28}O_6$, *l*-Diethyl *O*-*n*-octoylmalate (I, II) k_E = 3.2 (29, 44)

t, °C	γ (air or vapor)
0	32.5 ± 0.2
20	30.7 ± 0.2
50	28.1 ± 0.3
100	23.8 ± 0.3
145	20.3 ± 0.3

$C_{16}H_{34}N_2S$, Triisoamylammonium thiocyanate (I) k_E = 1.5 (88)

t, °C	γ (air) ±0.3
80	30.31
100	29.39
122	28.42

$C_{17}H_{14}O_3$, Dibenzoylacetone (I) (69)

t, °C	γ ±*ca.* 2.0
109.5	35.3
169.7	30.1

$C_{17}H_{30}O_6$, *l*-Diethyl *O*-*n*-nonoylmalate (I, II) k_E = 3.9 (29, 44)

t, °C	γ (air or vapor)
0	32.5 ± 0.4
20	30.8 ± 0.3
50	28.1 ± 0.3
100	23.8 ± 0.3
145	20.3 ± 0.3

$C_{18}H_{15}O_4P$, Triphenyl phosphate (III) (82)

t, °C	γ (air) ±1§§
65.5	40.63
74	39.64
84	38.71

$C_{18}H_{15}P$, Triphenylphosphine (I) k_E = 3.3 (89)

t, °C	γ (air) ±0.4
45.7	42.04
68.8	39.74
95.9	36.94
107.1	35.80

$C_{18}H_{15}Sb$, Triphenylstibine (I) k_E = 2.9 at 35°C; 3.6 at 100°C (89)

t, °C	γ (air) ±0.3
35.1	43.01
63.1	40.37
91.2	37.32
103.0	36.08

$C_{18}H_{18}N_2O_5$, Ethyl *p*-azoxybenzoate (III) (30)

t, °C	γ (N_2) ±2†
114	27.0
140	26.2
230	25.3

For notes †–§§ *see* p. 475.

$C_{18}H_{26}O_4$, Di-*act.*-amyl phthalate (I, II) (44, 89)

t, °C	γ (air) ±0.7‡	k_E
20	31.5	3.3
60	28.6	
105	25.2	2.5

$C_{18}H_{32}O_6$, *l*-Diethyl *O*-*n*-decoylmalate (I, II) k_E = 3.7 (29, 44)

t, °C	γ (air or vapor)
0	32.8 ± 0.4
20	31.0 ± 0.4
50	28.3 ± 0.3
100	23.0 ± 0.3
145	20.5 ± 0.3

$C_{18}H_{34}O_2$, Oleic acid (II) (18, 20)

At 20°C, γ (air) = 32.50 ± 0.3

$C_{18}H_{34}O_3$, Ricinoleic acid (II) (18)

At 16°C, γ (air) = 35.81 ± 0.3

$C_{19}H_{16}$, Triphenylmethane (I) (56)

At 125°C, k_E = 2.1; at 300°C, k_E = 1.5

t, °C	γ ±*ca.* 1
108.7	33.8
130.5	31.4
154.0	28.8
208.2	24.5
229.6	23.0
278.7	19.2
335.5	15.4

$C_{19}H_{16}O$, Triphenyl carbinol (I) k_E = 2.2 (28)

t, °C	γ ±0.4
165.8	30.38
190.5	28.67

$C_{20}H_{38}O_4$, Diisoamyl sebacate (I) k_E = 3.4 (90)

t, °C	γ (air) ±0.3
23.5	30.86
35.9	29.83
52.0	28.50
64.8	27.50
80.5	26.23
95.1	25.08

$C_{20}H_{44}IN$, Tetraisoamylammonium iodide (I) k_E = 1.8 (88)

t, °C	γ (air) ±0.3
99.5	27.27
109.5	26.84
119.0	26.39
130.5	25.88

$C_{21}H_{21}N$, Tribenzylamine (I) k_E = 3.6 (83)

t, °C	γ (?) ±0.5
95	33.7
105	32.8
120	31.3
135	29.8

$C_{21}H_{23}NO_3$, Ethyl p-ethoxybenzalamino-α-methylcinnamate (III) (30)

t, °C	γ (N_2) ±2†
85	28.7
123.7	28.3
179	27.7

$C_{21}H_{38}O_6$, Tricaproin (III) (30)

t, °C	γ (N_2) ±2†
−20	33.4
+99.8	25.3
200	19.6

$C_{22}H_{42}O_3$, Isobutyl ricinoleate (I) k_E = 3.4 (87)

t, °C	γ (air) ±0.3
23	31.30
55.5	28.81
85.3	26.49

$C_{23}H_{46}O_2$, act.-Amyl stearate (I, II) k_E = 3.5 (29, 44)

t, °C	γ (air or vapor) ±0.3‡
30	29.1
50	27.6
100	24.0
150	20.4

$C_{26}H_{54}$, n-Hexacosane (I) k_E = 3.9 (70)

t, °C	γ‡‡
91.7	24.8
121.8	22.5
158.3	19.9

$C_{27}H_{50}O_6$, Tricaprylin (III) (30)

t, °C	γ (N_2) ±2†
0	30.1
99.8	25.1
200.2	19.7

$C_{30}H_{62}O$, Myricyl alcohol (I) k_E = 4.2 (70)

t, °C	γ‡‡
95.3	26.2
131.3	23.4
158.2	21.6

$C_{33}H_{62}O_6$, Tricaprin (III) (30)

t, °C	γ (N_2) ±2†
35.4	27.6
121	23.0
201.2	18.8

$C_{34}H_{50}O_2$, Cholesteryl benzoäte (I) (67)

t, °C	γ‡‡
147.4	23.8
177.2	22.9
181.4	22.9
210.2	21.8

$C_{39}H_{74}O_6$, Trilaurin (III) (30)

t, °C	γ (N_2) ±2†
64.7	29.2
139	25.1
200	22.1

$C_{51}H_{98}O_6$, Tripalmitin (I) k_E = 5.4 (87)

t, °C	γ (air) ±0.3
55.7	29.47
65.9	28.78
76.9	27.98
87.6	27.19
96.7	26.56
115.3	25.32

$C_{57}H_{104}O_6$, Triolein (III) (30)

t, °C	γ (N_2) ±2†
17	40.1
99.8	29.3
200.6	25.0

$C_{57}H_{110}O_6$, Tristearin (I) k_E = 5.5 (87, 92)

t, °C	γ (air or vapor)
60	29.6
100	26.8
130	24.7

$C_{60}H_{122}$, n-Hexacontane (I) k_E = 5.5 (70)

t, °C	γ‡‡
115.4	24.2
159.9	21.6
190.6	19.8

For notes †–§§ *see* p. 475.

LITERATURE

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SURFACE TENSION OF SOLUTIONS

Abbreviations and Symbols; *v. further* p. 433

M = Moles per kg solvent.
M/l_s = Moles per liter solution.
g/l_s = grams per liter solution.
x_A = Mole fraction of A.

Contents

The values for *pure liquids* which appear in the tables of this section are not the best values but are those obtained with the liquid actually used in preparing the solutions (corrected, however, for obvious errors, such as the use of too small a tube for the larger tube in the capillary-height method). The use of these values is necessary in order to give the best values of $\Delta\gamma$ and the proper shape to the γ-composition curves.

See p. 474, 475 for effect of various inorganic gases and p. 475 for effect of organic vapors on the surface tension at the interface, liquid—gas.

Aqueous Solutions, One Solute

𝔅-Table,* Standard Arrangement (*v.* Vol. III, p. viii)

* Very dilute aqueous salt solutions have been studied by Gradenwitz (15, 22) and Kleine (22, 25). The results of these workers indicate that $d\gamma/dM$ decreases as M increases. The value of $\Delta\gamma$ found by them for relatively large values of M do not agree well with reliable modern determinations. Therefore, their results are not reproduced in these tables. Until their work is repeated the shape of the $\Delta\gamma$-M curves in dilute solutions (M < 0.2) will remain uncertain.

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LITERATURE REFERENCES

In all literature references cited in International Critical Tables the name of the journal or publication is indicated by means of a *Key Number* corresponding to the list given below. The numbers which follow this key number in a literature citation are, in the order named: (1) the volume, (2) the page, and (3) the last two figures of the year. Thus *64V*, **31**: 253; 22, indicates Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, page 253, 1922. Series numbers are not given. Key Numbers referring to books and other non-serial publications are preceded by the letter *B*, and the volume number is given in Roman numerals. Thus *B10*, **IV**: 191; 18, indicates Doelter, Handbuch der Mineralchemie, page 191 of Vol. 4 of the 1918 edition. The Key Number *O* is used to indicate "private communication from."

DAS LITERATURVERZEICHNIS

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In tutte le indicazioni bibliografiche che si incontrano nelle "Tabelle Critiche Internazionali" il nome del giornale o della pubblicazione è espresso con un *numero chiave* riportato nell'elenco dato più oltre. I numeri che, nella citazione, vengono dopo il numero chiave sono disposti con l'ordine seguente: (1) il volume, (2) la pagina, e (3) le ultime due cifre del millesimo. Cosi *64V*, **31**: 253; 22, indica la Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, pagina 253, 1922. I numeri di serie non vengono dati. Quando un numero chiave è preceduto dalla lettera *B* si riferisce a libri o ad altre pubblicazioni non periodiche, e il numero del volume viene allora scritto in cifre romane. Cosi *B10*, **IV**: 191; 18, indica Doelter, Handbuch der Mineralchemie, pagina 191 del IV° volume dell'edizione 1918. Il numero chiave *O* indica "Comunicazione privata da . . . "

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INTERNATIONAL CRITICAL TABLES

VISCOSITY AND FLUIDITY

VISCOSITY OF GASES

L. L. Bircumshaw and Vaughan H. Stott

DEFINITIONS AND FORMULAE

For small velocities, the rate of shear in a gas is proportional to the shearing stress. The ratio of the latter to the former is known as the viscosity (η). The C. G. S. unit of viscosity is called the "poise."

In the case of most gases, the influence of temperature on the viscosity may be represented by the following formula due to Sutherland (1893):

$$\eta = \eta_o \frac{T_o + C}{T + C}\left(\frac{T}{T_o}\right)^{3/2},$$

where η and η_o are the viscosities at the absolute temperatures T and T_o, respectively, and C is "Sutherland's constant." C may readily be determined graphically from a number of observations by plotting T against $T^{3/2}/\eta$, since we have

$$T = \left[\frac{T^{3/2}}{\eta}\right]\left[\frac{\eta_o\left(1 + \frac{C}{T_o}\right)}{T_o^{1/2}}\right] - C$$

FLOW OF GAS THROUGH A CAPILLARY TUBE

For very small velocities, the following equation due to Meyer may be used:

$$F = \frac{\pi r^4}{16\eta l p}\left(1 + \frac{4\xi}{r}\right)(p_1^2 - p_2^2),$$

where F = volume of gas (measured at mean pressure p) flowing per second, p_1 = entrance pressure, p_2 = exit pressure, l, r = length and radius of the tube, respectively, and ξ, the slip coefficient, is approximately equal to the mean free path of the molecules.

Except at very small velocities, the above formula requires a considerable correction for kinetic energy. The corrected formula may be written, according to Brillouin (3)

$$p_1^2 - p_2^2 = \frac{p}{\rho}\left[\frac{16\eta l M}{\pi r^4\left(1 + \frac{4\xi}{r}\right)} + \frac{2M^2}{\pi^2 r^4}\right],$$

where M = the mass of gas transpired per second and ρ = the density of the gas at the mean pressure p.

Fisher (4) gives the following correction to the pressure at the entrance end due to the kinetic energy effect:

$$RT \log_e \frac{p_1}{p_1} = -\frac{1}{384}\left[\frac{p_1^2 - p_2^2}{\eta p_1 l}\right]^2 [r^4 + 12\xi^2 r^2 + 6\xi r^3],$$

where R = the gas constant, T = the absolute temperature, p_1 = the pressure to be used in Poiseuille's law, and p_1' = the manometer pressure measured in the vessel at the end of the tube. A similar formula with subscripts "2" gives the correction at the exit end.

Rapp (28) found that the following empirical formula gives the same results as Fisher's formula within the limits of experimental error:

$$\eta = \eta'\left[1 + \mathrm{A}\frac{r^4(p_1 - p_2)}{l}\right],$$

where η is the corrected value of η'. The constant A is negative.

FLOW OF GASES THROUGH TUBES

The flow becomes turbulent when the value of $\mathrm{K} = \rho\frac{Vd}{\eta}$ exceeds a certain value depending on the material of the tube, where ρ is the density, η the viscosity, V the velocity of the gas, and d the diameter of the tube. For practical purposes, K may be taken as >2000 for ordinary tubes.

It has been found that when due allowance is made for slip, the viscosity of a gas is independent of the pressure. The coefficient of slip between a solid and a gas depends both on the nature of the gas and on that of the solid surface [Van Dyke (39), Millikan (14) and States (35)].

In most measurements of gaseous viscosities, the value for air at a given temperature is either assumed or determined. Unless otherwise indicated, the viscosity values in the following tables have been corrected, in cases where the air value assumed or determined by the author is known, by assuming that for air η_{23} = 1822.6 × 10^{-7} (9) and that C = 120.

A-TABLE.—ELEMENTARY SUBSTANCES AND ATMOSPHERIC AIR

Gas	t, °C	η, micropoise (10^{-6} poise)	Remarks	Lit.
A	0	209.6	C = 142	(20, 21, 22)
	23	221.0		(10)
Br_2	12.8	151		(24)
	65.7	170		
	99.7	188	C = 460	
	139.7	208		
	179.7	227		
	220.3	248		
Cl_2	12.7	129	C = 325	(23)
	99.1	168		
H_2	23	88.2	C = 72, Breitenbach C = 83, Rayleigh	(42)
	0	84.2		(7)
	−192.3	36.2		
	−252.5	8.5		
	−257.7	5.7		
	0	(84.11)	Down to −183°, $\eta = \eta_o\left(\frac{T}{273.1}\right)^{0.695}$; p = *ca.* 400 mm except for last value, where p = 200 mm	(15)
	+ 20.8	88.72		
	−102.9	60.93		
	−183.5	39.22		
	−202.2	31.93		
	−253.06	11.10		
	−253.06	10.6		
H_2, Vap.	B. P. (= −252.7)	1.0		
H_2, Liq.		13.00	d = 0.0708 g/ml	(40)
He	0	187.3	C = 70	(20, 21, 22)
	23	198.1		
	23	196.23		(5, 10)
	15	108.6		
	0	186.0		
	−191.6	87.1		(7)
	−252.6	35.0		
	−257.4	27.0		
	0	(188.7)		(16)
	+ 21.43	199.4	$\eta = \eta_o\left(\frac{T}{273.1}\right)^{0.647}$	(16)
	− 22.8	178.8		
	− 70.0	156.4		
	−102.6	139.2		
	−184.35	91.85		
	−198.0	81.54		
	−252.93	35.03		
	−258.1	29.46		
Hg	273	494		(11)
	313	551		
	369	641		
	380	654		
I_2	124.0	184		(25)
	170.0	204		
	205.4	220	C = 590	
	247.1	240		
Kr	0	232.7	C = 188	(20, 21, 22)
N_2	23	176.5	C = 110.6, Bestelmeyer	(42)
Ne	0	297.3	C = 56	(20, 21, 22)
O_2	23	203.9	C = 127, Eglin	(35, 42)
Rn	0	212.4 (calc.)	C = 337 (calc.)	(20, 21, 22)
Xe	0	210.1	C = 252	(20, 21, 22)

Atmospheric air based on Harrington's value at 23° (9) and computed with C = 120; unit is 10^{-7} poise

°C	η	Dif.	°C	η	Dif.
0	1709	50	200	2582	38
10	1759	49	210	2620	38
20	1808	48	220	2658	38
30	1856	48	230	2696	37
40	1904	47	240	2733	37
50	1951	46	250	2770	36
60	1997	46	260	2806	36
70	2043	46	270	2842	35
80	2088	45	280	2877	35
90	2132	44	290	2912	34
100	2175	43	300	2946	34
110	2218	42	310	2980	34
120	2260	42	320	3014	33
130	2302	42	330	3047	33
140	2344	41	340	3080	33
150	2385	40	350	3113	33
160	2425	40	360	3146	33
170	2465	40	370	3179	33
180	2505	39	380	3212	33
190	2544	38	390	3245	32

Atmospheric air.—(*Continued*)

°C	η	Dif.	°C	η	Dif.
400	3277	32	460	3463	30
410	3309	31	470	3493	30
420	3340	31	480	3523	30
430	3371	31	490	3553	30
440	3402	31	500	3583	
450	3433	30			

No change in the viscosity of air could be detected in an electric field of 18 000 volt/cm (30). For effect of saturation with vapors, *v.* p. 6.

𝔅-Table.—Standard Arrangement

(*v.* Vol. III, p. viii)

Substance	t, °C	η, micropoise (10^{-6} poise)	C	Lit.
H_2O	*v.* Table 1			
HCl	12.5	138.5	357	(8)
	100.3	182.2		
HBr	18.7	181.9	375	(8)
	100.2	234.4		
HI	20.6	185.7	390	(8)
	100.2	238.3		
SO_2	0	117		(33, 41)
	18	124.2	416	
	100	161.6		
H_2S	0	116.6	331	(26)
	17	124.1		
	100	158.7		
NO	0	178		(41)
N_2O	0	135		(41)
NH_3	− 78.5	67.2		(26, 41)
	0	91.8		
	100	129.3	370	
PH_3	0	106.1	290	(26)
	15	112.0		
	100	143.8		
AsH_3	0	145.8	300	(26)
	15	114.0		
	100	198.1		
CO	−191.5	56.1		(31, 41)
	− 78.5	127		
	0	166		
	15	172	118	
	100	210		
CO_2	*v.* Table 2			
CS_2	0	91.1		(36)
	14.2	96.4		
COS	15	119.0	330	(33)
	100	154.1		
C_2N_2	0	92.8	330	(26)
	17	98.7		
	100	127.1		
SiH_4	15	112.4	229	(27)
	100	142.4		

ℭ-Table.—The ℭ-Arrangement (*v.* Vol. III, p. viii)

Formula	Name	t, °C	η, micropoise (10^{-6} poise)	C	Lit.
$CHCl_3$	Chloroform	0	93.6		(29, 36, 41)
		14.2	98.9		
		100	129	292	
		212.5	164		
CH_3Br	Methyl bromide	0	103		(41)
CH_3Cl	Methyl chloride	− 15.3	92	454	(2, 41)
		15.0	104		
		99.1	137		
		182.4	168		
		302.0	211		
		0	96.9		
CH_4	Methane	−181.6	34.8		(26, 41)
		− 78.5	76.0		
		0	102.4		
		0	102.7	198	
		17	108.5		
		100	135.2		
C_2H_2	Acetylene	0	93.5		(41)
C_2H_4	Ethylene	15.0	99	226	(1)
		99.3	126		
		182.4	151		
		302.0	180		
C_2H_5Cl	Ethyl chloride	0	93.7		(41)
C_2H_6	Ethane	− 78.5	63.4		(41)
		0	84.8		
C_2H_6O	Ethyl alcohol	100	108	525	(29)
		212.5	140		
C_3H_6O	Acetone	100	93.1	670	(29)
		212.5	124		
$C_3H_6O_2$	Ethyl formate	99.8	92		(18)
$C_3H_6O_2$	Methyl acetate	99.8	98		(18, 29)
		100	100	660	
		212.5	134		
C_3H_7Br	*n*-Propyl bromide	99.8	119		(18)
C_3H_7Br	Isopropyl bromide	99.8	122		(18)
C_3H_8O	*n*-Propyl alcohol	99.9	93		(18)
C_3H_8O	Isopropyl alcohol	99.8	109		(18)
$C_4H_8O_2$	Propyl formate	99.9	92		(18)
$C_4H_8O_2$	Ethyl acetate	0	68.4		(29); *cf.* (18, 41)
		99.8	96		
		100	94.3	650	
		212.5	126		
$C_4H_8O_2$	Methyl propionate	99.8	94		(18)
C_4H_{10}	*n*-Butane (1 % C_2H_6)	14.7	83.2		(12)
		16.0	83.3		
		100	108.2		
C_4H_{10}	Isobutane	23	75.5		(10)
$C_4H_{10}O$	Ethyl ether	0	67.8		(18, 29, 36, 41)
		14.2	71.6		
		99.8	98		
		100	95.5	325	
		212.5	122		
$C_4H_{10}O$	Trimethyl carbinol	99.8	102		(18)

ℭ-Table.—The ℭ-Arrangement.—(*Continued*)

Formula	Name	*t*, °C	η, micropoise (10^{-6} poise)	C	Lit.
$C_4H_{11}N$	*n*-Butylamine	99.8	82		(18)
$C_4H_{11}N$	Isobutylamine	99.8	88		(18)
$C_4H_{11}N$	Diethylamine	99.9	92		(18)
$C_5H_{10}O_2$	Isobutyl formate	99.8	93		(18)
$C_5H_{10}O_2$	Ethyl propionate	99.9	88		(18)
C_5H_{12}	Isopentane	100 212.5	87.4 115	500	(29)
C_6H_6	Benzene	14.2 100 212.5	73.8 91.8 123	 700	(29, 36)

Table 1.—H_2O Vapor (34)

η in 10^{-6} poise

°C	100.0	151.2	207.1	261.3	C
η	127	145	168	190	650

°C	0	15	20.6	28.9	99.95
η (obs.)	90.4	97.5	97.5	100.6	132.0
η (extrap.)*	88	93	96	100	127

* Taking C = 650.

Table 2.—CO_2

η in 10^{-6} poise (39, 41)

°C	23	0	−78.5
η	147.15	137	102
C	274*	240†	

* Rankine and Smith.
† Breitenbach.

The following table for CO_2 is given by Phillips (17).

η in 10^{-6} poise; *d* in g/cm³

P, atm.	η	*d*	η/*d*
20°C			
83	823	0.835	986
72	771	0.812	950
59	697	0.768	907
56	186	0.190	977
50	177	0.145	1220
40	166	0.100	1660
20	156	0.036	4330
1	148	0.00183	80800
30°C			
110.5	770	0.795	968
104	733	0.781	939
96	693	0.760	913
90	643	0.743	864
82	592	0.716	827
80	565	0.706	800
76	529	0.680	778
74	495	0.664	745
73	478	0.653	732
72	458	0.635	723
70	229	0.287	798
60	187	0.177	1057
40	168	0.092	1830
20	159	0.0354	4500
1	153	0.00177	86400

Table 2.—CO_2.—(*Continued*)

P, atm.	η	*d*	η/*d*
32°C			
120	788	0.790	998
112	741	0.777	954
104	695	0.760	914
93	627	0.729	860
87	586	0.700	837
84	560	0.682	822
80	528	0.655	807
76	448	0.597	751
75	406	0.555	730
74	254	0.360	700
70	214	0.255	840
60	187	0.170	1100
40	175	0.090	1950
20	162	0.0352	4600
1	155	0.00176	88100
35°C			
114.5	693	0.755	918
109	660	0.741	891
96	586	0.696	841
88	511	0.653	782
85	456	0.626	728
80	361	0.494	731
75	237	0.289	820
70	214	0.227	943
60	178	0.163	1091
40	174	0.085	2045
20	163	0.0348	4680
1	156	0.00174	89600
40°C			
112	571	0.699	817
108	540	0.682	792
100	483	0.636	761
94	414	0.582	712
85	269	0.385	698
80	218	0.291	748
70	200	0.204	981
60	187	0.153	1220
40	176	0.083	2120
23.8	169	0.0408	4140
1	157	0.00173	90800

GAS MIXTURES

𝔄-𝔅 Table.—Standard Arrangement

He − H_2

η in micropoises (10^{-6} poise) (5)

% He	% H_2	η		*t*, °C	C
		Calc.	Obs.		
100.1 (*sic.*)	0.0	189.09	189.25	0.00	71.4
		195.46	195.36	13.37	
		234.08	234.10	100.05	
96.094	3.906	184.60	185.00	0.0	73.9
		192.17	191.77	15.93	
		228.95	229.07	100.22	
89.559	10.431	176.00	175.96	0.0	89.8
		182.02	182.14	12.63	
		220.36	220.33	100.02	
86.400	13.600	172.35	173.27	0.0	85.7
		180.10	179.29	16.86	
		215.27	215.57	100.05	

𝔄-𝔅 TABLE.—(*Continued*)

% He	% H_2	η Calc.	η Obs.	t, °C	C
75.087	24.913	159.71	160.32	0.0	
		166.35	165.67	15.86	77.8
		198.35	198.47	99.67	
59.716	40.284	142.52	143.06	0.0	
		148.14	147.55	14.67	87.75
		178.23	178.40	99.80	
39.857	60.143	122.24	122.67	0.0	
		127.00	126.53	15.03	75.50
		151.73	151.77	100.09	
18.807	81.193	101.56	101.65	0.0	
		106.09	106.01	17.0	80.63
		126.48	126.50	100.15	
0.0	100.00	84.10		0.0	
		87.40	87.72	14.79	83.0
		104.95	104.60	100.5	

$O_2 - H_2$

11.1°C (6)	% O_2	100	97.5	95	90	75	0
	$\eta_{rel.}$	1	0.9957	1.000	0.9946	0.9724	0.4502

$O_2 - N_2$

12.2°C (6), η (for 100% O_2) = 1

% O_2	$\eta_{rel.}$	% O_2	$\eta_{rel.}$	% O_2	$\eta_{rel.}$
97.5	0.9984	66.6	0.9550	10	0.8847
95	0.9941	50	0.9348	5	0.8804
90	0.9871	33.3	0.9138	2.5	0.8847
75	0.9734	25	0.9051	0	0.8750

$O_2 - CO$

η_{O_2} at $t°$ = 1 (6)

12.2°C	% O_2	100	25	10	5	2.5	0
	$\eta_{rel.}$	1	0.9040	0.8842	0.8757	0.8743	0.8701
11.1°C	% O_2	100	75	66.7	50	33.3	0
	$\eta_{rel.}$	1	0.9666	0.9593	0.9361	0.9129	0.8664

$O_2 - CO_2$

η_{O_2} at $t°$ = 1 (6)

13.3°C	% O_2	100	50	25	10	5	2.5	0
	$\eta_{rel.}$	1	0.8714	0.8071	0.7679	0.7559	0.7538	0.7464
12.2°C	% O_2	100	97.5	95	90	75	0	
	$\eta_{rel.}$	1	0.9943	0.9872	0.9759	0.9420	0.7510	

$O_2 - CH_4$

η_{O_2} at $t°$ = 1 (6)

12.8°C	% O_2	100	50	25	10	5	2.5	0
	$\eta_{rel.}$	1	0.8076	0.6902	0.5983	0.5827	0.5770	0.5629

$H_2 - SO_2$ (38)

17°C		45°C		70°C		92°C	
% H_2	$\eta \times 10^7$	% H_2	$\eta \times 10^7$	% H_2	$\eta \times 10^7$	% H_2	$\eta \times 10^7$
0.00	1241	0.00	1366	0.00	1476	0.00	1576
17.85	1274	19.72	1404*	19.72	1513	19.72	1609
49.25	1330	49.25	1453	30.01	1534	30.01	1624
70.37	1350	70.37	1472	38.25	1551	38.25	1651
77.14	1324	77.14	1431	51.77	1564	51.77	1657
83.24	1285	83.24	1389	70.37	1573	76.94	1616
100.00	875	100.00	931	76.94	1528	83.43	1554*
				83.43	1483	83.24	1550*
				83.24	1478*	100.00	1022
				100.00	979		

$H_2 - SO_2$.—(*Continued*)

124°C		159°C		199°C	
% H_2	$\eta \times 10^7$	% H_2	$\eta \times 10^7$	% H_2	$\eta \times 10^7$
0.00	1714	0.00	1869	0.00	2041
32.40	1751	32.40	1914	32.40	2087
53.02	1787	53.02	1931	50.95	2090
67.35	1775	67.35	1914	67.35	2068
83.64	1660	83.24	1777	84.88	1924
100.00	1086	84.88	1722	100.00	1219
		100.00	1152		

* For these values the temperature reading was obtained by interpolation over more than 5°C.

$H_2 - N_2$

12.8°C (6), $\eta_{rel.}$ to O_2 = 1	% H_2	100	50	0
	η_{rel}	0.04493	0.8014	0.8690

$H_2 - N_2O$

11.1°C (6), $\eta_{rel.}$ to O_2 = 1	% H_2	25	10	0
	η_{rel}	0.7510	0.7481	0.7481

$H_2 - NO$

11.1°C; values of % H_2 and of η relative to O_2 = 1 (6)

100%	75%	50%	25%	10%	5%	0%
0.4482	0.7159	0.8224	0.8491	0.8609	0.8788	0.8661

$H_2 - NH_3$

12–13°C; values of % H_2 and of η in 10^{-7} poise (37)

0.0%	8.2%	20.1%	33.9%	53.6%	68.4%	79.1%	90.2%	100.0%
1005	1017	1042	1068	1102	1104	1089	1036	915

$H_2 - CO$

11.1°C; $\eta_{rel.}$ to O_2 = 1 (6)

% CO	100	95	92.5	90	75	0
η_{rel}	0.8664	0.8650	0.8635	0.8650	0.8432	0.4586

$H_2 - CO_2$

Values of % H_2 and of $\eta_{rel.}$ to O_2 = 1 (6)

12.8°	100%	25%	10%				
	0.4493	0.7535	0.7521				
12.2°	100%	97.5%	95%	90%	75%	50%	0%
	0.4321	0.4983	0.5157	0.5722	0.6786	0.7339	0.7470

η in 10^{-7} poise

% H_2 (19)*	14.7°	% H_2 (19)*	14.7°	% H_2 (1)	15°	99.2°	% H_2 (37)	15°
0.0	1468	90.16	1215	0.0	1464	1869	0.0	1468
9.97	1477	93.58	1111	12.98	1484		8.5	1483
19.85	1491	96.12	1031	15.56		1897	17.2	1490
27.75	1499	97.60	991	14.99		1880	22.4	1493.5
56.54	1475	98.32	958	48.44	1485	1805	55.4	1485
73.59	1399	100	893	82.20	1289	1624	66.7	1450
83.92	1307			97.24	991	1195	76.5	1367
				100	893	1064	82.2	1292
							87.9	1901

* Not corrected to standard air value.

$H_2 - CH_4$

Values of % H_2 and of $\eta_{rel.}$ to O_2 = 1 (6)

12.2°	100%	17.5%	10%	5%	2.5%	0%	
	0.4497	0.5572	0.5629	0.5615	0.5502	0.5544	
12.8°	100%	97.5%	95%	90%	75%	50%	0%
	0.4616	0.4714	0.4797	0.4965	0.5313	0.5596	0.5481

$H_2 - C_2H_4$

12–13°; η in 10^{-7} poise (37)

% H_2	0.0	27.1	45.6	63.0	72.6	83.0	92.4	100.0
η	1016	1048	1078	1087	1086	1062	1008	915

$NH_3 - C_2H_4$

12-13°; η in 10^{-7} poise (37)

$\%\ NH_3$	0.0	8.0	17.5	27.5	42.0	58.9	81.3	100.0
η	1016	1037	1043	1047	1050	1046	1028	1005

$Air - H_2$

16.1°C (6)

$\%\ H_2$	100	95	90	75	25	0
$\eta_{rel.}$ ($O_2 = 1$)	0.4434	0.5282	0.5880	0.7488	0.8790	
$\eta_{rel.}$ (air = 1)	0.4927	0.5869	0.6534	0.7987	0.9767	1

16.4°C	$\%\ H_2$	50	10	5	0
	$\eta_{rel.}$ ($O_2 = 1$)	0.8197	0.8888	0.8960	
	$\eta_{rel.}$ (air = 1)	0.9108	0.9876	0.9956	1

$Air - H_2O$

Saturated at 26°; $10^7\eta = 1904$ (air = 1863) (13). Stearns (35.1) claims that the viscosity of air is *decreased* by saturating it with moisture, the decrease being ⅓ % at 760 mm and 35 % at 14 mm pressures.

$Air - C_2H_4$

η in 10^7 poise; not corrected to standard air value (1)

$\%\ C_2H_4$	100	90.3	69.0	54.6	30.0	13.6	0.0
η (15°)	1011	1078	1236	1345	1548	1692	1809
η (99.3°)	1282	1367		1674		2069	2209

$Air - C_2H_5OH$

Saturated at 26°; $10^7\eta = 1878$ (air = 1863) (13).

LITERATURE

(For a key to the periodicals see end of volume)

(1) Breitenbach, *8*, **67**: 803; 99. (2) Breitenbach, *8*, **5**: 166; 01. (3) Brillouin, *Leçons sur la viscosité des liquides et des gaz.* Paris, Gauthier-Villars, 1907. (4) Fisher, *2*, **32**: 216; 11. (5) Gille, *8*, **38**: 799; 15. (6) Graham, *62*, **136**: 573; 46. (7) Günther, *7*, **110**: 626; 24. (8) Harle, *5*, **100**: 429; 21. (9) Harrington, *2*, **8**: 738; 16.

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(40) Verschaffelt, *64P*, **20**: 986; 18. *168*, No. **153b**; 18. (41) Vogel, *8*, **43**: 1235; 14. (42) Yen, *3*, **38**: 582; 19.

VISCOSITY OF METALS AND ALLOYS

W. ROSENHAIN, EDITOR

Definitions and Meanings of Symbols

S_e	Tensile stress.
S_g	Shearing stress.
e	Unit elongation.
g	Shear.
E	Young's modulus of elasticity.
G	Modulus of rigidity.
ξ	"Normal" coefficient of viscosity.
η	Tangential coefficient of viscosity.
δ	Logarithmic decrement of damped vibrations.

The coefficients of elasticity and viscosity of an isotropic solid body are defined by the equations:

$$S_e = Ee + \xi\frac{de}{dt}$$

$$S_g = Gg + \eta\frac{dg}{dt}$$

The coefficient of viscosity of a liquid is defined by:

$$S_g = \eta\frac{dg}{dt}$$

The physical significance is different, however, the order of magnitude being 10^{-12} that for a solid.

The logarithmic decrement is the logarithm of the ratio of two successive maximum displacements, on the same side of the equilibrium configuration.

NOTE.—For material possessing no symmetry whatever, there are 21 elastic and 36 viscous constants, which are coefficients in the six linear equations giving the six stress components in terms of the six strain components and their time derivatives. The constants in the following tables have been computed on the assumption that the material is isotropic, though this is admittedly not the case in unannealed wires and possibly not in the other materials investigated.

In general, the coefficients of viscosity computed on this basis from the logarithmic decrement of vibrations, increase linearly with the amplitude of vibration. This may be due either to "after-effect" or to the fact that terms quadratic in the strain-velocities are necessary completely to define the stress components in terms of the strain components. For a discussion of the theory, *see* (11). The values of the coefficients for an amplitude of θ° are designated by ξ_θ and η_θ.

The values of the coefficients of viscosity of solid metals and alloys depend not only upon their chemical composition but very largely on their condition, especially their microstructure. The values given below are to be applied only to material in the same condition and only to specimens whose size is of the same order of magnitude as the specimens for which the results are given.

VISCOSITY OF SOLID METALS AND ALLOYS

F. P. UPTON

"NORMAL" COEFFICIENT OF VISCOSITY FOR ZERO AMPLITUDE AT ROOM TEMPERATURE, CGS UNITS

Determined from damping of flexural vibrations of rectangular strips

Material	Treatment	Dimensions, cm			Period, sec	$10^{-8}\xi_0$	Lit.*
		l	m	n			
Ag	Hammered	26.0	0.500	0.104	0.731	2.85	(5)
	Annealed at 400°C.	26.0	0.500	0.104	0.719	2.24	
Al	Rolled	26.0	0.719	0.0999	0.709	0.75	(5)
	Rolled	26.0	0.372	0.0997	0.798	0.82	
	Annealed at 400°C.	26.0	0.719	0.0999	0.716	1.25	
	Cast Cast	†	†	†	0.684	0.165‡	(11)
					0.934	0.257‡	
Cd	Cast Cast	†	†	†	0.892	8.0§	(11)
					1.220	11.4§	
Cu	Rolled	26.0	0.380	0.134	0.586	4.86	(5)
	Rolled	26.0	0.380	0.134	0.838	5.11	
	Rolled	26.0	0.373	0.049	0.903	4.68	
	Annealed at 300°C.	26.0	0.380	0.134	0.610	5.16	
	Cast	†	†	†	0.708	0.29‖	(11)
Cu-Sn-P	Cast Cast	†	†	†	0.537	0.41‖	(11)
					1.010	0.34‖	
Cu-Zn	Cast	†	†	†	0.732	0.23¶	(11)
Cu, 60; Zn, 40	Rolled	26.0	0.354	0.155	0.535	1.55	(5)
Fe-C, 0.18	Unannealed Annealed	26.0	0.489	0.0726	0.750	4.94	(5)
					0.756	2.68	

"NORMAL" COEFFICIENT OF VISCOSITY.—(*Continued*)

Material	Treatment	Dimensions, cm			Period, sec	$10^{-8}\xi_0$	Lit.*
		l	m	n			
Fe-C, 0.38	Unannealed	26.0	0.497	0.0892	0.688	5.12	(5)
	Annealed				0.684	3.51	
Fe-C, 0.67	Unannealed	26.0	0.500	0.123	0.479	5.93	(5)
	Annealed				0.481	4.30	
Fe-C, 1.17	Unannealed	26.0	0.497	0.0811	0.708	5.06	(5)
	Annealed				0.701	4.27	
Fe-C, 1.75	Unannealed	26.0	0.480	0.0725	0.766	7.20	(5)
Fe-C	Cast (steel)	†	†	†	0.508	1.25**	(11)
					0.724	1.58**	
Fe-C	Cast (iron)	†	†	†	0.480	3.6††	(11)
					0.641	6.0††	
Mg	Hammered	26.0	0.500	0.120	0.751	1.61	(11)
	Annealed at 400°C.				0.755	0.722	
Ni	Rolled	26.0	0.497	0.105	0.550	3.05	(5)
	Cast	†	†	†	0.553	0.96‡‡	(11)
Zn	Rolled	26.0	0.356	0.0669	0.978	27.4	(5)
	Annealed at 200°C.				0.883	9.27	

* Results of (5) were each obtained from damping of vibrations *in vacuo* of a strip loaded at lower end. Results of (11) were each obtained from damping of vibrations of a strip fixed at one end and at the other attached to a heavy disk rotatable in the plane of flexure, the plane of strip when unstrained passing through axis of disk. In (11) only values of $\frac{\xi_0}{E}$ were given. Values of ξ are computed from values of E given below.

In (5) $\delta = \frac{mn^3T}{8Ml^3}\xi$, where M is mass of load and T is period (½δ is called log decrement in the original). In (11) $\delta = \frac{mn^3T}{4M'l^3}\xi$ where M' is mass of heavy disk. The results in this table are not corrected for effect of non-rigidity of support.

For methods, *v.* (16). For more recent data, *v.* (17).

† Average dimension of strips, 10 × 0.6 × 0.1 cm.

‡ Assumed E = 6 570 kg/mm².

§ Assumed E = 7 070 kg/mm².

‖ Assumed E = 10 800 kg/mm².

¶ Assumed E = 9 400 kg/mm².

** Assumed E = 20 750 kg/mm².

†† Assumed E = 9 000 kg/mm².

‡‡ Assumed E = 20 300 kg/mm².

TANGENTIAL COEFFICIENT OF VISCOSITY FOR ZERO AMPLITUDE (6)

Determined from damping of torsional vibrations of annealed wires; for effect of temperature, *v.* Figs. 1–10

Material	t, °C	Length, cm	Radius, cm	Period, sec	$10^{-8}\eta$*
Ag	13	25.5	0.0285	9.671	12.50
Al	15	25.5	0.0315	7.035	25.50
Au	15	25.5	0.0280	9.603	17.00
Cu	22	25.7	0.0275	6.899	6.70
Fe	16	25.4	0.0295	5.744	12.89
Fe-C, 0.55	22	25.6	0.0290	5.684	12.90
Fe-C, 0.9	16	23.7	0.0335	5.693	7.70
Fe-C, 1.30	19	25.5	0.0275	6.670	9.82
Ni	16	25.5	0.0250	6.521	1.65
Pt	15	25.6	0.0240	8.198	1.75
Pt, 85; Rh, 15	17	25.5	0.0195	10.059	4.19
W	16	25.5	0.0215	7.625	9.37
Zn	22	25.5	0.0270	8.642	410.7

* $\delta = \frac{\pi R^4 T}{4Il}\eta$, where R = radius of wire, l = length of wire, T = period, I = moment of inertia of load (½δ is called log decrement in the original paper, and tabulated values are $\log_{10}$); η in poises.

VISCOSITY OF LIQUID METALS AND ALLOYS

C. H. M. JENKINS (CHMJ), N. E. DORSEY (NED), O. F. HUDSON (OFH), T. K. ROSE (TKR)

% Composition	t, °C	100η
Bi, 100 (13)	304	1.662
	451	1.280
	600	0.998
Bi, 77.88; Sn, 22.12	306	1.682
	444	1.318
	600	1.049
Bi, 58.0; Sn, 42.0	305	1.690
	445	1.267
	606	1.014
	751	0.886
Bi, 46.82; Sn, 53.18	303	1.642
	399	1.336
	444	1.234
	601	1.003
	750	0.881
Cd, 100 (1) (CHMJ)	349	1.44
	406	1.34
	466	1.27
	506	1.18
	550	1.15
	603	1.10
Cu, 100 (14)	1145	3.41
	1179	3.19
	1187	3.25
Cu, 85; Sb, 15 (14)	1008	3.77
	1108	3.28
Cu, 72; Sb, 28 (14)	737	6.73
	895	4.42
	998	3.60
	1090	3.08
Cu, 61.34; Sb, 38.66 (14)	786	5.41
	890	4.02
	998	3.24
	1003	3.23
	1090	2.82
Cu, 56.94; Sb, 43.06 (14)	797	4.69
	790	4.71
	895	3.72
	989	3.14
	1087	2.66
Cu, 61.64; Sn, 38.36	803	5.609
Cu, 82.0; Sn, 18.0 (14)	1025	3.62
	1110	3.26
Cu, 71.0; Sn, 29.0 (14)	898	4.34
	1001	3.56
Cu, 61.64; Sn, 38.36 (14)	799	5.19
	900	3.93
	1005	3.16
	1096	2.74
Cu, 50.0; Sn, 50.0 (14)	755	3.65
	903	2.69
	1005	2.28
Fe, 97.5; C, 2.5 (15)	1400	2.25
	1350	2.65
Fe, 97; C, 3.0 (15)	1400	2.025
	1350	2.375
	1300	2.800
Fe, 96.5; C, 3.5 (15)	1400	1.75
	1350	2.00
	1300	2.40
	1250	2.90
Fe, 96.0; C, 4.0	1400	1.45
	1350	1.55
	1300	1.75
	1250	2.10
Hg, 100 (2, 4, 8, 10, 12) (NED)*	−20	1.85
	0	1.68
	+20	1.55
	50	1.39
	100	1.21
	150	1.09
	200	1.01
	250	0.96
	300	0.92
	350	0.90
Hg, 98; Cd, 2 (10) (TKR)	14.5	1.679
	20	1.652
	40	1.551
Hg; Cu (10) (TKR)	10	1.671
	20	1.620
	40	1.520
Hg, 99; Pb, 1 (10) (TKR)	13	1.664
	20	1.627
	30	1.586
	48	1.511
Hg, 99.4; Zn, 0.6 (10) (TKR)	13	1.672
	20	1.639
Pb, 100 (14)	441	2.116
	456	2.059
	551	1.700
	703	1.349
	844	1.185
Pb, 51.3; Bi, 48.7	403	1.571
	543	1.276
	682	1.100
	833	0.977
Pb, 70.0; Bi, 30.0	403	1.728
	413	1.668
	543	1.370
	704	1.145
	852	1.021
Pb, 90; Bi, 10	545	1.522
	550	1.526
	704	1.274
	840	1.114
	867	1.100
Pb, 83.05; Sb (9) (OFH)	292	2.768
84.60	292	2.579
87.03	292	2.355
89.98	292	2.413
92.39	292	2.654

* $1/\eta = 59.40 + 0.264t - 0.000341t^2$ (2, 4, 8, 10, 12). At p = 1500 atm., η is 4.8 % greater than at 1 atm. (3).

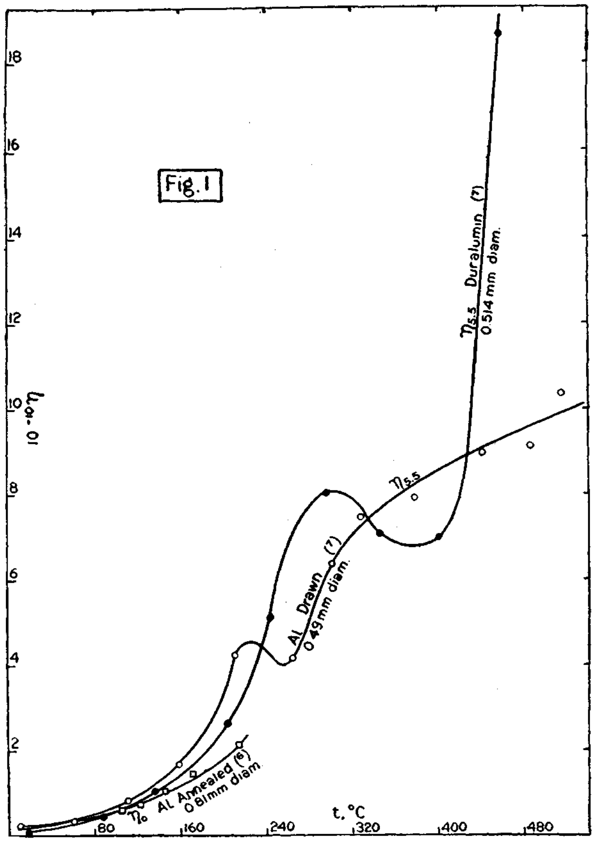
Fig. 1

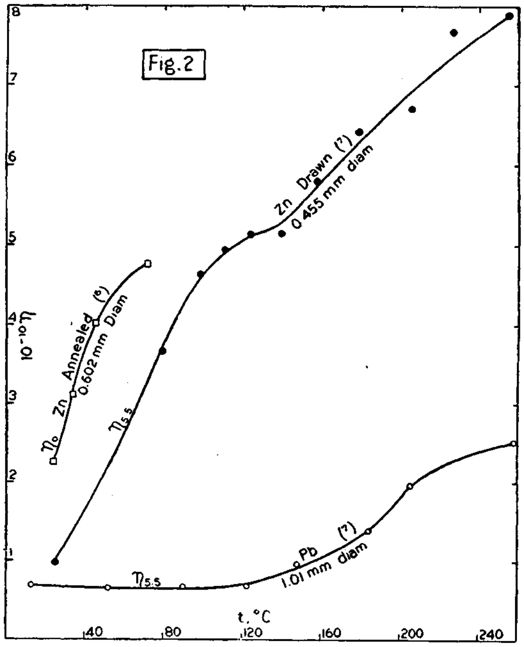
Fig. 2

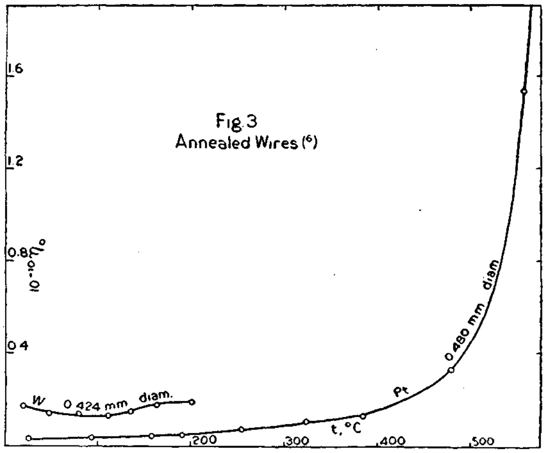
Fig. 3
Annealed Wires (6)

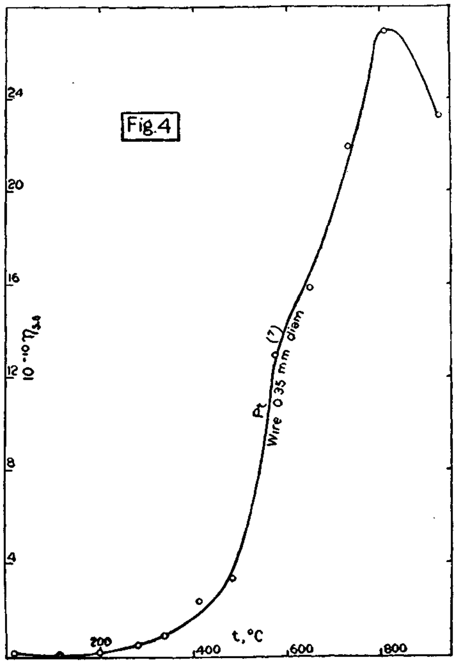
Fig. 4

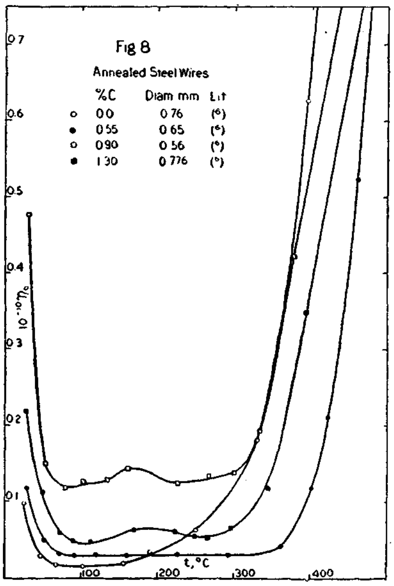
Fig 8
Annealed Steel Wires

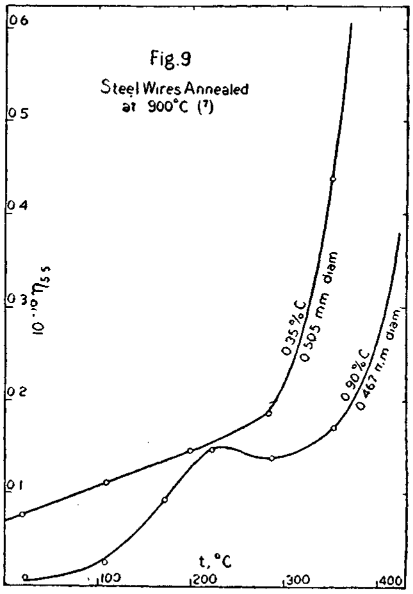
Fig. 9
Steel Wires Annealed at 900°C (7)

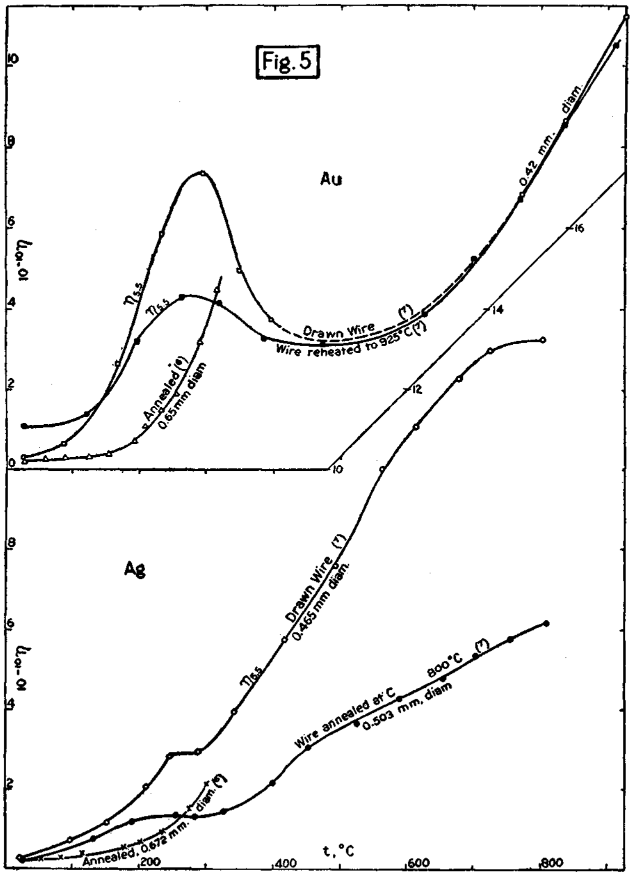
Fig. 5

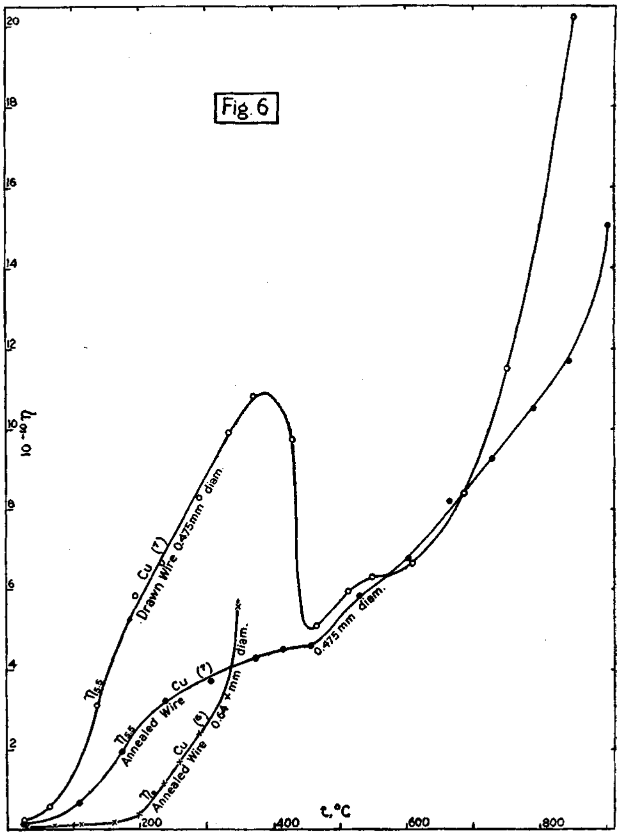
Fig. 6

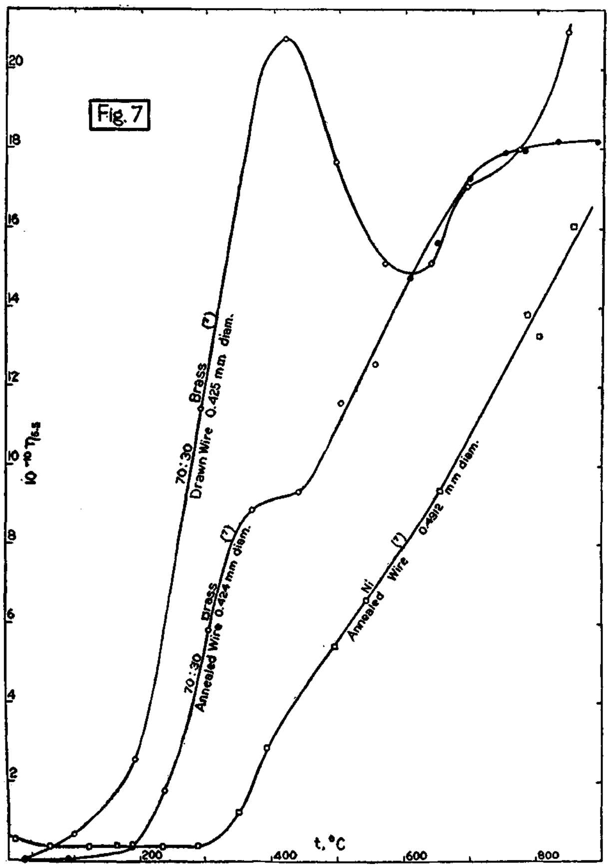
Fig. 7

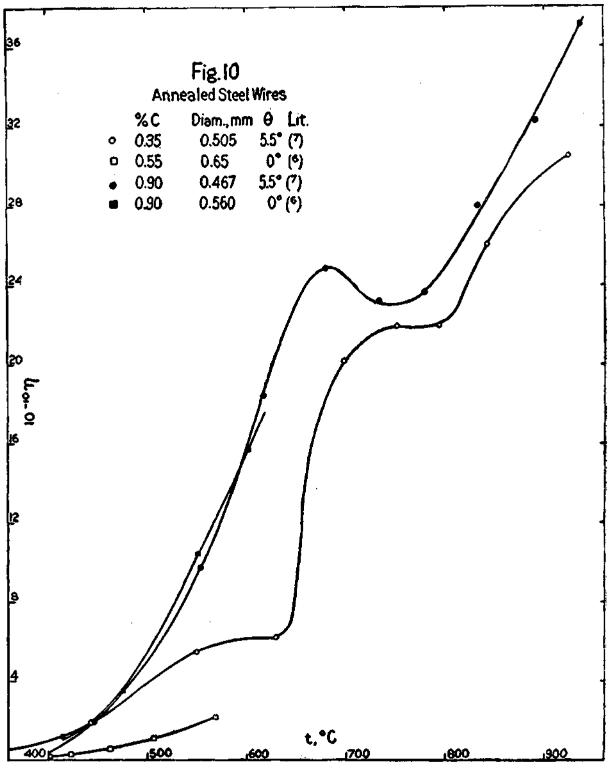
Fig. 10
Annealed Steel Wires

% Composition	t, °C	100η
Pb, 5.02; Sn (9)		
(OFH).........	280	1.706
9.29	280	1.746
15.54	280	1.830
19.55	280	1.919
30.31	280	2.066
32.99	280	2.052
36.08	280	1.965
39.21	280	2.053
49.38	280	2.189
64.27	280	2.349
69.80	280	2.451
79.57	280	2.716
Sb, 100 (14).....	702	1.304
	801	1.113
	902	1.010
	1002	0.905
Sb, 57.0; Cu, 43.0	715	2.93
	802	2.47
	900	2.12
	998	1.867
	1096	1.683
Sb, 76.0; Cu, 24.0	644	1.886
	804	1.483
	903	1.304
	1011	1.176
Sn, 100 (9) (OFH)	280	1.678
	296	1.664
	357	1.421
	389	1.311
Sn, 100 (13).....	301	1.680
	320	1.593
	351	1.518
	450	1.270
Sn, 100—(*Cont'd*)	604	1.045
	750	0.905
Sn, 75.0; Cu, 25.0		
(14)............	685	1.833
	830	1.510
	1001	1.266

LITERATURE

(For a key to the periodicals see end of volume)

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VISCOSITY OF WATER, SULFURIC ACID, LIQUID CARBON DIOXIDE AND CERTAIN ORGANIC LIQUIDS*

N. Ernest Dorsey

Formulae and Units

At a pressure of 1 atm., $\eta = a/(b + t)^n$.

At a pressure of P kg/cm², $\eta_p = \eta_1[1 + k_t(P - 1) \times 10^{-4}]$.

η_1 is the value of η when P is 1 kg/cm², which may be taken as the value of η at 1 atm.

The unit of η is the poise unless otherwise stated.

Water between 0 and 100°. I. C. T. Values

The following table was prepared from a critical evaluation of all available data. It is estimated that the accuracy is of the order of 0.1% between 0 and 40° and of 0.5 to 1% at higher temperatures. Linear interpolation may be safely employed throughout the table.

Values in millipoises (**1, 12, 16, 17, 22, 24, 30, 31, 32, 38**)

t, °C	0	1	2	3	4	5	6	7	8	9
0	17.93_8	17.32_0	16.74_0	16.19_3	15.67_6	15.18_8	14.72_6	14.28_8	13.87_2	13.47_6
10	13.09_7	12.73_5	12.39_0	12.06_1	11.74_8	11.44_7	11.15_6	10.87_5	10.60_3	10.34_0
20	10.08_7	9.84_3	9.60_8	9.38_0	9.16_1	8.94_9	8.74_6	8.55_1	8.36_3	8.18_1
30	8.00_4	7.83_4	7.67_0	7.51_1	7.35_7	7.20_8	7.06_4	6.92_5	6.79_1	6.66_1
40	6.53_6	6.41_5	6.29_8	6.18_4	6.07_5	5.97_0	5.86_8	5.77_0	5.67_5	5.58_2
50	5.49_2	5.40_5	5.32_0	5.23_6	5.15_3	5.07_2	4.99_4	4.91_8	4.84_3	4.77_0
60	4.69_9	4.62_9	4.56_1	4.49_5	4.43_1	4.36_8	4.30_6	4.24_5	4.18_6	4.12_8
70	4.07_1	4.01_6	3.96_2	3.90_9	3.85_7	3.80_6	3.75_6	3.70_8	3.66_1	3.61_5
80	3.57_0	3.52_6	3.48_3	3.44_0	3.39_6	3.35_7	3.31_7	3.27_8	3.24_0	3.20_3
90	3.16_6	3.13_0	3.09_5	3.06_1	3.02_7	2.99_4	2.96_2	2.93_0	2.89_9	2.86_9
100	2.83_9	2.82	2.79	2.76	2.73	2.70	2.67	2.64	2.62	2.59

H_2O below 0°C (39)

Values corrected and adjusted to accord with I. C. T. values above 0°C

t, °C..............	−2	−4	−5	−6	−8	−10
1000η..............	19.1	20.5	21.4	22.2	24.0	26.0

H_2O above 100°C (16)

Values as recorded by author accord with I. C. T. values below 100°C; the others are given as he has published them. The pressure is that of the saturated vapor at the temperatures indicated.

t, °C........	110	120	130	140	150	160
1000η........	2.56	2.32	2.12	1.96	1.84	1.74

H_2O: Variation with Pressure

Unit of P = 1 kg/cm²

t, °C	0	10.3	30	75	P	t	k_t	Lit.
P	k_t (3)							
					23.8	9	−2.0	(28)
500	−1.24	−0.62	+0.49	$+0.7_2$	100	1	−2.14	(4)
1 000	−0.79	−0.46	+0.53	+0.76	300	1	−1.28	(4)
1 500	−0.45	−0.29	+0.57	+0.75	600	1	−1.05	(4)
2 000	-0.21_5	-0.16_0	+0.64	+0.81	100	15	−0.55	(4)
3 000	$+0.08_0$	$+0.05_1$	+0.76	+0.84	200	15	−0.63	(4)
4 000	$+0.27_8$	$+0.20_2$	+0.87	+0.90	300	15	−0.51	(4)
5 000	+0.44	$+0.33_2$	+0.95	+1.00	400	15	−0.54	(4)
6 000	+0.58	+0.43	+1.02	+1.09	500	15	−0.46	(4)

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* For main section of Viscosity of Pure Liquids, *see* final index.

H_2O: VARIATION WITH PRESSURE.—(*Continued*)

t, °C	0	10.3	30	75
P	k_t (3)			
7 000		+0.52	+1.07	+1.17
8 000		+0.60	+1.12	+1.25
9 000			+1.16	+1.36
10 000			+1.17	
11 000			+1.19	

Variation of k_t with *t*, *P* = 413 kg/cm² (14)

t, °C	20	30	40	50
k_t	−0.33	−0.07	+0.17	+0.34
t, °C	60	70	80	90
k_t	+0.48	+0.62	+0.73	+0.82

P	*t*	k_t	Lit.
600	15	−0.39	(4)
700	15	−0.33	(4)
900	15	−0.30	(4)
100	23	−0.47	(4)
300	23	−0.25	(4)
600	23	−0.17	(4)
413	20	−0.33	(14)
310	50 to 80	+0.4	(14)
362	55	+0.6	(14)
516	40	+0.4	(14)

In disagreement with the preceding data, the observations of (29, 37) indicate that at 20°C and pressures not exceeding 150 kg/cm², $k_t = -1.7$.

SULFURIC ACID

$$\eta = \frac{1}{3(1 - 0.0075t - 0.001t^2)}$$ if *t* lies between 11 and 90°C (5, 6, 7, 8, 25, 26). The observations are discordant by ±5% and more; the composition of the acid is indefinite but presumably between 98 and 100%. At 0°, η is 45% greater than that given by the formula (5); *cf.* (19); there is only one recorded observation at 0° and none between 0 and 11°.

t, °C	0	11	15	20	30	40	50	60	70	80	90
$10^3\eta$	484	321	299	267	199	145	107	80	62	49	40

LIQUID CARBON DIOXIDE

Under essentially the pressure of its saturated vapor (36)

t, °C	5	10	15	20	25	29
p, atm	40.4	45.7	51.6	58.2	65.6	73.6
$10^3\eta$	0.925	0.852	0.784	0.712	0.625	0.539

At higher pressures

20°C (23)

p, atm	59	72	83
$10^3\eta$	0.697	0.771	0.823

25.1°C (36)

p, atm	70	75	85	95	105
$10^3\eta$	0.628	0.665	0.703	0.741	0.800

30°C (23)	*p*, atm	72	73	74	76	80
	$10^3\eta$	0.458	0.478	0.495	0.529	0.565

30°C (23)	*p*, atm	82	90	96	104	110.5
	$10^3\eta$	0.592	0.643	0.693	0.733	0.770

At the critical point, $10^3\eta$ is 0.321 (23).

ORGANIC LIQUIDS

$CHCl_3$, CHLOROFORM

a = 93.3±0.5, *b* = 163, *n* = 1.865, if *t* lies between −15 and 60° (32); *cf.* (13, 21, 40)

t, °C	−10	0	+10	20	30	40	50	60
$10^3\eta$	7.86	6.99	6.25	5.63	5.10	4.64	4.24	3.89

P	500	1 000	2 000	4 000	
k_{30}	5.77	6.25	7.16	8.92	(3)
k_{75}	6.81	7.22	7.36	7.96	

CHLOROFORM.—(*Continued*)

P	6 000	8 000	10 000	
k_{30}	11.08			(3)
k_{75}	9.68	12.98	18.19	

CH_3OH, METHYL ALCOHOL

a = 21 000 ± 100, *b* = 175.5, *n* = 2.858, if *t* lies between 0 and 66°C (32); *cf.* (2, 10)

t, °C	0	10	20	30	40	50	60
$10^3\eta$	8.08	6.90	5.93	5.15	4.49	3.95	3.49

P	500	1 000	2 000	4 000	
k_{30}	4.85	4.69	4.66	4.89	(3)
k_{75}	4.79	4.59	4.40	4.37	

P	6 000	8 000	10 000	12 000	
k_{30}	5.21	5.78	6.48	7.46	(3)
k_{75}	4.45	4.72	5.11	5.58	

C_2H_5OH, ETHYL ALCOHOL

a = (8.20 ± 0.04) × 10^7, *b* = 200, *n* = 4.2, if *t* lies between 0 and 75°C (32); *cf.* (2, 10, 11, 33, 34, 35)

t, °C	0	10	20	30	40	50	60	70
$10^3\eta$	17.90	17.52	17.16	16.81	16.47	16.13	15.81	15.49

P	k_0	$k_{15.1}$	k_{30}	$k_{53.5}$	k_{75}	Lit.
400	8.2	8.0				(9)
500			5.59		6.07	(3)
1 000	7.9	8.2	6.4	4.4		(9)
1 000			5.85		6.44	(3)
2 000	9.6	8.6	6.9	5.0		(9)
2 000			6.54		7.22	(3)
2 500	10.2	9.0	7.3	5.5		(9)
4 000			7.85		8.25	(3)
6 000			9.57		9.25	(3)
8 000			11.92		10.60	(3)
10 000			15.25		12.27	(3)
12 000			19.62		14.40	(3)

$(C_2H_5)_2O$, ETHYL ETHER

Excepting from 0 to +30°C, only non-overlapping series of data are available for variation of η with *t*; different series do not agree satisfactorily; for each, $\eta = c(10)^{-3}/[1 + dt(10)^{-3} + et^2\,(10)^{-6}]$ with average deviation of δ. Actual uncertainty exceeds δ and, except between 0 and +30°C, may amount to several %.

Range	*c*	*d*	*e*	δ	Lit.
0 to +30°C	2.842	10.40	26.2	0.1 %	(32); *cf.* (10, 18, 27, 40)
0 to +50	2.876*	10.40	26.2	0.2	(15, 16)
+50 to +100	2.520*	4.395	70.2	0.1	(15, 16)
0 to − 32	2.898	10.54	26.1	0.1	(41); *cf.* (20)
−40 to −110	2.793	10.87	25.2	0.5	(41); *cf.* (20)

t, °C	−110	−100	−90	−80	−60	−40	−30	−20
$10^3\eta$	25.6	16.9	12.4	9.58	6.37	4.61	4.10	3.62
t, °C	−10	0	+20	30	40	60	80	100
$10^3\eta$	3.23	2.842	2.332	2.128	1.97	1.66	1.40	1.18

* At pressure of saturated vapor.

P	k_0 (9)	k_{20} (9)	k_{30} (3)	k_{34} (9)	k_{75} (3)
500	9.6	9.6	10.92	8.7	8.02
1 000	10.4	10.0	11.09	9.2	8.66
2 000	12.4	11.3	11.32	10.5	9.62
3 000	15.1	14.1	12.0	13.2	10.0
4 000			12.98		10.71
6 000			16.69		12.45
8 000			21.55		14.78
10 000			28.45		17.92
12 000			38.15		21.75

C_6H_6, BENZENE

$a = 14.42 \pm 0.03$, $b = 90$, $n = 1.64$; if t lies between 0 and 75°C (27, 32, 40); *cf.* (10)

t, °C	0	10	20	30	40	50	60	70
$10^3\eta$	9.00	7.57	6.47	5.61	4.92	4.36	3.893	3.502

For the liquid under the pressure of its saturated vapor the viscosity ($\eta_{p,t}$) may be calculated by means of the equation $\eta_{p,t} = \eta_{1,t}\ [1 - 0.0123(p - 1)]$, if t lies between 0 and 190°C, where $\eta_{1,t}$ is value of η at $t°$ and 1 atm. as computed by the preceding formula ($\eta_{1,t} = 14.42/(90 + t)^{1.64}$), and p is the pressure (in atm.) of the saturated vapor. Observations between 0 and 100°C lie on the average 1.3% below the computed values, from 100 to 190° observed and computed agree to within 0.1% (15, 16).

P	500	1000	2000	3000	Lit.
k_{30}	9.80	12.23			(3)
k_{75}	9.80	10.70	12.45	14.70	

LITERATURE

(For a key to the periodicals see end of volume)

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(40) Wijkander, *427*, **3**: 8; 79. (41) Archibald and Ure, *4*, **1927**: 610.

VISCOSITY OF AQUEOUS SOLUTIONS OF STRONG ELECTROLYTES

Stuart J. Bates and Warren P. Baxter

In the following tables, the concentration F, is given in formula weights per 1000 g of water, and η* is the viscosity referred to that of water at the same temperature as unity, except as otherwise noted. Temperature in °C is indicated by the subscript.

Few of the investigators have determined and applied any correction for failure of their viscometers to obey Poiseuille's law exactly. Where feasible, corrections of this nature have therefore been applied.

In general, the last figure given is to be regarded as not being in error by more than 5 units. Where it is given in smaller type, the probable error is somewhat greater, and the last figure may or may not be significant. In cases where it has been possible to estimate the probable error with considerable certainty, this is given. Thus for HCl at 25° and 1F the relative viscosity is 1.060 ± 0.003. This indicates that the probable error for all solutions up to a concentration of 1F is about 0.3%.

For some electrolytes, additional data, chiefly at higher or lower temperatures or at higher concentrations than those covered by the tables, may be found by consulting the literature.

Should it be desired to interpolate the viscosity data to other units of concentration, for example to (volume) normal, this may usually be readily done algebraically by noting that, in general, for small changes of concentration, the expression $\frac{\eta/\eta_0 - 1}{F}$ changes but slowly with the concentration.

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* All interconversions between η and η/η_w have been based upon the values for water given on page 10.

AQUEOUS SOLUTIONS CONTAINING A SINGLE STRONG ELECTROLYTE

𝔅-Table; Standard Arrangement (*v.* Vol. III, p. viii)

HCl (27, 45, 66, 69, 91); *cf.* (103)

F	η_0 (91)	F	η_{25}	F	η_{25}
1	1.020*	0.1	1.007†	6	1.355
2	1.040	0.25	1.017†	7	1.418
3	1.058	0.5	1.032†	8	1.485
	η_{15} (91)	1	1.060†	9	1.56
		2	1.116	11	1.71
1	1.041*	3	1.175	13	1.86
2	1.083	4	1.233	16	2.12
3	1.125	5	1.294	* ±0.005.	† ±0.003.

$HClO_3$

F	η_{15} (79)
0.25	1.004
0.5	1.010
1.0	1.030
F	η_{25} (66)
0.1	1.005*
0.25	1.013*
0.5	1.025*
1.0	1.051*

* ±0.003.

$HClO_4$ (100)

M %	η_{20}	η_{50}
5	1.05	1.13
10	1.29	1.42
15	1.74	1.89
20	2.51	2.72
25	3.41	3.64
30	4.44	4.77
35	5.75	6.04
40		6.77
45		6.82
50		6.10
65		3.66
75		2.45
80	1.77	2.06
100	0.76	1.03

F	η_{25} (66)
0.25	1.000
0.5	1.003
1.0	1.011

HBr

F	η_0 (91)
1	0.987*
2	0.974
3	0.964
F	η_{15} (91)
1	1.014*
2	1.029
3	1.045
F	η_{25} (15, 66, 91)
0.25	1.008†
0.5	1.016†
1.0	1.031†
2	1.058
3	1.081

* ±0.005. † ±0.002.

$HBrO_3$ (80)

F	η_{15}
0.25	1.016
0.5	1.034
0.75	1.053

HI (88)

F	η_{25}
0.1	0.996
0.2	0.9954

H_2SO_4

F	Values of η						
	20° (29)	25° (29, 95)	40° (29)	60° (29)	80° (29)	Wt. %	80° (29)
0.1		1.017				10	1.24
0.25		1.043				20	1.55
0.5	1.090	1.091	1.096	1.103	1.120	30	2.05
1.0	1.184	1.185	1.188	1.197	1.211		
2.0	1.405	1.406	1.409	1.41	1.41		
4.0	1.89	1.89	1.89	1.89	1.90		

Wt. %	Values of η						
	0° (67)	10° (3)	20° (29)	25° (3, 18, 19)	40° (3, 29)	60° (29)	75° (67)
10	1.2	1.2	1.211	1.212	1.215	1.223	1.23
20	1.45	1.5	1.535	1.535	1.537	1.54	1.55
30	1.9	1.97	2.02	2.02	2.02	2.02	2.04
40	2.6	2.60		2.68	2.72		2.8

H_2SO_4.—(*Continued*)

Wt. %	Values of η						
	0° (67)	10° (3)	20° (29)	25° (3, 18, 19)	40° (3, 29)	60° (29)	75° (67)
50	3.6	3.74		3.83	3.80		4.2
60	6.0	5.8		5.9	5.8		6
70	11	10		10.0	9.3		8
75	17	16		14.3	12.8		10
80				20.3			
86				24.7			
90	26			23.5			14
95	25			21.9			14
98	29	27		23.2	20		15

HNO_3

F	Values of η			
	4° (9)	11° (9)	18° (9)	25° (9, 66)
0.1	0.9956	0.9990	1.0011	1.0035
0.25	0.9927	0.9987	1.0030	1.0074
0.5	0.9903	1.0007	1.0072	1.0133
1	0.9886	1.0100	1.0197	1.0295

Wt. %	10° (3)	20° (3, 25)	40° (3)	−15°† (49)
10	1.005	1.035	1.075	
25	1.14	1.20	1.28	0.0272
40	1.46	1.56	1.63	0.0353
50	1.76	1.82	1.91	0.0445
60	2.00	2.03	2.07	0.0562
70	1.99	2.03	2.06	0.0581
80	1.80	1.86	1.94	0.0427
90	1.27	1.35	1.48	
100	0.79	0.89	1.04	

† In poises.

NH_4OH

F	η
25° (4, 5, 43)	
0.25	1.005*
0.5	1.010*
1	1.019*
2	1.038*
3	1.055*
4	1.071
5	1.086
6	1.100
7	1.114
8	1.127
9	1.139
10	1.151
11	1.162
12	1.173
13	1.182

* ±0.003.

NH_4NO_3

F	Values of η				F	η	F	η
	10° (84)	20° (84)	40° (84)	50° (84)	25° (23, 43)			
1	0.943	0.965	0.996	1.012	0.25	0.993	4	0.981
2	0.912	0.954	1.005	1.03	0.5	0.986	5	1.009
5	0.920	0.988	1.09	1.13	1.0	0.973	6	1.042
7.5	0.985	1.060	1.19	1.25	2	0.956		
12	1.185	1.295	1.455	1.535	3	0.960		

NH_4Cl

F	Values of η					
	0° (84)	10° (84)	18°* (2, 12, 72)	25°† (5, 23, 32, 43)	40° (84)	60° (84)
0.25			0.993	0.997		
0.5			0.987	0.994		
1	0.931	0.965	0.978	0.991	1.014	1.033
2	0.891	0.940	0.965	0.988	1.028	1.065
3	0.863	0.924	0.961	0.993	1.045	1.095
4	0.846	0.917	0.963	1.002	1.065	1.13
5			0.970	1.017		
6	0.829	0.924	0.983	1.034	1.12	1.20

* ±0.003. † ±0.005.

NH_4Br

F	Values of η					
	0° (84)	10° (84)	20° (84)	25° (23)	40° (84)	60° (84)
2	0.830	0.890	0.932	0.945	0.987	1.035
3.5	0.784	0.856	0.917	0.934	0.997	1.07
6	0.772	0.854	0.930	0.957	1.045	1.145

At 25°, F = 0.25; 0.993. F = 0.5; 0.985. F = 1; 0.970. F = 5; 0.945 (23).

NH_4I

F	Values of η					
	10° (23)	15° (23)	20° (23)	25° (23)	30° (65)	45° (65)
0.25				0.981	0.986	0.991
0.5				0.963	0.971	0.982
1	0.892	0.901	0.917	0.932	0.947*	0.970*
2	0.809	0.840	0.869	0.892		
3.5	0.760	0.808	0.838	0.878		
5	0.764	0.810	0.844	0.894	0.911	
6.5	0.794	0.840	0.878	0.926		
9					1.027	

* ±0.003.

$(NH_4)_2SO_4$

F	Values of η						
	0° (84)	10° (84)	20° (29, 84)	25° (43)	40° (29, 84)	60° (29, 84)	80° (29)
0.25				1.053			
0.5			1.092	1.100	1.112	1.134	1.162
1.0	1.13	1.18	1.198	1.209	1.236	1.269	1.30
2.0			1.452		1.52	1.57	1.61
2.5	1.46	1.55		1.61	1.67	1.74	
4.5			2.32		2.43	2.50	2.56

H_3PO_4

F	η_{18} (57)	η_{25} (66)
0.25	1.064	1.062
0.5	1.140	1.130
1	1.294	1.273
2	1.650	

H_3AsO_4

F	η_{25} (66)
0.1	1.023
0.25	1.060
0.5	1.126
1	1.257

CH_3NH_3OH

F	η_{25} (43)
0.1	1.013
0.25	1.034
0.5	1.071
1	1.146

$(CH_3)_2NH_2OH$

F	η_{25} (43)
0.1	1.025
0.25	1.064
0.5	1.134
1	1.279

$NH_4C_2H_3O_2$

F	η_{15} (81)
0.25	1.058
0.5	1.117
1	1.238

$(CH_3)_3NHOH$ (43)

F	η_{25}
0.1	1.053
0.25	1.139
0.5	1.282
1	1.599

$(CH_3)_4NOH$ (43)

0.1	1.028
0.25	1.070
0.5	1.140
1	1.286

CH_3NH_3Cl (43)

F	η_{25}
0.1	1.005
0.25	1.014
0.5	1.028
1	1.057

$(CH_3)_2NH_2Cl$ (43)

0.1	1.010
0.25	1.025
0.5	1.051
1	1.099

$C_2H_5NH_3Cl$ (43)

0.1	1.015
0.25	1.038
0.5	1.076
1	1.154

$(CH_3)_3NHCl$ (43)

0.1	1.039
0.25	1.098
0.5	1.201
1	1.439

$(CH_3)_4NCl$ (43)

0.1	1.014
0.25	1.037
0.5	1.073
1	1.146

$(C_2H_5)_2NH_2Cl$ (43)

0.1	1.029
0.25	1.073
0.5	1.146
1	1.294

$C_6H_5NH_3Cl$ (74)

0.1	1.040
0.25	1.082
0.5	1.150
1	1.292
2	1.568
3	1.855
4	2.183
5	2.560
6	2.990
7	3.445

$(C_2H_5)_3NHCl$ (43)

F	η_{25}
0.1	1.038
0.25	1.098
0.5	1.199
1	1.414

$(C_2H_5)_4NCl$ (90)

F	η_{25}	η_{35}
0.25	1.089	1.089
0.5	1.190	1.188
1	1.436	1.432

$(C_3H_7)_4NCl$ (90)

0.25	1.216	1.190
0.5	1.494	1.436
0.75	1.786	1.750

$(C_2H_5)_4NBr$ (90)

0.25	1.087	1.081
0.5	1.186	1.174
1	1.406	1.385

$(CH_3)_4NI$ (90)

0.1	1.005	1.004
0.25	1.012	1.012

$(C_3H_7)_4NI$ (90)

0.25	1.199	1.182
0.5	1.458	1.426

$Pb(NO_3)_2$

F	η_{18} (28)
0.1	1.0165
0.25	1.0435
0.5	1.0971

F	η_{25} (32, 95)
0.1	1.019
0.25	1.049
0.5	1.105
1.0	1.255
1.5	1.447

$Pb(C_2H_3O_2)_2$ (47)

F	η_{15}	η_{20}
0.25	1.140	1.139
1	1.647	1.603

F	η_{25}	η_{30}
0.25	1.138	1.137
1	1.560	1.550

TlOH (102)

$TlNO_3$ (95)

F	η_{25}
0.1	0.994
0.25	0.987

$ZnCl_2$

F	η_{18} (2)
0.5	1.187

F	η_{25} (4, 95)
0.1	1.039
0.25	1.096
0.5	1.187

$ZnSO_4$

F	η_{18} (2)
0.5	1.361

F	η_{25} (4, 32, 95)
0.1	1.063
0.25	1.167
0.5	1.366
1	1.89_5
2	3.78

$Zn(NO_3)_2$ (95)

F	η_{25}
0.1	1.030
0.25	1.079
0.5	1.164

$CdCl_2$ (95)

0.1	1.023
0.25	1.063
0.5	1.132

$CdSO_4$ (95)

0.1	1.060
0.25	1.158
0.5	1.344

$Cd(NO_3)_2$ (95)

0.1	1.028
0.25	1.074
0.5	1.161

$HgCl_2$ (33, 65, 95)

0.1	1.012
0.25	1.032

$Hg(CN)_2$

F	η_{15} (65)
0.1	1.014
0.25	1.036

F	η_{25} (33, 65)
0.1	1.013
0.25	1.034
0.4	1.055

F	η_{45} (65)
0.1	1.012
0.25	1.031

$CuCl_2$

F	η_{18} (72)	η_{25} (32, 95)
0.1	1.040	1.040
0.25	1.100	1.102
0.5	1.201	1.208
1	1.425	1.435
2	1.943	1.942
3		2.564

$CuSO_4$

F	η_{18} (2)	η_{25} (4, 32, 95)
0.1	1.063	1.061
0.25	1.169	1.161
0.5	1.369	1.357
0.75	1.607	1.598
1		1.875

$Cu(NO_3)_2$

F	η_{18} (2)	η_{25} (4, 95)
0.1	1.034	1.030
0.25	1.089	1.080
0.5	1.188	1.174
1	1.435	
2	2.04	2.01
4.5	5.45	5.25

F	η_{35} (94)	η_{45} (94)
2	1.98	1.95
4.5	4.95	4.63

$Cu(CHO_2)_2$ (73)

F	η_{18}
0.05	1.032
0.1	1.058
0.2	1.108
0.3	1.157

$Cu(C_2H_3O_2)_2$ (73)

0.05	1.041
0.1	1.081
0.2	1.156

$Cu(C_3H_5O_2)_2$ (73)

0.05	1.058
0.1	1.105
0.2	1.200

$AgNO_3$ (4, 70, 95)

F	η_{25}
0.25	1.008
0.5	1.020
1	1.055
3	1.265
6	1.65
12	2.71

$AgTl(NO_3)_2$

0 to 100 % of salt at 100° (64)

$MnCl_2$ (32, 95)

F	η_{25}
0.1	1.038
0.25	1.098
0.5	1.207
1	1.44
2	2.04
3	2.89

$MnSO_4$ (32, 95)

0.1	1.064
0.25	1.169
0.5	1.368
1	1.90
2	3.86
3	7.9_9

$Mn(NO_3)_2$ (32, 95)

F	η_{25}
0.1	1.033
0.25	1.085
0.5	1.176
1	1.37_0
2	1.84
3	2.49

$FeCl_3$

F	η_0 (56)	η_{18} (56)
0.05	1.035	1.036
0.1	1.070	1.073
0.25	1.18	1.18
0.5	1.39	1.38
0.75	1.64	1.62
1.0	1.93	1.88
1.5	2.07	2.53
2.0	3.64	3.30
3.0	6.9	5.7
4.7	19.0	12.7

F	η_{25} (43, 56)	η_{35} (56)
0.05	1.036	1.034
0.1	1.072	1.067
0.25	1.18	1.17
0.5	1.37	1.35
0.75	1.60	1.57
1.0	1.85	1.80
1.5	2.45	2.34
2.0	3.18	3.00
3.0	5.2	3.9
4.7	11.3	9.8

$CoCl_2$ (54, 95, 99)

F	η_{25}
0.1	1.038
0.25	1.098
0.5	1.202
1	1.432

F	η_{75} (99)
1	1.408

$CoSO_4$ (95)

0.1	1.060
0.25	1.160
0.5	1.353

$Co(NO_3)_2$ (95)

0.1	1.028
0.25	1.074
0.5	1.162

$Co(CNS)_2$ (99)

F	η_{25}
0.5	1.195

F	η_{75}
0.5	1.185

$NiCl_2$ (95)

F	η_{25}
0.1	1.036
0.25	1.094
0.5	1.204

$NiSO_4$ (95)

0.1	1.059
0.25	1.161
0.5	1.361

$Ni(NO_3)_2$ (95)

0.1	1.032
0.25	1.083
0.5	1.177

CrO_3 (104)

H_2CrO_4 (83)

F	η_{10}	η_{20}
2	1.12	1.14
4	1.31_5	1.36_5
7	1.71_5	1.76_5
12	2.67_5	2.71_5

F	η_{30}	η_{40}
2	1.16	1.17
4	1.39_5	1.42

H_2CrO_4.—(*Cont'd*)

F	η_{30}	η_{40}
7	1.80_5	1.83_5
12	2.74	2.75_5

F	η_{15} (78)
0.25	1.016
0.5	1.032
1	1.064
2	1.129

$CrCl_3$ (61)

F	η_{18}	η_{25}
Green solution		
0.25	1.078	1.10_9
0.5	1.16_8	1.22
1	1.39	1.45
Violet solution		
0.25	1.160	1.150
0.5	1.34_0	1.31_5
1	1.75	1.78

$Cr_2(SO_4)_3$ (26)

F	η_{10}	η_{20}	η_{25}	η_{40}	η_{60}
Violet solution					
0.1	1.22_2	1.19_0	1.18_2	1.16_5	1.12_0
0.2	1.51_0	1.48_5	1.48_5	1.43_0	1.33
0.3	1.95_0	1.93_5	1.92_0	1.84_5	1.68_5
Green solution					
0.1	1.14_5	1.12_5	1.11_7	1.11_0	1.10_0
0.2	1.36_0	1.32_5	1.31_0	1.29_0	1.25_0
0.3	1.71	1.65	1.65	1.60_5	1.50

$(NH_4)_2Cr_2O_7$ (82)

F	η_{10}	η_{20}
0.25	0.990	1.000
0.5	0.990	1.011
1	1.006	1.046

F	η_{30}	η_{40}
0.25	1.013	1.027
0.5	1.032	1.055
1	1.081	1.111

$(NH_4)_2CrO_4$ (82)

F	η_{10}	η_{20}
0.5	1.052	1.069
1	1.11_2	1.14_3
2.5	1.37	1.42_2

F	η_{30}	η_{40}
0.5	1.079	1.095
1	1.16_4	1.19
2.5	1.47	1.51_5

$Al_2(SO_4)_3$ (95)

F	η_{25}
0.05	1.100
0.1	1.219
0.15	1.355

$BeCl_2$ (21)

0.15	1.065
0.25	1.110

$BeSO_4$ (95)

0.1	1.060
0.25	1.161
0.5	1.356

$MgCl_2$

F	η_{18} (28)	η_{25} (32, 95)
0.05	1.022_0	1.016
0.1	1.042_3	1.034
0.25	1.102	1.093
0.5	1.209_5	1.200
1		1.468
2		2.23_3
3		3.36_1

$MgSO_4$

F	η_{18} (2, 28, 84)	η_{25} (32, 95)
0.05	1.033_9	1.030
0.1	1.067_3	1.061
0.25	1.173_3	1.164
0.5	1.379_5	1.366
1	1.95	1.93
2	3.9_5	3.8_0

F	η_{40} (84)
1	1.89
2	3.5_5

$Mg(NO_3)_2$

F	η_{25} (32)
0.5	1.165
1	1.374
2	1.95
3	2.84

$Mg(C_2H_3O_2)_2$ (68)

$MgCrO_4$ (82)

F	η 10°	20°	40°
1	1.52	1.51	1.49
2	2.28	2.23	2.16

$CaCl_2$

F	η_{10} (84)	η_{40} (84)
2	1.72	1.82
4	3.48	3.7_2
6	9.4	8.2

F	η_{18} (28, 75, 84)	η_{25} (52, 84, 95)
0.1	1.030_5	1.030
0.25	1.075_0	1.076
0.5	1.148_5	1.155
1	1.30_8	1.33
2	1.74	1.78
4	3.54	3.6_0
6	9.0_0	8.5

$Ca(NO_3)_2$ (58, 95)

F	η_{25}
0.1	1.020
0.25	1.054
0.5	1.120
1	1.29_0
2	1.75_0
3	2.45_0

$Ca(C_2H_3O_2)_2$ (81)

F	η_{15}
0.25	1.212
0.5	1.465
1	2.13_5

$CaCrO_4$ (28)

F	η_{18}
0.05	1.026_3
0.1	1.051_2
0.25	1.129_0
0.5	1.272

$SrCl_2$

F	η_{18} (72)	η_{25} (32, 95)
0.1	1.027	1.027
0.25	1.067	1.069
0.5	1.139	1.146
1	1.300	1.33
2	1.77	1.81
3	2.50	2.56

F	η_{40} (84)
0.5	1.16
1	1.35
2	1.85
3	2.63

$Sr(NO_3)_2$ (95)

F	η_{25}
0.1	1.019
0.25	1.050
0.5	1.112

$Sr(C_2H_3O_2)_2$ (81)

F	η_{15}
0.25	1.212
0.5	1.465
1	2.135

$Ba(OH)_2$ (102)

$BaCl_2$

F	η_{10} (54, 84)	η_{50} (54, 84)
0.25	1.045	1.070
0.5	1.095	1.14
1	1.22	1.31
F	η_{18} (2, 12, 72)	η_{25} (32, 95)
0.1	1.024	1.024
0.25	1.060	1.061
0.5	1.120	1.126
1	1.259	1.285

$BaBr_2$ (17)

F	η_{18}
0.1	1.018

$Ba(NO_3)_2$ (95)

F	η_{25}
0.1	1.017
0.25	1.043

$Ba(C_2H_3O_2)_2$ (81)

F	η_{15}
0.25	1.202
0.5	1.426
1	2.019

$Ba(CNS)_2$ (99)

F	η_{25}	η_{75}
0.5	1.106	1.131

LiOH (10); *cf.* (102)

F	η_0	η_{25}
0.5	1.13	1.12
1	1.24	1.23
2	1.67	1.61
4	3.40	2.88
F	η_{50}	η_{75}
0.5	1.11	1.10
1	1.22	1.21
2	1.56	1.51
4	2.58	2.30

LiCl

F	η_{18} (2, 8, 27, 28, 36)	η_{25} (27, 52, 62, 70, 95)
0.1	1.0160	1.014
0.25	1.0385	1.035
0.5	1.0747	1.069
1	1.1476	1.142
2	1.298	1.302
3	1.473	1.479
4	1.669	1.673
5	1.891	1.895
6	2.145	2.155
7	2.445	2.455
8	2.801	2.81
9	3.235	3.235
10	3.765	3.73
11	4.405	4.33
12	5.14	5.06
13	6.03	5.94
14	7.14	6.99
15	8.47	8.23
16	9.99	9.60
17	11.80	11.12
20		18.9

LiCl.—(*Cont'd*)

F	η_0 (36, 97)	η_{10} (36, 84)
0.1	1.012*	
0.25	1.033*	
0.5	1.069*	1.071
1	1.129*	1.141
3	1.454	1.465
6	2.09	2.125
9	3.24	3.23
14		7.34
F	η_{40} (36, 84)	η_{60} (36)
0.5	1.067	1.066
1	1.143	1.143
3	1.495	1.515
6	2.185	2.215
9	3.26	3.28
14	6.69	6.40
F	η_{80} (36)	η_{100} (36)
0.5	1.068	1.066
1	1.140	1.140
3	1.53	1.53
6	2.24	2.26
9	3.28	3.26
14	6.16	5.92

* ±0.002.

$LiClO_3$ (70)

F	η_{25}
1	1.141
3	1.456
7	2.44
17	9.19
35	61

LiBr (41, 71)

0.1	1.015

$LiBrO_3$ (89)

F	η_{20}
0.1	1.017
0.25	1.044
0.5	1.090
0.8	1.146

$LiIO_3$ (28)

F	η_{18}
0.05	1.0158
0.2	1.0622
1	1.3815
3	3.020

Li_2SO_4

F	η_{18}* (2, 28)	
0.05	1.0294	
0.1	1.0568	
0.25	1.1420	
0.5	1.300	
F	η_{25} (5, 95)	η_{40} (93)
0.1	1.053†	1.049‡
0.25	1.136†	1.128‡
0.5	1.287†	1.27‡
1	1.665	1.63

* ±0.001. † ±0.005. ‡ ±0.01.

$LiNO_3$

F	η_0 (1)
0.05	1.0038
0.1	1.0070
0.25	1.0166
0.5	1.0323
1	1.0687
2	1.157
3	1.274

$LiNO_3$.—(*Cont'd*)

F	η_{18} (1, 28)	η_{25} (1)
0.05	1.0060	1.0060
0.1	1.0109	1.0116
0.25	1.0259	1.0277
0.5	1.0503	1.0534
1	1.0996	1.1063
2	1.2110	1.2230
3	1.341	1.358
4	1.492	1.514
5	1.670	1.694
6	1.874	1.898
9		2.730

$LiC_2H_3O_2$

F	η_{15} (81)
0.25	1.115
0.5	1.234
1	1.475

NaOH

See also (102)

F	η_{18} (57)	η_{25} (43)
0.1	1.020	1.023
0.25	1.052	1.055
0.5	1.108	1.110
1	1.234	1.236
2	1.59	
4	2.78	
8	7.04	

NaCl and **NaI**: *v. next column*

$NaIO_3$ (28)

F	η_{18}
0.2	1.0493

$NaHSO_4$ (57)

F	η_{18}
0.25	1.056
0.5	1.114
1	1.245
2	1.550
5	2.874

Na_2SO_4

F	η_{10} (84, 92)	η_{25} (2, 84, 92, 95)
0.1	1.036	1.040
0.25	1.096	1.106
0.5	1.217	1.227
0.75	1.372	1.374
1	1.56	
F	η_{40} (84, 92)	
0.1	1.044	
0.25	1.109	
0.5	1.226	
0.75	1.365	
1	1.54	

NaN_3 (11)

F	η_0	η_{25}
1.5	1.089	1.126
3	1.294	1.343
5	1.82	1.82
6		2.10

NaCl

18° (2, 7, 12, 22, 28, 53); 25° (32, 35, 66, 69, 76); 0°, 80°, 100° (35, 53); 10°, 40°, 60° (35, 53, 84)

F	Values of η							
	0°	10°	18°	25°	40°	60°	80°	100°
0.1	1.004*	1.006*	1.0085†	1.009‡	1.010*	1.012*	1.013*	1.013*
0.25	1.009*	1.016*	1.0205†	1.022‡	1.026*	1.030*	1.031*	1.032*
0.5	1.020*	1.032*	1.0405†	1.046‡	1.053*	1.060*	1.062*	1.065*
1	1.047*	1.071*	1.0840†	1.094‡	1.108*	1.121*	1.127*	1.131*
2	1.147	1.173	1.192	1.205	1.229	1.249	1.26	1.26
3	1.282	1.312	1.329	1.341	1.365	1.39	1.40	1.405
4	1.450	1.481	1.498	1.509	1.524	1.54	1.55	1.555
5		1.692	1.700	1.706	1.713	1.72		

* ±0.005. † ±0.001. ‡ ±0.002.

	$NaClO_3$			$NaClO_4$	$NaBrO_3$	
F	Values of η					
	15° (79, 84)	25° (66, 84)	40° (84)	25° (66)	15° (80)	20° (89)
0.25	1.012	1.021		1.008	1.022	1.028
0.5	1.028	1.041		1.018	1.047	1.057
1	1.067	1.086	1.10	1.044	1.101	1.117
2.5	1.24	1.265	1.285			
4.5	1.61	1.625	1.64			

NaBr (84) except at 25° (66)

F	Values of η						
	25°	F	10°	20°	25°	40°	60°
0.1	1.005	1	1.029	1.054	1.062*	1.08	1.10
0.25	1.014	2	1.108	1.141	1.154	1.18	1.215
0.5	1.029	3.5	1.29	1.328	1.338	1.365	1.405

* ±0.003.

NaI (84)

F	Values of η					
	10°	20°	30°	40°	50°	60°
0.5	1.000	1.011	1.017	1.024	1.028	1.033
1.5	1.012	1.042	1.060	1.079	1.092	1.106
4	1.193	1.227	1.253	1.284	1.312	1.334
8	2.035	2.03	2.03	2.045	2.06	2.07

NaN_3.—(*Cont'd*)

F	η_{35}	η_{50}
1.5	1.135	1.148
3	1.358	1.385
5	1.81	1.80
6	2.07	2.03

$NaNO_3$

F	η_{10} (84)	η_{40} (84)
1	1.041	1.08
2	1.125	1.18
3	1.24	1.30
5	1.58	1.62
F	η_{18} (2, 22, 28, 59, 84)	η_{25} (66)
0.1	1.0043*	1.005†
0.25	1.0101*	1.012†
0.5	1.0216*	1.025†
1	1.0521*	1.062†
2	1.15	
3	1.27	
5	1.60	

* ±0.0005. † ±0.003.

NaH_2PO_4 (66)

F	η_{25}
0.1	1.040
0.25	1.102
0.5	1.208
1	1.464

NaH_2AsO_4 (66)

0.1	1.040
0.25	1.104
0.5	1.217
1	1.484

Na_2CO_3

See also (102)

F	η_{18} (57, 83)	η_{25} (43, 83)
0.1	1.048	1.048
0.25	1.126	1.130
0.5	1.274	1.285
1	1.660	
2	3.040	2.93

$Na_2C_2O_4$ (50)

F	η_{25}
0.05	1.022
0.1	1.046

$Na_2C_4O_4$ (50)

Acetylenedicarboxylate

F	η_{25}
0.1	1.127

$NaHCO_2$ (66, 81)

Formate

0.1	1.018
0.25	1.045
0.5	1.094
1	1.202

$NaHCO_3$ (57)

F	η_{18}
0.25	1.057
0.5	1.118
1	1.253

$NaC_2H_3O_2$

F	η_{15} (81)	η_{25} (66)
0.1		1.035
0.25	1.091	1.088
0.5	1.184	1.176
1	1.389	1.373

$NaC_2H_3O_3$ (50)
Glycolate

F	η_{25}
0.1	1.031
0.25	1.078
0.5	1.155
1	1.325

$NaC_3H_5O_2$ (66, 81)
Propionate

0.1	1.043
0.25	1.110
0.5	1.228
1	1.504

$NaC_3H_5O_3$ (66)
Lactate

0.1	1.040
0.25	1.103
0.5	1.216
1	1.464

$NaC_4H_5O_6$ (57)
Acid tartrate

F	η_{18}
0.25	1.095
0.5	1.195

$NaC_4H_7O_2$ (66)
Butyrate

F	η_{25}
0.1	1.052
0.25	1.133
0.5	1.280
1	1.620

$NaC_4H_7O_2$ (66)
Isobutyrate

0.1	1.056
0.25	1.140
0.5	1.287
1	1.627

$NaC_5H_9O_2$ (66)
Isovalerate

0.1	1.060
0.25	1.153
0.5	1.316

$NaC_6H_{11}O_2$ (66)
Isocaproate

0.1	1.063
0.25	1.166
0.5	1.355

$NaC_7H_5O_2$ (66)
Benzoate

0.1	1.050
0.25	1.127
0.5	1.264
1	1.581

$NaC_7H_5O_3$ (50)
m-Hydroxybenzoate

0.1	1.030
0.25	1.086
0.5	1.220
1	1.608

$NaC_7H_5O_3$ (50)
p-Hydroxybenzoate

0.1	1.050
0.25	1.129
0.5	1.277
1	1.653

$NaC_7H_5O_3$ (66)
Salicylate

F	η_{25}
0.1	1.041
0.25	1.102
0.5	1.210
1	1.468

$NaC_8H_7O_2$ (50)
Phenylacetate

0.1	1.056
0.25	1.145
0.5	1.304
1	1.668

$NaC_8H_7O_2$ (50)
o-Toluate

0.1	1.061
0.25	1.157

m-Toluate

0.1	1.038
0.25	1.103
0.5	1.248
1	1.606

p-Toluate

0.1	1.056
0.25	1.146
0.5	1.308
1	1.695

$NaC_8H_7O_3$ (50)
Phenoxyacetate

0.1	1.056
0.25	1.143
0.5	1.294
1	1.654

$NaC_8H_7O_3$ (50)
Anisate

0.1	1.055
0.25	1.142
0.5	1.302

$NaC_8H_7O_3$ (50)
Phenylglycolate

0.1	1.055
0.25	1.143
0.5	1.295
1	1.658

$NaC_9H_7O_2$ (50)
Cinnamate

0.1	1.054
0.25	1.154
0.5	1.334

$NaC_9H_9O_2$ (50)
Hydrocinnamate

0.1	1.065
0.25	1.165
0.5	1.337
1	1.773

$Na_2C_3H_2O_4$ (50)
Malonate

0.1	1.034
0.25	1.107
0.5	1.252

$Na_2C_4H_2O_4$ (50)
Maleate

0.1	1.035
0.25	1.109
0.5	1.270

$Na_2C_4H_2O_4$ (50)
Fumarate

F	η_{25}
0.1	1.060
0.25	1.152
0.5	1.307

$Na_2C_4H_4O_4$ (50)
Succinate

0.1	1.068
0.25	1.175
0.5	1.375

$Na_2C_4H_4O_4$ (50)
Isosuccinate

0.1	1.072
0.25	1.177
0.5	1.373

$Na_2C_4H_4O_5$ (50)
Malate

0.1	1.062
0.25	1.167
0.5	1.363

$Na_2C_4H_4O_6$
Tartrate

F	η_{18} (57)	η_{25} (50, 62)
0.1	1.047	1.055
0.25	1.137	1.146
0.5	1.318	1.322
1	1.790	

$Na_2C_5H_4O_4$ (50)
Itaconate

F	η_{25}
0.1	1.094
0.25	1.211
0.5	1.365

$Na_2C_5H_4O_4$ (50)
Citraconate

0.1	1.076
0.25	1.191
0.5	1.409

$Na_2C_5H_4O_4$ (50)
Mesaconate

0.1	1.074
0.25	1.187
0.5	1.405

$Na_2C_5H_6O_4$ (50)
Pyrotartrate

0.1	1.084
0.25	1.214
0.5	1.457

$Na_2C_6H_8O_4$ (50)
Adipate

0.1	1.088
0.25	1.230
0.5	1.526

$Na_2C_8H_4O_4$ (50)
Phthalate

0.1	1.085
0.25	1.219
0.5	1.464

$Na_2C_8H_4O_4$ (50)
Isophthalate

0.1	1.080
0.25	1.208
0.5	1.457

$Na_2C_8H_4O_4$ (50)
Terephthalate

F	η_{25}
0.1	1.077
0.25	1.201

$Na_2C_8H_{12}O_4$ (50)
Suberate

0.1	1.105
0.25	1.285

$Na_2C_9H_{14}O_4$ (50)
Azelate

0.1	1.164
0.25	1.412

$Na_3C_6H_5O_7$ (50)
Citrate

0.05	1.050
0.1	1.102
0.25	1.272

$Na_4C_{11}H_2O_{10}$ (60)
Benzenepenta-carboxylate

F	η_0	η_{25}
0.005		1.0101
0.02	1.0314	1.0336
0.05	1.0748	1.0758
F	η_{50}	
0.05	1.0753	

$Na_5C_{11}HO_{10}$ (60)
Benzenepenta-carboxylate

$Na_5C_{11}HO_{10}$.—
(*Cont'd*)

F	η_0	η_{25}
0.005		1.0125
0.02		1.0378
0.05	1.0850	1.0879
F	η_{50}	
0.05	1.0857	

$NaC_2H_2ClO_2$
Chloroacetate

F	η_{15} (81)	η_{25} (16)
0.1		1.035
0.2		1.071
0.25	1.086	
0.5	1.174	
1	1.364	

$NaC_2Cl_3O_2$ (81)
Trichloroacetate

F	η_{15}
0.5	1.215

$NaC_7H_4ClO_2$ (50)
m-Chlorobenzoate

F	η_{25}
0.1	1.054
0.25	1.136
0.5	1.282
1	1.621

$NaC_7H_4BrO_2$ (50)
m-Bromobenzoate

0.1	1.053
0.25	1.139
0.5	1.293

$NaC_7H_4BrO_2$ (50)
p-Bromobenzoate

F	η_{25}
0.1	1.055
0.25	1.141
0.5	1.292

$NaC_7H_4NO_4$ (50)
o-Nitrobenzoate

0.1	1.054
0.25	1.136
0.5	1.285
1	1.628

$NaC_7H_4NO_4$ (66)
m-Nitrobenzoate

0.1	1.052
0.25	1.130
0.5	1.269
1	1.606

$NaC_7H_4NO_4$ (50)
p-Nitrobenzoate

0.1	1.031
0.25	1.089
0.5	1.220

$NaC_8H_4NO_2$ (50)
m-Cyanobenzoate

0.1	1.050
0.25	1.128
0.5	1.269

$Na_2O.xSiO_2$ (86)
Viscosity in centipoises at 20°C

The solutions employed in determining the data for the following table were commercial solutions of sodium silicate. The only sample completely analyzed was $Na_2O.2.06SiO_2$; for this the following analysis is given: Na_2O, 18.42%; SiO_2, 36.84%; Al_2O_3, 0.23%; Fe_2O_3, 0.16%; CaO, 0.14%; MgO, 0.05%. The compositions given in the table below refer to the percentages by weight of $Na_2O.xSiO_2$. For given values of x the original data lie on fairly smooth curves which were interpolated to round concentrations. But for a given percentage composition, particularly in the less concentrated solutions, the viscosity data considered as a function of x are quite irregular and it did not seem practicable to smooth them. This effect may be due to varying amounts of impurities in the different solutions.

% \ x	3.90	3.36	2.44	2.06	1.69
3.0	3.3	4.2	3	3	
5.0	4.4	5.5	3.5	4.5	3
10.0	6.5	7.3	5.2	7.5	5.5
15.0	9.0	9.0	7.0	10.0	7.5
20.0	12	12	9	12	10.5
25.0	18	16	12	16	15
28.0	28	22	15	19	19
30.0	49	27	19	22	23
32.0	180	37	24	27	29
33.0	800	44	27	31	34
33.60	7 026				
34.0		55	30	35	39
36.0		120	43	48	58
38.0		270	72	70	95
39.0		460	95	90	120

$Na_2O.xSiO_2$.—(*Continued*)

x %	2.44	2.06	1.69	x %	
40.0	130	120	150	50.76	8 496*
42.0	210	190	250	51.60	6 115†
44	400	310	430	52.36	22 900*
46	900	550	750	55.26	87 080†
47		750	1050		

* $x = 1.69$. † $x = 2.06$.

Viscosity at 25° (53.5)

x F	0	0.5	1.0	2.0	2.5
0.5	1.22	1.28	1.31	1.42	1.49
1.0	1.50	1.70	1.86	2.18	2.50
1.25	1.67	1.93	2.21	2.81	3.43
1.5	1.86	2.30		3.80	4.70

x F	3.0	3.3	3.8	3.95	4.2
0.5	1.61	1.68	1.79	1.90	1.87
1.0	3.19	3.48	4.87	5.49	6.77
1.25	4.60	5.42	9.79	13.4	
1.5	7.32	9.38	27.65	104	

$F = 1.5$

t, °C x	20	25	40
0.5	2.35	2.30	2.15
2.0	3.95	3.80	3.33
3.95	121.6	103.6	50.1

There is considerable discrepancy between the values at 20° and 25°, probably due to the difference in previous history of the solutions.

Na_4SiO_4 (51)

F	η_{30}
1	2.89

Na_2CrO_4 (82)

F	η_{10}	η_{15} (78)
0.1		1.039
0.25		1.101
0.5	1.24	1.209
1	1.66	
F	η_{20}	η_{30}
0.5	1.25	1.25$_5$
1	1.65	1.64$_5$
F	η_{40}	
0.5	1.26	
1	1.64$_5$	

$Na_2Cr_2O_7$ (78)

F	η_{15}
0.1	1.020
0.25	1.050

Na_2WO_4 (51)

F	η_{30}
1	1.64$_5$

KOH

See also (102)

F	η_{18} (57)
0.1	1.009
0.25	1.024
0.5	1.050
1	1.106
2	1.230
4	1.54$_1$
7.5	2.32$_5$

KOH.—(*Cont'd*)

F	η_{25} (43)	η_{60} (24)
0.1	1.013	1.013
0.25	1.031	1.032
0.5	1.064	1.065
1	1.128	1.134
2	1.268	1.275

KF (72)

F	η_{18}
0.2	1.026$_8$
0.5	1.067$_4$
1.0	1.134$_8$
1.5	1.206$_0$
3.0	1.462
6.0	2.083

KCl

0° (91, 97); 15° (6, 12, 65, 91); 18° (2, 6, 12, 22, 28, 59, 84, 98); 25° (31, 69, 91, 95); 35 and 45° (65, 84)

F	Values of η					
	0°	15°	18°	25°	35°	45°
0.1	0.994$_5$*	0.997†	0.998$_2$*	0.999†	1.001‡	1.003‡
0.25	0.980$_5$*	0.991†	0.994$_9$*	0.998†	1.003‡	1.008‡
0.5	0.957$_5$*	0.984†	0.989$_8$*	0.997†	1.007‡	1.015‡
0.75	0.942$_3$*	0.978†	0.984$_9$*	0.996†	1.011‡	1.023‡
1.0	0.928$_6$*	0.974†	0.981$_6$*	0.995†	1.015‡	1.031‡
1.5	0.90$_9$§	0.969‡	0.980‡	0.997‡	1.02$_5$§	1.04$_8$§
2.0	0.89$_5$§	0.968‡	0.982‡	1.002‡	1.03$_5$§	1.06$_5$§
2.5	0.89§	0.970‡	0.987‡	1.010‡	1.05§	1.08$_5$§

KCl.—(*Continued*)

F	Values of η					
	0°	15°	18°	25°	35°	45°
3.0	0.88$_5$§	0.975‡	0.994‡	1.021‡	1.06$_5$§	1.10$_5$§
4.0	0.88$_5$§	0.994‡	1.017‡	1.050‡	1.10§	1.14$_5$§

* ±0.001. † ±0.002. ‡ ±0.003. § ±0.01.

$KClO_3$ (65, 79); for 18° (72)

F	Values of η				
	15°	18°	25°	35°	45°
0.1	0.994*	0.998†	0.999*	0.999*	1.002‡
0.2	0.990*	0.995†	0.998*	0.999*	1.004‡
0.3	0.987*	0.992†	0.996*	1.000*	1.006‡
0.5	0.981	0.985			

* ±0.003. † ±0.002. ‡ ±0.005.

KBr (84); for 0° (91); for 18° (22, 72, 84, 91); for 25° (31, 91)

F	Values of η							
	0°	5°	10°	18°	25°	40°	50°	60°
0.25				0.986*	0.992			
0.5				0.974*	0.984			
1	0.91$_3$	0.92$_5$	0.94	0.954*	0.969	1.00$_5$	1.02	1.04
2	0.84$_5$	0.87$_5$	0.90$_5$	0.930*	0.959	1.02$_5$	1.05	1.08
3	0.81$_7$				0.967			
4.5		0.87	0.90$_5$	0.952	1.007	1.10	1.14$_5$	1.19
5.5					1.050			

* ±0.003.

KI for 0° (40, 91); for 5°, 10°, 40°, 50°, 60° (84); for 18° (2, 22, 28, 84); for 25° (31, 40, 84, 91)

F	Values of η							
	0°	5°	10°	18°*	25°	40°	50°	60°
0.1	0.982*			0.990$_8$	0.993			
0.25				0.976$_8$	0.981			
0.5		0.94$_0$	0.94$_7$	0.956$_1$	0.964	0.99$_0$	1.00$_1$	1.00$_9$
1	0.86$_0$	0.89$_3$	0.90$_6$	0.922$_8$	0.936	0.98$_3$	1.00$_4$	1.02$_0$
2	0.78$_7$			0.89$_8$	0.915			
3	0.75$_5$	0.81	0.84$_5$	0.89$_2$	0.916	0.98$_9$	1.03$_5$	1.07$_5$
5		0.80$_5$	0.85$_5$	0.91$_6$	0.95$_1$	1.04$_8$	1.10$_5$	1.16
7		0.86$_5$	0.91	0.978	1.03	1.14$_9$	1.21	1.28$_5$
7.5				1.003				
9					1.20			

* ±0.001.

	$KBrO_3$ (80)	KIO_3 (28, 72)			$KHSO_4$ (57)			
F.	0.25	0.1	0.2	0.3	0.25	0.5	1	2
η_{15}. . . .	0.994							
η_{18}. . . .		1.014$_1$	1.027$_8$	1.042	1.035	1.071	1.144	1.310

K_2SO_4 (84, 92); for 18° (2, 28, 57, 84, 92); for 25° (95)

F	Values of η					
	10°*	18°†	25°*	30°*	40°*	50°*
0.05		1.011	1.011			
0.1	1.017	1.021	1.022	1.023	1.024	1.025
0.25	1.044	1.051	1.054	1.057	1.062	1.065
0.5	1.087	1.099$_5$	1.109	1.118	1.12$_8$	1.13$_6$

* ±0.005. † ±0.001

KN_3 (11)

F	Values of η				
	0°	25°	35°	50°	75°
1	0.945	1.006	1.019	1.035	1.053
3	0.926	1.043	1.075	1.120	1.171
4	0.939	1.077	1.116	1.17$_2$	1.23$_7$
6		1.188	1.23$_1$	1.29$_7$	1.38$_3$

KNO_3

F	η_{10} (84)	η_{40} (84)
1	0.948	1.01
2	0.94	1.04

F	η_{18} (2, 22, 28, 59, 84)	η_{25} (84, 95)
0.1	0.9941	0.995
0.25	0.9857	0.989
0.5	0.9748	0.982
1	0.9630	0.976
2	0.975	0.999

F	η_{50} (84)	η_{60} (84)
1	1.02	1.035
2	1.06	1.085

K_3PO_4 (57)

F	η_{18}
0.1	1.050
0.25	1.130
0.5	1.292
1	1.721

K_2HPO_4 (57)

0.1	1.034
0.25	1.091
0.5	1.201
1	1.513
2	2.18

KH_2PO_4 (57)

0.25	1.064
0.5	1.137
1	1.291

K_2CO_3 (2, 57, 72)

F	η_{18}	η_{25}† (43)
0.1	1.029*	1.031
0.25	1.073*	1.078
0.5	1.152*	1.165
1	1.340*	
2	1.82	
3	2.46	
4	3.34	

* ±0.003.
† ±0.005.

$K_2C_2O_4$ (28, 57)
Oxalate

F	η_{18}
0.05	1.0125
0.1	1.0235
0.25	1.0545
0.5	1.110
1	1.225

$KHCO_3$ (57)

0.25	1.029
0.5	1.059
1	1.123
2	1.261

$KHCO_2$ (81)
Formate

F	η_{15}
0.5	1.039

$KC_2H_3O_2$ (2, 72, 81)
Acetate

F	η_{18}
0.1	1.028
0.25	1.064
0.5	1.125
1	1.248
2	1.515
3	1.817
4	2.172

$KC_3H_5O_2$ (81)
Propionate

F	η_{15}
0.5	1.164

$K_2C_4H_4O_6$ (44, 57)
Tartrate

F	η_{18}
0.25	1.078
0.5	1.183
0.75	1.30
1.5	1.74

$KC_2Cl_3O_2$ (81)
Trichloroacetate

F	η_{15}
0.5	1.164

KC_2H_2ClO (81)
Chloroacetate

0.5	1.106

KCNS

F	η_{18} (72)
0.1	0.997
0.25	0.989
0.5	0.977
1	0.960
2	0.950
5	1.036

F	η_{25} (99)
1	0.970

F	η_{75} (99)
1	1.020

$K_3Fe(CN)_6$

F	$\eta_{1.6}$ (65)
0.1	0.988
0.25	0.990

F	η_{15} (65)	η_{25} (65, 95)
0.1	1.007*	1.016*
0.25	1.022*	1.044*
0.5	1.062*	1.098*

* ±0.003.

$K_4Fe(CN)_6$

0.1	1.035	1.045
0.25	1.091	1.113
0.5	1.202	1.236

K_2CrO_4

F	η_{10} (84)	η_{18} (72, 78)
0.1		1.105
0.25		1.038
0.5		1.078
1	1.13	1.174
2	1.35	1.425

F	η_{30} (84)	η_{40} (84)
1	1.20	1.23
2	1.47	1.51

K_2CrO_4.—(*Cont'd*)

F	η_{50} (84)
1	1.25·
2	1.54

$K_2Cr_2O_7$

F	η_{10} (82)	η_{25} (43)
0.1	0.993	1.001
0.25	0.986	1.006

F	η_{40} (82)
0.1	1.008
0.25	1.024

$KNaC_4H_4O_6$ (57)
Tartrate

F	η_{18}
0.25	1.108
0.5	1.246
0.75	1.410
1.5	2.05

RbOH (20)

F	η_{25}
0.1	1.009
0.25	1.023
0.5	1.048
1	1.103

RbCl

F	η_5* (76)	η_{10}* (76)
0.25	0.975	0.982
0.5	0.955	0.967
1	0.923	0.941

F	η_{18} (72, 76)	η_{25}* (76,95)
0.25	0.990†	0.995
0.5	0.980†	0.990
1	0.965†	0.983
2	0.943	

* ±0.003. † ±0.002.

RbBr (14)

F	η_{25}	η_{35}
0.1	0.995	0.999
0.25	0.989	0.998
0.5	0.979	0.997

F	η_{45}
0.1	1.001
0.25	1.004
0.5	1.015

RbI (23)

F	η_{25}
0.25	0.978
0.5	0.957
1	0.921
2	0.877
3	0.873
3.5	0.883

Rb_2SO_4; *v. next column*

CsCl

F	η_{18} (72)	η_{25} (39, 95)
0.25	0.986*	0.992
0.5	0.973*	0.985
1	0.952*	0.975
2	0.927	

* ±0.002.

Rb_2SO_4 (93)

F	Values of η				
	10°	20°	30°	40°	50°
0.1	1.005	1.011	1.017	1.021	1.027
0.25	1.016	1.03	1.043	1.053	1.067
0.5	1.040	1.07	1.090	1.105	1.129
1.0	1.113	1.15	1.19	1.21	1.25

Cs_2SO_4 (93)

F	Values of η				
	10°	20°	30°	40°	50°
0.1	1.008	1.012	1.016	1.020	1.026
0.25	1.022	1.031	1.040	1.050	1.061
0.5	1.047	1.067	1.082	1.099	1.117
1.0	1.105	1.145	1.170	1.197	1.23

$CsNO_3$ (55)

F	Values of η			
	0°	10°	18°	25°
0.025	0.9960	0.9973	0.9984	0.9986
0.05	0.9902	0.9938	0.9961	0.9971
0.1	0.9796	0.9870	0.9910	0.9932
0.2	0.9612	0.9742	0.9808	0.9853
0.3	0.9445	0.9618	0.9715	0.9784
0.4	0.9288	0.9510	0.9632	0.9723
0.5		0.9413	0.9559	0.9668
0.6		0.9324	0.9494	0.9621
0.7		0.9239	0.9434	0.9579
0.8			0.9377	0.9540

AQUEOUS SOLUTIONS CONTAINING TWO STRONG ELECTROLYTES

𝔅-Table; Standard Arrangement (*v.* Vol. III, p. viii)

A	B	t, °C	Lit.
HCl................	$CdCl_2$	25	(43)
	$HgCl_2$	25	(43, 101)
	$CuCl_2$	25	(101)
	$FeCl_3$	25	(43)
	$CoCl_2$	25	(101); *cf.*(103)
	NaCl	25	(69)
	KCl	25	(69)
H_2SO_4..............	HNO_3	10	(3)
		20	(3)
		40	(3)
	$K_2Cr_2O_7$	25	(43)
HNO_3..............	$Ba(NO_3)_2$	25	(43)
NH_4NO_3............	NH_4Cl	25	(43)
	$Pb(NO_3)_2$	25	(43)
	$Ba(NO_3)_2$	25	(43)
	$NaNO_3$	25	(43)
	KNO_3	25	(43)
NH_4Cl..............	$FeCl_3$	25	(43)
	$BaCl_2$	25	(43)
	NaCl	15	(12)
		20	(12)
	KCl	15	(12)
		20	(12)
		25	(43)
$(NH_4)_2SO_4$..........	$CuSO_4$	25	(43)
	$MnSO_4$	25	(43)
	$Al_2(SO_4)_3$	25	(43)
	K_2SO_4	25	(43)

𝔅-Table.—*(Continued)*

A	B	*t*, °C	Lit.
$Pb(NO_3)_2$	$NaNO_3$	25	(43)
	KNO_3	25	(43)
$CuCl_2$	$MgCl_2$	25	(101)
	LiCl	25	(101)
	NaCl	25	(101)
	KCl	25	(101)
$CuSO_4$	$MnSO_4$	25	(43)
	Na_2SO_4	25	(43)
	K_2SO_4	25	(43)
$MnSO_4$	Na_2SO_4	25	(43)
	K_2SO_4	25	(43)
$CoCl_2$	$MgCl_2$	25	(101)
	LiCl	25	(101)
	NaCl	25	(101)
	KCl	25	(101)
$Al_2(SO_4)_3$	Na_2SO_4	25	(43)
	K_2SO_4	25	(43)
$MgCl_2$	$NaNO_3$	20	(59)
$Mg(NO_3)_2$	NaCl	20	(59)
	KNO_3	20	(59)
$CaCl_2$	NaCl	20	(59)
	$NaNO_3$	20	(59)
$Ca(NO_3)_2$	$NaNO_3$	20	(59)
$SrCl_2$	NaCl	20	(59)
	KNO_3	20	(59)
$Sr(NO_3)_2$	$NaNO_3$	20	(59)
		25	(43)
	KCl	20	(59)
	KNO_3	20	(59)
		25	(43)
$BaCl_2$	$Ba(NO_3)_2$	25	(43)
	NaCl	15	(12)
		20	(12, 59)
		25	(43)
	KCl	25	(43)
$Ba(NO_3)_2$	$NaNO_3$	25	(43)
	KNO_3	25	(43)
NaOH	KOH	25	(43)
NaCl	$NaNO_3$	25	(43)
	KCl	15	(12)
		20	(12)
		25	(43, 69, 85)
NaI	KI	25	(85)
Na_2SO_4	K_2SO_4	25	(43)
$NaNO_3$	KNO_3	25	(43)
Na_2CO_3	K_2CO_3	25	(43)
Na_2SiO_3	Na_2WO_4	30	(51)
KCl	KNO_3	25	(43)
K_2SO_4	$K_2Cr_2O_7$	25	(43)

For solutions containing NH_4OH and various salts, *v.* (4, 5, 43).

AQUEOUS SOLUTIONS CONTAINING THREE OR MORE STRONG ELECTROLYTES

		Lit.
$HCl + NaCl + KCl$	25°	(69)
$MgCl_2 + CaCl_2 + SrCl_2 + NaNO_3$	20°	(59)
$MgCl_2 + Sr(NO_3)_2 + Ba(NO_3)_2$	20°	(59)
$Mg(NO_3)_2 + Ca(NO_3)_2 + NaCl$	20°	(59)
$Mg(NO_3)_2 + Sr(NO_3)_2 + KCl + KNO_3$	20°	(59)
$Mg(NO_3)_2 + SrCl_2 + NaCl + KNO_3$	20°	(59)

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KINETICS OF PHYSICAL PROCESSES

VELOCITY OF VAPORIZATION (AND GAS EVOLUTION) AND OF CONDENSATION (AND GAS ABSORPTION)

A. C. Egerton

EVAPORATION IN VACUO

GENERAL FORMULA

$m = \alpha p\,(M/2\pi RT)^{1/2}$ (28, 41); *see further* Vol. I, p. 91.

m = mass in grams vaporized per cm² per sec.

p = vapor pressure at T, °K.

M = gram-molecular weight.

R = gas constant.

$\alpha = 1 - \nu$, where ν is the fraction of molecules reflected without condensation ("accommodation coefficient").

EVAPORATION FROM HOT FILAMENTS

For more recent critical compilation, *v.* (83.5)

Substance	$\log_{10} m$ (for p in mm Hg and $\alpha = 1$)	Range, °K	Lit.
Carbon*...........	$14.19 - 47\,000/T - 1.25 \log T$	3 100–3 800	(1, 77)
Molybdenum.......	$17.11 - 38\,600/T - 1.76 \log T$	2 000–2 400	(46)
Platinum..........	$14.00 - 27\,800/T - 1.76 \log T$	1 680–2 000	(46)
Tungsten†..........	$9.42 - 45\,450/T$	2 000–3 000	(18, 19, 41, 83)
Calcium‡...........	$10.97_8 - 10\,350/T$	770–970	(59)

* *See* (1); α varies with adsorption layer.

† Zwikker gives $\log_{10} m = 11.92 - 48\,400/T - 0.368 \log_{10} T - 0.00016T$; Langmuir gives $\log_{10} m = 15.402 - 47\,440/T - 1.4 \log_{10} T$ (M. P. 3540°K); Forsythe in close agreement with Zwikker's equation; Fonda's value at 2825°K lies between those of Langmuir and of Zwikker. For small crystals m is 30 % greater than for large (18). In N_2, m is 6 % of the value *in vacuo;* 3.9 % in argon (18). Rosenhain and Ewen (63) found the following ratio of m for coarse and for fine crystals: Zn, 2.3; Ag, 1.2; Cu, 1.4.

‡ Formula deduced from vapor pressure formula given by Pilling for $\alpha = 1$; the measurements of p included allowance for value of α obtained by comparative measurements with Zn and Cd (59).

EVAPORATION THROUGH AN APERTURE

If the diameter of the aperture is $\not> 0.1$ of the mean free path, m is the same as from a free surface, $\alpha = 1$. Measurements have been made by this method for Cd, Hg, K, Na, Pb, Zn and benzophenone (13, 35, 62, 73).

EVAPORATION OF SMALL DROPS (74, 75)

Spherical drop (*see* general formula for evaporation *in vacuo*).

For a drop of mercury resting on plane, $m = -1.11 \dfrac{dr}{dt} \times \rho$, where ρ is the density of mercury and $\dfrac{dr}{dt}$ is the rate of change of radius with time.

ACCOMMODATION COEFFICIENTS

Values of α for Saturated Vapors

Substance	α	t, °C	Lit.
Hg (liquid)...........	1.00 ± 0.01	60 to −30	(37, 74, 75)
Hg (solid)............	0.85	−64	(74, 75)
Cd (solid)............	0.98 ± 0.2	(*ca.* 200)	(4, 14)
Th, Ta, W............	1.0	(*ca.* 2000)	(42)
Benzophenone.........	0.2 to 0.5		(73)

Values of α for Gases on Various Solids (36, 43, 64)

Gas	Polished Pt*		Pt black at 20°C	W at 1500°K	Glass at 0°C
	°C	α			
H_2.............	−190	0.42	0.71	0.19	0.26
	0	0.26			
CO_2............	20	0.86	0.96		
O_2.............	20	0.83	0.95		
N_2.............	20	0.87		0.60	
He.............	−100	0.49			
	+200	0.38			
A..............	30–260	0.85			
Ne.............		0.65			

* Soddy and Berry found same results for Pd as for Pt surface.

CONDENSATION IN VACUO

Observed Temperature Region for Irreversible Condensation

Substance	On glass, t, °C	Lit.	Substance	t, °C	Lit.
NH_4Cl......	< −183	(39)	Cd on paraffin.....	−70	(9)
Hg*.........	−140 to −130	(39, 81)	Cd on mica	−80	(9)
			Cd on glass........	−90	(81)
Zn*.......	−183 to −78	(39)	Vapor at 280°....	−110	(16)
Cd*.......			Vapor at 365°....	−50	(16)
Mg.......					

Observed Temperature Region for Irreversible Condensation.—(*Continued*)

Substance	On glass, *t*, °C	Lit.	Substance	On glass, *t*, °C	Lit.
Cu	350 to 575	(39)	Ag*	< 575	(39)
			I_2	−60	(39)

* *Cf.* (15, 44).

Substance (16); *cf.* (38, 44, 78)	Vapor pressure, mm Hg	*t*, °C	Latent heat of adsorption, g-cal/g
Cd on glass	0.008	−107	5200
	0.03	−86	
Cd on copper	0.008	−111	2940
	0.03	−83	
Cd on silver	0.008	−86	3540
	0.03	−66	
Hg on silver	0.0083	−120	2560
	0.033	−88	

Although vaporization occurs according to the cosine law (38, 81), and for Ag, Zn, Sb_2S_3, and S (40), condensation is directed in the case of Cd, Hg, Zn and As but not HgI_2 or S, *v.* (23, 71, 72, 75).

EVAPORATION IN STILL AIR AND OTHER GASES

THEORETICAL EQUATIONS (66)

For values of diffusion coefficients, *v.* p. 62.

From flush circular area:

$$V = 4r\Delta \log_e \frac{p - p_0}{p - p_s}$$

when p_s is small, $V = Kp_s/p$ [Dalton (11)]. V = rate of evaporation (volume per unit time), p_s = saturation pressure at surface of liquid, p_0 = pressure of vapor in gas at distance from surface, p = total gas pressure, r = radius of circular area, Δ = diffusion coefficient (50, 58, 66, 80).

From elliptical area (a and b = axes of ellipse) approximate formula:

$$V = 4\sqrt{ab}\Delta \log_e \frac{p - p_0}{p - p_s} \text{ (58, 60, 66).}$$

From circular vessels (surface distant h below rim):

$$V = 4(\sqrt{h^2 + r^2} - h)\, \Delta \log_e \frac{p - p_0}{p - p_s} \text{ (6, 47, 68, 69, 70, 80).}$$

From vertical tube (distance from upper end of tube to surface of liquid in the tube, greater than the diameter):

$$V = \frac{A\Delta}{h} \log_e \frac{p - p_0}{p - p_s}.$$

A = area of cross section of tube, h = distance from upper end to surface (48, 52, 69, 79).

From spherical drop:

$$V = 4\pi r\Delta \log_e \frac{p - p_0}{p - p_s} \text{ (65)}$$

or

$$m = 4\pi r\Delta \frac{Mp_s}{RT} \text{ (45) } \left(\text{for small values } \frac{p_s}{p}\right)$$

m = mass evaporated per unit time; M = mol. wt.; r = radius of sphere, *v.* (84, 85).

The references refer to experimental work on the subject; the formulae hold only under ideal conditions. The essential conditions are adequacy of rate of supply of heat to maintain temperature of the surface (48) and absence of disturbance of the atmosphere in the neighborhood of the evaporating liquid (50, 58).

EVAPORATION OF SMALL DROPS

I_2 in air: $dm/dt = 1.83 \times 10^{-6} r$ (r radius of drop; m = g cm^{-2} sec^{-1} (54, 84).

Hg in air: $dr/dt = 1.4 \times 10^{-10}$, cm/sec for drops 10^{-4} to 10^{-3} cm radius. [Evaporation of small drops is checked by oxidation of droplet, *v.* (51)].

H_2O: Evaporation of small drops less than 10^{-4} cm radius checked by absorption of gases other than hydrogen (24).

Change in Radius with Time

Minutes	Air	H_2, 70%; Air, 30%
5	0.89×10^{-4} cm	0.99×10^{-4} cm
20	0.86×10^{-4} cm	0.90×10^{-4} cm
45	0.86×10^{-4} cm	0.74×10^{-4} cm

PLATINUM METALS IN AIR

Loss in weight, g/cm²/sec in air at atmospheric pressure (7)

t	Pt	Pt + 1% Ir	Pt + 2.5% Ir	Pt + 8% Rh
900	0	0	0	0
1000	2.2×10^{-7}	8.3×10^{-7}	1.6×10^{-6}	1.9×10^{-7}
1200	2.2×10^{-6}	3.3×10^{-6}	7.0×10^{-6}	1.5×10^{-6}

Crookes (10) found the following percentage loss of total weight at 1300°C in air but did not mention extent of surface: 8 hr, Ru, 25%; 22 hr, Ir, 7.3%; 30 hr, Pd, 0.745%; Pt, 0.245%; Rh, 0.131%. (In case of Ru and Ir oxidation occurred. Ir *in vacuo* at 1300°C lost 0.069% in 30 hr.)

EVAPORATION IN A CURRENT OF GAS

In steady horizontal wind (velocity W):

$$V = k\sqrt{W} \text{ and } V = \alpha r^{1.5}$$

k and α, constants (circular area of radius r, areas 250 m² to 10 cm² or in gentle draughts 25 m² to 1 cm²) (33, 68). For very large areas, *see* especially (21).

Numerous meteorological formulae connect evaporation with temperature, hygrometric and wind conditions (*see* annotated bibliography (49).

General form: $dE/dt = A(p_s - p_d) + B(p_s - p_d)W$ (Dalton-Weilermann).

E, fall of level due to evaporation in time, t; p_s, saturation pressure at temperature of surface; p_d, saturation pressure at dew point; W, wind velocity; A and B, constants, *v. also* (53).

Typical formula: $E_{mm} = 0.425\ (p_s - p_d)\ (1 + 0.805W)$ (Fitz-Gerald); W measured in km/hr (up to 20 km/hr). p in mm. *See* especially (5, 17, 61, 67).

Similar formulae are used for *chemical engineering* purposes; *e.g.*, evaporation from pans in still air: $M = 0.02\ (p_s - p_d)^{1.2}$ (29).

Evaporation from pans in air current:

$$M = (0.031 + 0.0135W)(p_s - p_d)\frac{p_0}{p_1}$$

M kg m^{-2}hr^{-1}; W = air velocity m/sec from 0.5 to 4 m/sec; p_0 = 760 mm and p_1 = barometric pressure; range 20 − 70°C (28.5, 29, 31).

Notes

Rate of evaporation of water approximately proportional to vapor pressure up to (B. P. − 15°) (3).

At 50°C evaporation of water in a current of air (W = 2.5 m/sec) is 2.8 times as rapid as in still air, and for W = 5 m/sec, 3.8 times (3).

Number of gram-molecules of a liquid evaporated per unit time and unit surface is proportional to vapor pressure, *v.* (26, 30); for evaporation of toluene, nitrobenzene, *m*-xylene, and chlorobenzene in wind tunnel, *v. also* (69).

Evaporation from large areas (lakes, etc.) about two-thirds evaporation from small pans.

Evaporation of sea water approximately 5% less than fresh water.

Evaporation of ocean approximately 820 mm *per annum* (34, 82).

VAPOR PRESSURE BY STREAMING METHOD

$$\log_e \frac{p_s}{p_s - p} = \frac{\text{const.}}{\sqrt{W}}$$

where W is velocity of gas stream and p is partial pressure of vapor in gas.

Dependence of velocity of vaporization on pressure, temperature and nature of gas (27, 32). For measurements on Ag, Tl, Pb and Sn, *v.* (76).

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THE VELOCITY OF DISSOLVING OF CRYSTALS IN LIQUIDS

R. G. VAN NAME

The velocity constant K has usually the value given by equation I or II. As recorded in the tables it has the dimensions [cm min^{-1}] and is independent of the unit of concentration. In cases where it has been necessary to give the constant in the author's or arbitrary units, it is designated by K_{arb}.

For the case of simple solution in a solvent (reversible)

$$K = \frac{v}{S(C_s - C)} \frac{\mathrm{d}C}{\mathrm{d}t} = \frac{v}{S(t_2 - t_1)} \ln \frac{C_s - C_1}{C_s - C_2} \qquad \text{(I)}$$

in which v = volume in cm^3, t = time in min, S = surface of contact in cm^2, C = concentration at time t, C_s = concentration at saturation, and $\ln = \log_e$.

For the case of solution by interaction with a dissolved reagent

$$K = -\frac{v}{SC} \frac{\mathrm{d}C}{\mathrm{d}t} = \frac{v}{St} \ln \frac{C_0}{C} \qquad \text{(II)}$$

in which C_0 and C are the concentrations of the reagent at time zero and time t, respectively; other symbols as in I.

Since K depends upon the intensity of the stirring and upon the form and dimensions of the apparatus, a quantitative comparison of the results of different investigators is usually impossible.

The velocities of dissolving of metals in acids are subject to various disturbing effects, such as passivity, period of induction, large influence of physical state and of traces of certain impurities, evolution of gas, etc., and are often not expressible by definite velocity constants. The results obtained are frequently too complicated and difficultly reproducible to justify their inclusion in the following tables. In the case of magnesium, however, the disturbing effects seem to be of minor importance.

La constante de vitesse K a ordinairement la valeur donnée par l'équation I ou II. Dans les tables elle a la dimension [cm min^{-1}] et elle est indépendante de l'unité de concentration. Dans les cas où il a été nécessaire de donner la constante dans les unités arbitraires de l'auteur, elle est désignée par K_{arb}.

Pour le cas d'une simple dissolution dans un solvant (reversible)

$$K = \frac{v}{S\ (C_s - C)} \frac{\mathrm{d}C}{\mathrm{d}t} = \frac{v}{S(t_2 - t_1)} \ln \frac{C_s - C_1}{C_s - C_2} \qquad \text{(I)}$$

où v = volume en cm^3, t = temps en min, S = surface de contact en cm^2, C = concentration au temps t, C_s = concentration à la saturation et $\ln = \log_e$.

Pour le cas d'une dissolution par reaction avec un réactif dissout

$$K = -\frac{v}{SC} \frac{\mathrm{d}C}{\mathrm{d}t} = \frac{v}{St} \ln \frac{C_0}{C} \qquad \text{(II)}$$

où C_0 et C sont respectivement les concentrations du réactif au temps zéro et au temps t; pour les autre symboles comme en I.

Comme K dépend de l'intensité de l'agitation et de la forme et des dimensions de l'appareil, une comparaison quantitative des résultats obtenus par différents expérimentateurs est ordinairement impossible.

Les vitesses de dissolution des métaux dans les acides sont sujets à des effets perturbateurs variés, tels que: la passivité, la période d'induction, la grande influence de l'état physique et des traces de certaines impuretés, l'évolution du gaz, etc., et de la sorte ne peuvent souvent pas être exprimées par des constantes de vitesse définies. Les résultats obtenus sont fréquemment trop compliqués et difficilement reproductibles pour justifier leur publication dans les tables suivantes. Cependant, dans le cas du magnésium, les effets parasites paraissent être d'importance moindre.

Die Geschwindigkeitskonstante K hat gewöhnlich den nach Gleichung I oder II sich ergebenden Wert und wie aus den Tabellen folgt, besitzt sie die Dimension [cm min^{-1}] und ist von der Einheit der Konzentration unabhängig. In Fällen wo es nötig war die Konstante in den vom Autor gegebenen, oder in sonst willkürlichen, Einheiten anzuführen, wird sie mit $K_{\text{arb.}}$ bezeichnet.

Für den Fall der einfachen reversiblen Lösung in einem Lösungsmittel gilt

$$K = \frac{v}{S(C_s - C)} \frac{dC}{dt} = \frac{v}{S(t_2 - t_1)} \ln \frac{C_s - C_1}{C_s - C_2} \qquad \text{(I)}$$

wo v = Volumen in cm³, t = Zeit in Minuten, S = Kontaktoberfläche in cm², C = Konzentration zur Zeit t, C_s = Sättigungskonzentration und ln = $\log_e$.

Für den Fall der Wechselwirkung mit einem gelösten Stoff, hat man

$$K = -\frac{v}{SC} \frac{dC}{dt} = \frac{v}{St} \ln \frac{C_0}{C} \qquad \text{(II)}$$

Es bedeutet, C_0 und C die Konzentration des reagierenden Bestandteiles zur Zeit Null bezw. zur Zeit t. Die anderen Zeichen sind die gleichen wie bei I.

Da K von der Rührgeschwindigkeit, der Form und der Dimension des verwendeten Apparates abhängt, ist ein quantitativer Vergleich der Ergebnisse der verschiedenen Beobachter meist nicht möglich.

Die Lösungsgeschwindigkeit der Metalle in Säuren unterliegt den verschiedenen störenden Einflüssen, wie Passivität und Induktionsdauer. Bedeutend ist der Einfluss des physikalischen Zustandes der Probe, der Spuren von Verunreinigungen, der Gasentwickelung, u.s.w. Dies alles ist nicht durch eine bestimmte Geschwindigkeitskonstante ausdrückbar. Die Ergebnisse sind häufig zu kompliziert und zu schwer reproduzierbar um in diese Tafeln aufgenommen zu werden. Beim Magnesium scheinen sich jedoch die störenden Einflüsse weniger bemerkbar zu machen.

Generalmente il valore della costante di velocità K è quello dedotto dalle equazioni I o II. Questa velocità, come è indicato nelle tabelle, ha le dimensioni di [cm min^{-1}] ed è indipendente dalla unità di concentrazione. Nei casi in cui si è dovuto dare la costante in unità arbitrarie, quelle adoperate dagli autori, essa è stata indicata con K_{arb}.

Nel caso che si tratti di semplice dissoluzione in un solvente (riversibile)

$$K = \frac{v}{S(C_s - C)} \frac{dC}{dt} = \frac{v}{S(t_2 - t_1)} \ln \frac{C_s - C_1}{C_s - C_2} \qquad \text{(I)}$$

nella quale v = volume in cm³, t = tempo in minuti, S = superficie di contatto in cm², C = concentrazione al tempo t, C_s = concentrazione al punto di saturazione e ln = $\log_e$.

Nel caso di dissoluzione con reazione con una sostanza disciolta si ha:

$$K = -\frac{v}{SC} \frac{dC}{dt} = \frac{v}{St} \ln \frac{C_0}{C} \qquad \text{(II)}$$

nella quale C_0 e C rappresentano le concentrazioni della sostanza reagente al tempo 0 ed al tempo t, mentre gli altri simboli hanno lo stesso significato che nella I.

Poichè K dipende dalla intensità della agitazione, dalla forma e dalle dimensioni dell'apparecchio, è impossibile confrontare quantitativamente i risultati dei vari sperimentatori.

Le velocità di dissoluzione dei metalli negli acidi risentono molto della azione di varie cause perturbatrici, come ad esempio: passività, periodo di induzione, stato fisico, presenza di tracce di certe impurezze, svolgimento di gas, ecc., e perciò spesso non sono esprimibili con valori ben definiti delle costanti. Spesso i risultati ottenuti sono troppo complessi e difficili a riprodursi per poter essere compresi nelle tabelle che seguono. Nel caso del magnesio tuttavia sembra che le cause perturbatrici non abbiano molta importanza.

VELOCITY CONSTANTS

1. Salts in Water

Rotary stirring, 400 r.p.m.; exposed surface horizontal, below stirrer; 25°C (30)

Salt	C_s,* g/100 g H_2O	K, cm/min
KI	146.45	0.186
KBr	67.75	0.171
KCl	36.32	0.147
NaCl	35.92	0.105
TlCl	0.385	0.204†
TlBr	0.057	0.144†
$PbCl_2$	1.08	0.060†
$PbBr_2$	0.974	0.078†
$BaCl_2.2H_2O$	36.9	0.096
K_2SO_4	12.04	0.102
$K_4Fe(CN)_6.3H_2O$	32.0	0.048‡
$FeSO_4.7H_2O$	29.7	0.048
$NiSO_4.7H_2O$	39.6	0.033
$CoSO_4.7H_2O$	37.8	0.036
$ZnSO_4.7H_2O$	57.9	0.030
$MgSO_4.7H_2O$	38.3	0.030
$CuSO_4.5H_2O$	22.29	0.039
$CdSO_4.\frac{8}{3}H_2O$	77.0	0.021
$CaSO_4.2H_2O$	0.210	0.021§

* Calculated as anhydrous salt. ‡ ∥ to cleavage surface.
† Fused salt used. § Selenite, ∥ to face (010).

2. Salts in Water

Rotary stirring, 50 r.p.m.; whole crystal exposed (12)

Salt	C_s, g/100 g soln.	$K_{\text{arb.}}$, 4.8°C	C_s, g/100 g soln.	$K_{\text{arb.}}$, 30.1°C
K_2SO_4	7.82	0.027	11.43	0.071
$NaClO_3$	45.47	0.043	51.22	0.083
$K_2Cr_2O_7$	5.52	0.026	15.17	0.069

3. Metals in Dissolved Iodine (and Bromine)

Disk of metal 40 mm diameter, 0.6 mm thick, supported vertically, whole surface exposed. Rotary stirring, 240 r.p.m.; S = 2.60 cm², but velocity per unit area not accurately calculable on account of difference in stirring on the two sides of the disk. Aqueous solution of I_2 (resp. Br_2) in KI (resp. KBr); 25 ± 0.1°C (27)*.

Metal	Salt, mole/l, I_2 in KI	$K \times S$, cm³/min	Metal	Salt, mole/l, I_2 in KI	$K \times S$, cm³/min
Hg	0.6	8.81	Zn	1.2	9.64
Cd	0.6	8.69	Hg	2.4	10.48
Zn	0.6	8.64	Cu	2.4	9.98
Hg	1.2	9.55	Ag	2.4	9.93
Cd	1.2	9.56		Br_2 in KBr	
			Hg	3.3	12.27

* These and further results in original seem to show that these five metals dissolve in I_2 + KI with the same velocity, expressed in equivalents of metal dissolving.

4. METALS IN DISSOLVED IODINE

Method as above: Disk 38.3 mm × 0.5 mm. $S = 2.36$ cm^2; velocity per unit area not accurately calculable, (*cf.* 3); 25 ± 0.1°C (26).* 0.5 mole KI and 0.02 mole H_2SO_4 per l.

Metal	Cd	Fe	Ni	Co
$K \times S$, cm^3/min	6.86	6.88	6.88	6.87

Cd in acid solutions of iodides

H_2SO_4, mole/l	0	0.02						
Iodide, mole/l	0.5				0.25			
Iodide	HI	LiI	NaI	KI	MgI_2	CaI_2	BaI_2	CdI_2
$K \times S$, cm^3/min	6.45	6.41	6.56	6.86	6.25	6.23	6.45	6.82

* The results show that K is independent of the metal but varies to a marked extent with the nature of the other cation present.

5. METALS IN AQUEOUS FERRIC SULFATE, FERRIC CHLORIDE AND CHROMIC ACID

Values of $K \times S$, cm^3/min; method and dimensions of disk as in 4 (28)

Ferric sulfate (ferric alum)* 24.6 ± 0.1°C

H_2SO_4, mole/l	0.01	0.25	1.25	5.0
Zn	4.38			
Cd	4.12	4.15	3.54	1.76
Fe	3.95	3.92	3.37	1.74
Ni	3.80	3.75	3.27	1.71
Sn		3.96		1.72
Cu		3.74	3.30	1.71
Ag		1.67	1.63	1.24

Ferric chloride, 24.6 ± 0.1°C

HCl, mole/l	0.1	0.5
Cd	4.19	4.17
Fe	4.14	4.35
Cu	3.44	4.20

Chromic acid* (added as CrO_3), 25 ± 0.1°C

H_2SO_4, mole/l	0.25	1.25	5.0
Cd	7.02	5.32	2.67
Ni	irregular		2.67
Sn			2.74
Cu	6.95	5.34	2.72
Ag	4.28		1.22

* Velocities for different metals tend to become the same with increasing H_2SO_4 concn., probably because it increases the viscosity and thus retards diffusion.

6. METALS IN AQUEOUS FERRIC SULFATE (9)

18 ± 0.1°C; no stirring; dissolving surface vertical; $S = 22.5$ cm^2

Metal	Cu	Fe	Cd	Sn
K, cm/min	0.0142	0.0138	0.0144	0.0137

The agreement between the different metals in spite of the low acidity (*see* 5) is probably due to the slowness of diffusion in the unstirred solutions.

7. COPPER IN AQUEOUS FERRIC CHLORIDE AND CUPRIC CHLORIDE

All solutions contained NH_4Cl, 3.7 to 4.7 mole/l. Variations in concentration of NH_4Cl were without effect on K when over 2.5 mole/l were present. Rotary stirring, 1500 r.p.m.; dissolving surface horizontal; $S = 34$ to 35.3 cm^2; 25°C (2).

Salt	No. of exps.	Initial concentration, mole/l	Mean, K, cm/min
$FeCl_3$ alone	3	(0.186) (0.191) (0.290)	0.205
$CuCl_2$ alone	2	(0.166) (0.195)	0.205
$FeCl_3 + CuCl_2$	4	Various	0.204
		Mean of the 9 exps.	0.2044

8. MAGNESIUM AND ZINC IN AQUEOUS ACIDS

Rotary stirring, 300 r.p.m.; value of S in doubt, but apparently 0.22 cm^2 in all experiments; 25°C. K_a = Ionization constant (22).

Solution, initial concn. in mole/l	$K \times S$, cm^3/min*	K_a
Mg		
HCl, 0.1	1.12	
HCl, 0.1 + $MgCl_2$, 0.0671	1.25	
HCl, 0.1 + $MgCl_2$, 0.1341	1.31	
HAc (Acetic acid), 0.1	0.405	
HAc, 0.1 + $Mg(Ac)_2$, 0.1	0.366	
HAc, 0.1 + $Mg(Ac)_2$, 0.2	0.326	
HAc, 0.1 + $MgSO_4$, 0.2	0.416	
HAc, 0.1 + Na_2SO_4, 0.2	0.454	
HAc, 0.1 + NaAc, 0.2	0.441	
H_2SO_4, 0.05	1.15	
H_2SO_4, 0.05 + KCl, 0.1341	1.43	
H_2SO_4, 0.05 + KBr, 0.1341	1.64	
H_2SO_4, 0.05 + KI, 0.1341	1.48	
HCl, 0.02	1.27	
2,5-Dihydroxybenzoic acid	0.774	108×10^{-5}
2,4-Dihydroxybenzoic acid	0.518	52×10^{-5}
Tricarballylic acid, 0.02	0.493	22×10^{-5}
Acetic acid (HAc), 0.02	0.449	1.8×10^{-5}
Zn		
HCl, 0.1	0.133	After period of induction

* The value of K is here not wholly independent of the acid concentration, but for any given acid tends to be larger the higher the dilution.

9. METALS IN AQUEOUS HYDROCHLORIC ACID

After period of induction or adequate pretreatment with acid. (*a*) A plate of the metal with one surface exposed, attached eccentrically to stirrer stem, acts as blade of stirrer. Radius of path not given; 100 r.p.m.; 25°C. (*b*) Same apparatus and temp. Stirrer stationary.

(*a*)	Metal	Solution, initial conc. in mole/l		K, cm/min	Lit.
		HCl	Salt		
	Al*	0.5		0.0025	(8)
		1.0		0.0037	
		1.5		0.026	
		2.0		0.057	
		3.0		0.088	
		4.0		0.123	
		1.0	$AlCl_3$, 0.33	0.044	
		2.0	$AlCl_3$, 1.0	0.064	
		1.0	KCl, 1.0	0.0078	
	Zn†	2.0		0.10	(7)
	Mg‡	0.125		0.41	(5)
(*b*)	Mg§	0.0625		0.20	(6)
		0.125		0.27	
		0.25		0.32	

* Cut from rolled bar. † Kahlbaum. ‡ Sheet metal, Kahlbaum. § A different sample of Mg from the above, not rolled.

10. PbS, ZnS AND RELATED MINERALS IN DILUTE SULFURIC ACID

Material, screened fragments of uniform size. No stirring. Velocities were proportional to concentration of acid between 0.0125 and 1.25% H_2SO_4. The relative values of the velocity constant tabulated below were the same at all temperatures between 0 and 50° (15, 16).

Mineral	Locality	$K_{\text{arb.}}$
Galena (PbS, about 98%)	Clausthal	1.00
Sphalerite (ZnS, about 99%)	Spain	3.2
Sphalerite (Pb, 11.4%; Fe, 3.6%)	Clausthal	6.3

10.—(*Continued*)

Mineral	Locality	$K_{arb.}$
Sphalerite (Pb, 14.9%; Fe, 3.5%; SiO_2, 11%)	Bensberg	11.1
Christophite (ferriferous ZnS; Fe, 16%; SiO_2, 19%)	Breitenbrunn	14.0

11. Mineral Carbonates in Acids

Material, except in cases of malachite and marble, large crystals. Single exposed surface vertical. Stirring by gas evolved only; 15°C (19, 20).

Mineral	Acid	$K_{arb.}$	Remarks
Iceland spar ($CaCO_3$)	HCl, HNO_3 or HI	1.00	Cleavage face. Velocity with HBr *ca.* 40% higher
Aragonite ($CaCO_3$)	HCl or HNO_3	0.48	Face (010)
Dolomite ($CaCO_3.MgCO_3$)	HCl or HNO_3	0.025	Face not specified
Witherite ($BaCO_3$)	HCl or HNO_3	1.28	Face not specified
Smithsonite ($ZnCO_3$)	HCl or HNO_3	0.087	Face not specified
Cerussite ($PbCO_3$)	HNO_3	0.76	Face (010)
Azurite [$2CuCO_3.Cu(OH)_2$]	HCl or HNO_3	0.33	Face not specified
Malachite [$CuCO_3.Cu(OH)_2$]	HCl or HNO_3	0.23	Massive
Marble ($CaCO_3$)	HCl or HNO_3	1.7	Massive

12. Copper in Aqueous Ammonia

Reaction autocatalytic, accelerated by dissolved copper. $K = \frac{v}{S(C+\alpha)}\frac{dC}{dt} = \frac{v}{S(t_2 - t_1)} \ln \frac{C_2 + \alpha}{C_1 + \alpha}$ in which C = concentration of dissolved copper. $\alpha = \frac{K_0}{K}$, $K_0 = \left(\frac{v}{S}\frac{dC}{dt}\right)_{C=0}$, the initial velocity. For a given concentration of dissolved oxygen K_0 and α are constants. K_0 is approximately proportional to the square root of the oxygen concentration; K is practically independent of it. The validity of this equation ends abruptly with the formation of an oxide coating on the metal, due to accumulation of OH^- ions produced by the reaction. This stage is deferred by a higher concentration of ammonia, and also by ammonium salts.

Mean values of K for various constant concentrations of ammonia in solutions kept saturated with air. Two copper plates 1.5 × 1.3 cm describe in liquid a circular path 2 cm in radius, 1120 r.p.m.; S = 7.6 to 8.6 cm²; 24.8°C (32).

$K_0 = 13.6 \times 10^{-4}$		$\alpha = 0.0020$
NH_3, mole/l	NH_4 salt, mole/l	K,* cm/min
1.047	0	0.640
1.921	0	0.703
3.963	0	0.653
1.047	$(NH_4)_2SO_4$, 0.01	0.710
1.088	$(NH_4)_2SO_4$, 0.05	0.680
1.080	$(NH_4)_2SO_4$, 0.1	0.671
1.080	NH_4NO_3, 0.1	0.681
1.080	NH_4Cl, 0.1	0.691
		Mean 0.679

* The results show that within these limits K is independent of the concentration of free ammonia and of ammonium salts.

13. Silver in Aqueous Potassium Cyanide

For constant concentration of dissolved oxygen $K = \frac{v}{St}\left[m(C_0 - C) + \log_{10}\frac{C_0}{C}\right]$ in which C = concn. of KCN, C_0 = initial concn., m = a constant = $0.4343 \frac{k_2}{k_1}$ (k_2 = velocity constant of the diffusion of cyanide. k_1 = velocity constant of the chemical reaction at interface). The validity of this equation is ultimately disturbed by OH^- ions produced by the reaction itself, and the sooner the smaller the value of C_0.

Mean values of K and m for various initial concentrations of KCN for solutions kept saturated with air.* Stirring like last; 600 r.p.m.; two silver plates 1.5 × 1.2 cm; S = 7.3 to 8.7 cm², 25°C (33).

C_0, mole/l	m	K, cm/min	C_0, mole/l	m	K, cm/min
0.1480	135	0.226	0.0042	140	0.231
0.0632	140	0.230	0.0022	150	0.217
0.0316	145	0.231	0.0011	150	0.209
0.0158	155	0.222		——	——
0.0079	140	0.225		Mean 144.4	0.224

* In solutions saturated with pure oxygen the velocity of dissolving, $\frac{dC_{Ag}}{dt}$, was 2.5 times larger, indicating approximate proportionality with $[O_2]^{1/2}$. K was also increased but in a somewhat smaller ratio.

14. Zinc in HCl Dissolved in Alcohols and in Acetone

A thin rod of zinc mechanically raised and lowered in liquid 72 times per minute. S = 2.78 cm²; organic solvents anhydrous, and contained initially 0.5 mole/l of HCl; presence of a small amount of H_2O in CH_3OH, C_2H_5OH and $(CH_3)_2CO$ lowered velocity; 20°C (34).

HCl in	Methyl alc.	Ethyl alc.	Amyl alc.	Acetone	H_2O
K, cm/min	0.37	0.17	<0.01	0.42	0.14

TEMPERATURE COEFFICIENTS

M designates mechanical stirring; G, stirring by gas evolved by reaction; O, no stirring

Reaction and stirring		Comparable velocities at two temperatures		$\frac{K_{t+10°}}{K_t}$	Lit.
Benzoic acid in H_2O,	M	$(1.587)_{1.5}$	$(2.851)_{17.5}$	1.44_2	(31)
		$(2.851)_{17.5}$	$(4.524)_{31}$	1.40_8	
		$(4.524)_{31}$	$(5.756)_{40}$	1.30_7	
		$(5.756)_{40}$	$(9.946)_{60}$	1.31_4	
Cd in I_2 + KI,	M	$(3.72)_0$	$(5.87)_{15}$	1.35_6	(25)
		$(5.87)_{15}$	$(7.62)_{25}$	1.29_8	
		$(7.62)_{25}$	$(9.55)_{35}$	1.25_3	
		$(9.55)_{35}$	$(11.81)_{45}$	1.23_7	
		$(11.81)_{45}$	$(14.26)_{55}$	1.20_7	
		$(14.26)_{55}$	$(16.93)_{65}$	1.18_7	
K_2SO_4 in H_2O,	M	$(0.027)_{4.8}$	$(0.071)_{30.1}$	1.47	(12)
		$(0.071)_{30.1}$	$(0.166)_{68.9}$	1.25	
$K_2Cr_2O_7$ in H_2O,	M	$(0.026)_{4.8}$	$(0.073)_{35.3}$	1.40	
$NaClO_3$ in H_2O,	M	$(0.043)_{4.8}$	$(0.083)_{30.1}$	1.30	
		$(0.183)_{35.1}$	$(0.261)_{44.7}$	1.45	
Benzoic acid in H_2O,	M	$(2.30)_{20}$	$(3.35)_{30}$	1.5	(4)
$Mg(OH)_2$ in benzoic acid,	M	$(1.55)_{20}$	$(2.35)_{30}$	1.5	
$Mg(OH)_2$ in HCl,	M	$(8.1)_{20}$	$(12.2)_{30}$	1 5	
Cu in $FeCl_3$ or $CuCl_2$,	M	$(0.1508)_{15}$	$(0.2044)_{25}$	1.36	(2)
Cu in $Fe_2(SO_4)_3$,	O	$(0.031)_0$	$(0.045)_{11}$	1.40	(9)
		$(0.045)_{11}$	$(0.054)_{18}$	1.30	
		$(0.054)_{18}$	$(0.070)_{25}$	1.45	
Fe in $Fe_2(SO_4)_3$,	O	$(0.055)_{18}$	$(0.074)_{25}$	1.53	
Cd in $Fe_2(SO_4)_3$,	O	$(0.037)_0$	$(0.048)_{11}$	1.27	
		$(0.048)_{11}$	$(0.062)_{18}$	1.44	
		$(0.062)_{18}$	$(0.076)_{25}$	1.34	
Sn in $Fe_2(SO_4)_3$,	O	$(0.030)_0$	$(0.050)_{18}$	1.33	
		$(0.050)_{18}$	$(0.062)_{25}$	1.36	
Cu in $K_2Cr_2O_7$ + H_2SO_4,	M	$(8.15)_{21}$	$(10.38)_{31}$	1.27*	(29)
		$(10.38)_{31}$	$(13.03)_{41}$	1.26	
Cu in NH_4OH(air-satd.),	M	$(2.094)_{19.8}$	$(2.263)_{24.8}$	1.17	(32)
		$(2.263)_{24.8}$	$(2.588)_{34.8}$	1.14	

TEMPERATURE COEFFICIENTS.—(*Continued*)

Reaction and stirring		Comparable velocities at two temperatures		$\frac{K_{t+10^\circ}}{K_t}$	Lit.
Ag in KCN(air-satd.),	M	$(2.51)_{15}$	$(2.82)_{25}$	1.13	(33)
		$(2.82)_{25}$	$(3.26)_{35}$	1.16	
		$(3.26)_{35}$	$(3.84)_{45}$	1.18	
Mg in HCl,	G	$(2054)_0$	$(3059)_{25}$	1.17†	(6)
		$(3059)_{25}$	$(5564)_{50}$	1.27	
		$(1.00)_{50}$	$(1.51)_{75}$	1.2†	(3)
Al in HCl (2*N*),	M	$(55)_0$	$(1396)_{45}$	2.05	(8)
Al in HCl (3*N*),	M	$(248)_0$	$(982)_{25}$	1.73	
Fe in HCl,	G	$(2.5)_{50}$	$(5.8)_{61.4}$	2.1	(18)
		$(5.8)_{61.4}$	$(19)_{78.4}$	2.0	
Fe in H_2SO_4,	G	$(1.83)_{2.3}$	$(11.5)_{28.7}$	2.0	(10)
		$(11.5)_{28.7}$	$(26.2)_{45}$	1.7	
		$(26.2)_{45}$	$(63.1)_{58.5}$	1.9	
Iceland spar in HCl,	G	$(0.044)_0$	$(0.095)_{15}$	1.67	(21)
		$(0.095)_{15}$	$(0.251)_{35}$	1.62	
		$(0.251)_{35}$	$(0.565)_{55}$	1.50	
Witherite in HCl,	G	$(0.122)_{15}$	$(0.406)_{35}$	1.8	(20)
Azurite in HCl,	G	$(0.031)_{15}$	$(0.062)_{35}$	1.4	
Dolomite in HCl,	G	$(0.0024)_{15}$	$(0.0046)_{35}$	1.38	
Smithsonite in HCl,	G	$(0.0083)_{15}$	$(0.0142)_{35}$	1.31	
Malachite in HCl,	G	$(0.022)_{15}$	$(0.037)_{35}$	1.30	
PbS, ZnS (minerals) in dilute H_2SO_4,	O	Range 0 to 80° (8 temps.), coefficient constant		1.54	(15)
Cu in benzaldehyde dissolved in toluene, 10% by Vol.		$(52.8)_{40}$	$(72.2)_{50}$	1.36	(17)
		$(72.2)_{50}$	$(106)_{60}$	1.46	
		$(106)_{60}$	$(153)_{70}$	1.44	
	O	$(153)_{70}$	$(220)_{80}$	1.43	
		$(220)_{80}$	$(320)_{90}$	1.45	
		$(320)_{90}$	$(455)_{100}$	1.42	

* Two other determinations at different concentrations but same temperature range gave 1.29 and 1.30, respectively.

† Practically the same value was obtained also in mechanically stirred solutions.

RELATIVE VELOCITIES FOR DIFFERENT CRYSTAL FACES

In the case of simple (reversible) solution in a solvent a difference in the observed velocities of dissolving of two faces of the same crystal may be partly or wholly due to a difference in the solubilities (C_s) of the two faces, rather than in their velocity constants K. In some cases the evidence decidedly favors this explanation, notably when the velocities for the two faces differ appreciably only when the solution is nearly saturated.

Sodium Chloride in Water and in Various Solutions

Dissolving face vertical. No stirring. 25°C (14). The table summarizes results for other faces compared with results for cube. Owing to influence of convection currents, K for cube increased linearly with $(C_s - C)$. A face other than the cube gave a different value of K and a different rate of increase if C_s for cube was used in the calculations, but complete agreement was obtained by assuming C_s for the second face to differ by the percentage amount, Δ. Differences were appreciable only in solutions very nearly saturated, and disappeared entirely if saturation was 90% or less. The author concludes that K has the same value within error of experiment for all faces of NaCl, and that Δ represents actual percentage differences in the solubility of the given face from that of the cube.

	Various faces in pure NaCl solutions, Δ%	With formamide, 150 g/l, Δ%
Octahedron	+0.04	−0.4
Tetrahexahedron (310)	±0.00	±0.0
Tetrahedron (320)	−0.18	
Dodecahedron	−0.18	−0.4
Trisoctahedron (221)	±0.00	−0.3
Hexoctahedron (321)	−0.18	−0.2
Trapezohedron (211)	−0.18	−0.2

Octahedron in NaCl solutions containing

Urea		Formamide		KNO_3	
g/l	Δ%	g/l	Δ%	g/l	Δ%
0	±0.04	23	±0.0	40	±0.0
50	±0.00	53	±0.0	80	±0.0
96	−0.10	80	−0.2	120	+0.1
130	−0.12	110	−0.3	160	+0.1
180	−0.17	150	−0.4	200	±0.0
230	−0.34	188	−0.4		
280	−0.42				

Gypsum ($CaSO_4.2H_2O$) in Water

$C_s = 2.094$ g/l (anhyd. salt). C at all times $<0.16C_s$; rotary stirring; relative velocities for surfaces cut parallel to pinacoid (010), prism (110) and pyramid (111); 25° (23).

$$V_{010}: V_{110}: V_{111} = 1.00: 1.76: 1.88$$

Wagner (30) finds at 25° $V_{010}: V_{111} = 1.00: 156.$

$CuSO_4.5H_2O$ in Water

$C_s = 228.0$ g/l (anhydrous salt); C at start $= 0.9175C_s$; method like last; 24.9° (24).

$$V_{110}:V_{1\bar{1}0} = 1.00:1.27$$

Tartaric Acid and Salts in Water

Relative velocities. Two unlike faces acted upon simultaneously. Exposed surfaces vertical; no stirring; *ca.* 20° (11)

Tartaric acid in water	(100)	$(10\bar{1})$	(110)	$(1\bar{1}0)$	(101)	(011)	(001)
C = 875 g/l	1.00	1.29	1.49	1.55	1.63	1.68	1.76

$CuSO_4.5H_2O$ in water	(100)	$(1\bar{1}0)$	(111)	(010)	(110)
C = 168 g/l (anhyd. salt)	1.00	1.37	1.28	1.18	1.12

$K_4Fe(CN)_6.3H_2O$ in water	(010)	(110)	(011)
C = 389 g/l (anhyd. salt)	1.00	.1.79	1.86

$NaNO_3$ in Water

$C = 485.5$ g/l; no stirring; 25° (13)

Rhombohedron $(10\bar{1}0)$	Rhombohedron $(\bar{1}2\bar{1}0)$	Base (0001)
$V = 11.8$	10.7	10.8 mg/cm² min⁻¹

$MgSO_4.7H_2O$ in Water

$C = 331$ g/l (anhyd. salt); no stirring (13)

Base (001)	Pinacoid (010)	Prism (110)	Sphenoid (111)
$V = 3.7$	3.5	3.5	3.7mg/cm²min⁻¹

Quartz in Hydrofluoric Acid

Sol. I:HF = 97.18 g/l; Sol. II:HF = 201.7 g/l; no stirring (13)

	Base (0001)	Prism $(11\bar{2}0)$	Prism $(10\bar{1}0)$	Rhombohedron $(10\bar{1}1)$
(I) V =	7.2	1.15	1.17	0.97 mg/cm² day⁻¹
(II) V =	18.76	4.37	4.41	3.7 mg/cm² day⁻¹

Iceland Spar in HCl

Single exposed surface vertical. Stirring by gas evolved only. 15° (21). For surfaces cut, 1, parallel to principal axis; 2, parallel to cleavage plane; and 3, perpendicular to axis.

$$V_1: V_2: V_3 = 1.00: 1.05: 1.14$$

α-Chlorodinitrobenzene in Ether (1)

Prism (110) was compared with pinacoid (001). When the same value of C_s was used in the calculations for both faces the ratio $K_{(110)} : K_{(001)}$ varied with the concentration, reaching 0.4 in nearly saturated solution but approaching unity at slightly lower concentration. The author concludes that $K_{(110)} = K_{(001)}$ and that observed differences are due entirely to the fact that prism face is less soluble than the pinacoid. 15.1° and 19.8°; mechanical stirring.

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VELOCITY OF CRYSTALLIZATION

H. C. Burger

FORMATION OF CRYSTAL NUCLEI

If extraneous influences are eliminated, the number, N, of nuclei which are formed at a given temperature should be proportional to the volume of the liquid and to the time. This number is a characteristic temperature function of the liquid. Transition in the crystal state from one form to another can occur spontaneously in a similar manner.

The measurements of the number of nuclei are however not very accurate, and the values given below represent, therefore, only order of magnitude. The first temperature given is the melting point. N is given in cm^{-3} sec^{-1}.

FORMATION DES NOYAUX CRISTALLINS

Si l'on élimine les influences extérieures, le nombre, N, de noyaux qui sont formés à une température donnée doit être proportionnel au volume du liquide et au temps. Ce nombre est pour un liquide une fonction caractéristique de la température. La transition à l'état cristallin d'une forme dans une autre peut se produire spontanément d'une manière analogue.

Les mesures du nombre de noyaux ne sont cependant pas très précises et les valeurs données ci-dessous ne représentent par conséquent que l'ordre de grandeur. La première température donnée est le point de fusion. N est exprimé en cm^{-3} sec^{-1}.

Diopside (Zermatt) (44)

t, °C	1310	1260	1200	1175
N	0	60	150	180

Melilite (Alnö, Sweden) (44)

t, °C	1180	1130	1100	1080	1060
N	0	120	300	430	500

Spinel (Amity, N. Y.) (44)

t, °C	1360	1225	1210	1200	1185	1175
N	0	60	180	270	420	570

Hedenbergite (Nordmarken) (44)

t, °C	1160	1120	1100	1080
N	0	70	180	250

BILDUNG VON KRISTALLKEIME

Wenn äussere Einflüsse eliminiert sind, sollte die Zahl, N, der bei gegebener Temperatur gebildeten Keime, dem Volum der Flüssigkeit und der Zeit proportional sein. Diese Zahl ist eine für die Flüssigkeit charakteristische Temperaturfunktion. In ähnlicher Weise können im kristallisierten Zustande spontan Übergänge von der einen Form in die andere stattfinden.

Die Messungen der Keimzahl sind aber nicht sehr genau, und die folgenden Werte geben deshalb nur die Grössenordnung an. N ist in cm^{-3} sec^{-1} gegeben.

FORMAZIONE DEI GERMI CRISTALLINI

Quando siano eliminate influenze esterne, il numero, N, di germi che si formano ad una data temperatura, deve essere proporzionale al volume di liquido ed al tempo. Questo numero è una funzione della temperatura caratteristica per il liquido. In maniera simile possono verificarsi trasformazioni (allo stato solido) di una forma cristallina nell'altra.

Le misure del numero di germi non sono però molto esatte, ed i valori seguenti danno perciò solo un'idea dell'ordine di grandezza. La prima temperatura data è il punto di fusione. N è dato in cm^{-3} sec^{-1}.

Aegirite (Lange Sundfjord) (44)

t, °C	1020	1000	975	950
N	0	80	130	160

3, 4-Dinitrobromobenzene, 3, 4-$(O_2N)_2C_6H_3Br$.—N is the number of nuclei of the stable form (M. P. = 59.5°) in the metastable crystal phase (M. P. = 34.8°) (45).

°C	10	±0	−10	−20	−30	−40	−50	−60	−70	−80
N	0.01	0.1	0.3	1	1	2	4	2	0.3	0.3

Betol (β-Napthyl Salicylate) $OHC_6H_4CO_2C_{10}H_7$.—N is a maximum at 15 ±5° and equals 0.7 to 2 (45).

Piperine, $C_{17}H_{19}NO_3$.—N is a maximum at 40 ± 5° and equals 0.2 to 10 (45); *cf.* (54).

CRYSTAL GROWTH

The linear crystallization velocity at the crystal-liquid boundary is a function of its temperature (9, 10) which, however, is seldom measured (10, 53), the temperature of the surrounding bath only, being known. The maximum linear crystallization velocity (K. G.) of the liquid or transition velocity (U. G.) of one crystal phase to another is a characteristic property of the substance, which, however, is very sensitive to impurities, so that the values recorded below may be 5–10% in error from this cause, in cases where another precision is not indicated.

Maximum linear crystallization (K. G.) and transition (U. G.) velocities. The unit is millicentimeters (10^{-3} cm) per sec; M. P. = melting point, °C; (*s*) = stable form; (*m*) = metastable form.

ACCROISSEMENT DU CRISTAL

La vitesse de cristallisation linéaire dans la zone cristal liquide est une fonction de sa température (9, 10) qui est cependant rarement mesurée (10, 53). Dans la plupart des cas on ne connait que la température du bain environnant. La vitesse maximum de cristallisation linéaire (K. G.) du liquide, ou la vitesse de transition (U. G.) d'une phase cristalline en une autre, est une propriété caractéristique de la substance qui est cependant très sensible aux impuretés. Les valeurs données ci-dessous peuvent donc être entachées d'une erreur de 5 à 10% lorsque la limite de l'erreur n'est pas exprimée.

Vitesse maximum de cristallisation linéaire (K. G.) et vitesse de transition (U. G.). L'unité est le millicentimètre (10^{-3} cm) par sec; M. P. = point de fusion, °C; (*s*) = forme stable; (*m*) = forme metastable.

KRISTALLWACHSTUM

Die lineare Kristallisationsgeschwindigkeit an der Grenze Kristall-Flüssigkeit ist eine Funktion deren Temperatur (9, 10), welche aber selten gemessen ist (10, 53). Meistens ist nur die Temperatur des umgebenden Bades bekannt. Die maximale lineare Kristallisationsgeschwindigkeit der Flüssigkeit (K. G.) oder die Umwandlungsgeschwindigkeit (U. G.) der einen Kristallphase in die andere ist eine charakteristische Eigenschaft der Substanz, welche aber sehr empfindlich gegen Verunreinigungen ist. Deshalb können die unten angegebenen Werte mit einem Fehler von 5–10% behaftet sein, wenn keine andere Fehlergrenze genannt wird.

Maximale lineare Kristallisationsgeschwindigkeit (K. G.) und Umwandlungsgeschwindigkeit (U. G.). Die Einheit ist 10^{-3} cm pro sec; M. P. = Schmelzpunkt, °C; (*s*) = stabile Form; (*m*) = metastabile Form.

ACCRESCIMENTO DEI CRISTALLI

La velocità lineare di cristallizzazione in corrispondenza della zona di contatto cristallo-liquido è una funzione della temperatura (9, 10) alla quale essa si trova; questa temperatura però raramente è stata misurata direttamente (10, 53). Per lo più si conosce soltanto la temperatura del bagno nel quale il sistema in esame è immerso. La velocità lineare massima di cristallizzazione di un liquido (K. G.) o di trasformazione (U. G.) di una fase cristallina nell'altra è una proprietà caratteristica delle sostanze. Essa risente però molto l'influenza delle impurezze, per modo che i valori sotto riportati possono essere inesatti del 5–10%, quando non siano indicati altri limiti di errore.

Velocità lineare massima di cristallizzazione (K. G.) e velocità di trasformazione (U. G.). L'unità è 10^{-3} cm al secondo; M. P. = punto di fusione, °C; (*s*) = forma stabile, (*m*) = forma metastabile.

Formula	Name	K. G. or U. G.	Lit.
H_3PO_4	Orthophosphoric acid, M. P. 36.6°..	1.8±0.2	(5)
$Ca(NO_3)_2.4H_2O$	Calcium nitrate, 4-hydrate.........	22.7±0.3	(20, 22, 28)
$Cd(NO_3)_2.4H_2O$	Cadmium nitrate, 4-hydrate........	50	(22)
$Na_2S_2O_3.5H_2O$	Sodium thiosulfate, 5-hydrate (*s*)...	195	(37)
$Na_2S_2O_3.5H_2O$	Sodium thiosulfate, 5-hydrate (*m*) ..	185	(37)
$Na_2S_2O_3.5H_2O$	*m* → *s*, U. G. = ...	83	(37)
$C_2H_3ClO_2$	Chloroacetic acid:		
	(M. P.)$_{I}$ = 61.3°; (M. P.)$_{II}$ = 56.2°; (M. P.)$_{III}$ = 50.2°		
	III → II, U. G. = ...	120	(37)
	II → I , U. G. = ...	95	(37)
	III → I, U. G. = ...	410	(37)
$C_3H_4Br_2O_2$	α, β-Dibromopropionic acid:		
	s, M. P. = 64°, K. G. = ...	5.8	(37)
	m, K. G. = ...	7.2	(37)
	m → *s*, U. G. = ...	1.4	(37)
$C_3H_8N_2O$	Ethylurea, M. P. = 95°...........	145	(37)
$C_4H_{10}O_4$	Erythritol (*s*).....................	45	(4, 37)
$C_6H_3ClN_2O_4$	3, 4-Dinitrochlorobenzene, M. P. 50°	6.5	(37)
$C_6H_3N_3O_7$	Picric acid........................	1430	(4)
$C_6H_4FNO_2$	*m*-Fluoronitrobenzene............	25	(22)
$C_6H_4ClNO_2$	*m*-Chloronitrobenzene.............	1500	(22, 48)
$C_6H_4BrNO_2$	*m*-Bromonitrobenzene............	1150	(3, 22)
$C_6H_4INO_2$	*m*-Iodonitrobenzene.............	200	(22)
$C_6H_6O_2$	Resorcinol I, M. P. = 110°, K. G. =	700	(27)
	Resorcinol II, M. P. = 108, K. G. =	450	(27)
	I → II, U. G. = ...	0.70±0.07	(27)
$C_6H_{11}NO_2$	Ethyl β-aminocrotonate (*s*).........	58	(37)
C_7H_7NO	Formanilide......................	1.75	(13)
$C_7H_8O_2$	Guaiacol.........................	9.3	(15)
$C_8H_6O_2$	Phthalide........................	25	(37)
$C_9H_{10}O_2$	Hydrocinnamic acid...............	470	(15)
$C_{10}H_9N$	α-Naphthylamine..................	110	(14)
$C_{10}H_{11}NO_4$	1-Hydroxy-2(*p*-nitrophenyl)-ethyl methyl ketone..................	2.5	(5)
$C_{12}H_{10}N_2$	Azobenzene, I, M. P. = 115°; II, M. P. = 128°		
	I → II, U. G. = ...	530	(37)
$C_{12}H_{11}N$	Diphenylamine....................	190	(14, 15)
$C_{12}H_{14}O_4$	Apiol I, M. P. = 30°..........	12	(46)
	II, M. P. = 27.5°..........	24	(46)
$C_{13}H_{10}O$	Benzophenone.....................	97±2.5	(14)
$C_{13}H_{10}O_3$*	Salol I, M. P. = 42°............	6.5±0.2	(10, 15)
	II, M. P. = 38.8°.........	1.8	(15)
	III, M. P. = 28.3°..........	0.45	(15)
$C_{13}H_{11}N$	Benzalaniline....................	26	(22)
$C_{13}H_{13}N$	Benzylaniline....................	2.1	(22)
$C_{14}H_{10}O_2$	Benzil...........................	715	(4)
$C_{14}H_{10}O_3$	Benzoic anhydride................	53	(15)
$C_{17}H_{12}O_3$	Betol (β-Napthyl salicylate)		
	I, M. P. = 95°................	1.7	(46)
	III, M. P. = 93°................	0.8	(46)
$C_{18}H_{18}N_2O_4$	Saliperin (Antipyrine salicylate)		
	I, M. P. = 91.8°..............	3.0	(5)
	II, M. P. = 86.3°..............	5.0	(5)
$C_{17}H_{19}NO_3$*	Piperine..........................		
$C_{19}H_{16}$	Triphenylmethane.................	33±3	(37)
$C_{19}H_{17}N_3$	Triphenylguanidine,		
	I, M. P. = 139°.................	21	(27)
	II, M. P. = 144.2°..............	6.4	(27)
	I → II, U. G. = ...	1.5	(27)
$C_{57}H_{110}O_6$	Tristearin, M. P. = 71°...........	2.8	(27)

* For effect of electric and magnetic fields on undercooled compound, *v.* (54).

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INTERDIFFUSION OF GASES AND VAPORS

W. P. BOYNTON AND W. H. BRATTAIN

By the coefficient of diffusion of one gas or vapor into another is meant the quantity D occurring in the equation $\frac{\delta p_1}{\delta t} = \frac{\delta}{\delta x}\left(D\frac{\delta p_1}{\delta x}\right)$; t = time, p_1 = partial pressure of the diffusing gas, and x = a length in the direction of the diffusion (14, 15, 22, 24). As D varies only slightly with p_1, a good first approximation is $\frac{\delta p_1}{\delta t} = D\frac{\delta^2 p_1}{\delta x^2}$. For a given pair of gases (A, B), the value of D for diffusion of A into B is the same as that for B into A; also $D = D_0\left(\frac{T}{T_0}\right)^m \frac{p_0}{p}$, where D_0 = the value of D at T_0 (=273°K) and p_0 (= 1 atm.), D is its value at absolute temperature T and pressure p, and m is a constant which theoretically lies between 1.5 and 2.0, and practically may be taken either as 1.75 or as 2.00, depending upon the gases (9, 10, 14, 15). For methods of measurement, *see* (13, 17, 22). A temperature gradient in a mixture of two gases produces a diffusion of the more massive molecules towards the region of lower temperature (1, 2, 3, 4, 5). For separation of gases by diffusion through porous septa, *see* (7, 20); for diffusion through metals, *see* p. 77; through glass, rubber, and other solids, *see* p. 76. For diffusion of radioactive gases, *see* Vol. I, p. 364; of ions in gases, consult the index at the end of the last volume.

𝔄-𝔅-TABLE

DIFFUSION OF GASES INTO GASES

$D = D_0\left(\frac{T}{T_0}\right)^m \frac{p_0}{p}$, m = 2.00 for all cases except those marked * for which m = 1.75

Gases	D_0, cm/sec	Lit.	Gases	D_0, cm/sec	Lit.
He-Ar	0.641*	(12, 19)	H_2-CO_2	0550*	(6, 13, 17, 19)
H_2-O_2	.697*	(6, 11, 13, 17)	H_2-CH_4	.625*	(17)
O_2-N_2	.181*	(11, 17)	H_2-C_2H_4	.486*	(17)
O_2-CO	.185*	(13, 17)	H_2-C_2H_6	.459*	(17)
O_2-CO_2	.139	(13, 17)	H_2-air	.611*	(17, 21)
O_2-air	.178*	(17)	N_2O-CO_2	.096	(13, 17)
H_2-SO_2	.480*	(13)	CO-CO_2	.137*	(13, 17)
H_2-N_2	.674*	(11)	CO-C_2H_4	.116*	(17)
H_2-N_2O	.535*	(17)	CO_2-CH_4	.153*	(13, 17)
H_2-CO	.651*	(13, 17)	CO_2-air	.138	(13, 17, 23)

DIFFUSION OF VAPORS INTO GASES

Vapor	Values of D_0 (cm²/sec), and of m			
	Air	CO_2	H_2	Lit.
Hg, mercury	0.1124†			(16)
I_2, iodine	0.0654† 0.097			(16) (13.1)
H_2O, water	0.220*	0.1387	0.7516*	(9, 10, 11.1, 25)

ℭ-TABLE.—The ℭ-Arrangement (*v.* Vol. III, p. viii)

Vapor	Values of D_0 (cm²/sec), and of m			
	Air	CO_2	H_2	Lit.
CS_2, carbon disulfide	0.0892	0.063	0.3689	(22, 25)
CH_2O_2, formic acid	0.1308	0.0874	0.5104	(25)
CH_4O, methyl alcohol	0.1325	0.0879	0.5059*	(25)
$C_2H_4O_2$, acetic acid	0.1064	0.0716	0.4163	(18, 25)
$C_2H_4O_2$, methyl formate	0.0872*			(8)
C_2H_6O, ethyl alcohol	0.102	0.0685	0.3753	(11.1, 25)
$C_3H_6O_2$, propionic acid	0.0829	0.0588	0.3297	(18, 25)
$C_3H_6O_2$, ethyl formate	0.0840*	0.0573*	0.3368*	(18, 25)
$C_3H_6O_2$, methyl acetate	0.084	0.0567	0.3330	(8, 18, 25)
C_3H_7Br, isopropyl bromide	0.0902			(18)
C_3H_7Br, *n*-propyl bromide	0.085			(18)
C_3H_7I, isopropyl iodide	0.0802			(18)
C_3H_7I, *n*-propyl iodide	0.079			(18)
C_3H_8O, isopropyl alcohol	0.0818			(18)
C_3H_8O, *n*-propyl alcohol	0.085	0.0577	0.3153	(18, 25)
$C_4H_8O_2$, butyric acid	0.067	0.0476	0.264	(18, 25)
$C_4H_8O_2$, isobutyric acid	0.0679	0.0471	0.2713	(18, 25)
$C_4H_8O_2$, methyl propionate	0.0735	0.0528	0.2949	(8, 18, 25)
$C_4H_8O_2$, propyl formate	0.0712	0.0490	0.2810	(18, 25)
$C_4H_8O_2$, ethyl acetate	0.0715	0.0487	0.273	(18, 25)
$C_4H_{10}O$, *n*-butyl alcohol	0.0703	0.0476	0.2716	(18, 25)
$C_4H_{10}O$, isobutyl alcohol	0.0727	0.0483	0.2771	(18, 25)
$C_4H_{10}O$, trimethyl carbinol	0.087			(18)
$C_4H_{10}O$, ether	0.0778	0.05525	0.2964	(8, 18, 22, 25)
$C_4H_{11}N$, butylamine	0.0821			(18)
$C_4H_{11}N$, diethylamine	0.0884			(18)
$C_4H_{11}N$, isobutylamine	0.0853			(18)
$C_5H_{10}O_2$, isovaleric acid	0.0544	0.0376	0.2123	(18, 25)
$C_5H_{10}O_2$, *n*-valeric acid	0.050			(18)
$C_5H_{10}O_2$, ethyl propionate	0.0653	0.0450	0.2365	(18, 25)
$C_5H_{10}O_2$, isobutyl formate	0.0705			(18)
$C_5H_{10}O_2$, methyl butyrate	0.0633	0.0446	0.242	(18, 25)
$C_5H_{10}O_2$, methyl isobutyrate	0.0639	0.0451	0.2569	(18, 25)
$C_5H_{10}O_2$, propyl acetate	0.067			(11.1, 18)
$C_5H_{12}O$, *n*-amyl alcohol	0.0589	0.0422	0.2349	(25)
$C_5H_{12}O$, amyl alcohol, fermentation	0.0585	0.0419	0.234	(25)
C_6H_6, benzene‡	0.077	0.0528	0.2948*	(11.1, 25)
C_6H_7N, aniline	0.6095			(13.1)
$C_6H_{12}O_2$, caproic acid	0.050*			(18)
$C_6H_{12}O_2$, isocaproic acid	0.0513*			(18)
$C_6H_{12}O_2$, amyl formate	0.0543*			(18)
$C_6H_{12}O_2$, *n*-butyl acetate	0.058§			(18)
$C_6H_{12}O_2$, ethyl *n*-butyrate	0.0579	0.0407	0.2236	(18, 25)
$C_6H_{12}O_2$, ethyl isobutyrate	0.0591	0.0413	0.2289	(18, 25)
$C_6H_{12}O_2$, isoamyl formate	0.058§			(18)
$C_6H_{12}O_2$, isobutyl acetate	0.0612*	0.0425*	0.2364*	(18, 25)
$C_6H_{12}O_2$, methyl valerate	0.0569*			(18)
$C_6H_{12}O_2$, propyl propionate	0.057	0.0395	0.2115	(18, 25)
$C_6H_{14}O$, hexyl alcohol	0.0499	0.0351	0.1997	(25)
C_7H_7Cl, benzyl chloride	0.066			(11.1, 18)
C_7H_7Cl, *m*-chlorotoluene	0.054*			(18)
C_7H_7Cl, *o*-chlorotoluene	0.059			(18)
C_7H_7Cl, *p*-chlorotoluene	0.051			(18)
C_7H_8, toluene	0.0709			(13.1)
$C_7H_{14}O_2$, ethyl valerate	0.0512	0.0367	0.2052	(18, 25)
$C_7H_{14}O_2$, isobutyl propionate	0.0529*	0.0366*	0.2029*	(18, 25)
$C_7H_{14}O_2$, isopropyl isobutyrate	0.059§			(18)
$C_7H_{14}O_2$, propyl butyrate	0.0530	0.0364	0.2059	(18, 25)
$C_7H_{14}O_2$, propyl isobutyrate	0.0549	0.0388	0.212	(18, 25)
C_8H_{10}, ethylbenzene	0.0658*			(18)
C_8H_{10}, *m*-xylene	0.059*			(18)
C_8H_{10}, *o*-xylene	0.062*			(18)
C_8H_{10}, *p*-xylene	0.056			(18)

ℭ-TABLE.—(*Continued*)

Vapor	Values of D_0 (cm²/sec), and of m			
	Air	CO_2	H_2	Lit.
$C_8H_{16}O_2$, amyl propionate	0.046	0.0347*	0.1914*	(18, 25)
$C_8H_{16}O_2$, isobutyl butyrate	0.0468	0.0327	0.1850	(18, 25)
$C_8H_{16}O_2$, isobutyl isobutyrate	0.0457	0.0364*	0.191	(18, 25)
$C_8H_{16}O_2$, propyl valerate	0.0466	0.0341	0.1893	(18, 25)
C_8H_{18}, *n*-octane	0.0505			(13.1)
C_9H_{12}, isopropylbenzene	0.0489			(18)
C_9H_{12}, mesitylene	0.056			(18)
C_9H_{12}, *n*-propylbenzene	0.0481			(18)
$C_9H_{18}O_2$, amyl butyrate	0.040			(18)
$C_9H_{18}O_2$, amyl isobutyrate	0.0419	0.9307	0.171	(18, 25)
$C_9H_{18}O_2$, isobutyl valerate	0.0424	0.0308	0.1730	(18, 25)
$C_{10}H_8$, naphthalene	0.0513			(13.1)
$C_{10}H_{10}O_2$, isosafrol	0.0455*			(18)
$C_{10}H_{10}O_2$, safrol	0.0434*			(18)
$C_{10}H_{12}O_2$, eugenol	0.0377			(18)
$C_{12}H_{10}$, diphenyl	0.0610			(13.1)
$C_{12}H_{12}N_2$, benzidine	0.0298			(13.1)
$C_{14}H_{10}$, anthracene	0.0421			(13.1)

* $m = 1.75$. † Into N_2. ‡ Into O_2, $D_0 = 0.0633$, $m = 1.75$ (19).

§ Value of m is not known.

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COEFFICIENTS OF DIFFUSION IN LIQUIDS

H. R. Bruins

CONTENTS

Abbreviations and Conventions

Δ.—Defined by the equation $\frac{\partial c}{\partial t} = \Delta \frac{\partial^2 c}{\partial x^2}$ where c is the concentration of the diffusing substance at the time t and x is the distance in the direction of the diffusion. The diffusion coefficient, Δ, ("*true*" diffusion coefficient), is thus a function of c. In the following tables these "*true*" diffusion coefficients are in all cases marked with an *asterisk* and they correspond to the concentration given in the c-column of the table, this concentration being also marked with an asterisk.

All unmarked values in the Δ*-column of the tables represent some kind of "mean" value of* Δ over a range of concentration: they correspond to a diffusion *from* an initial concentration, c_0, (appearing in the c-column) *into* the pure solvent (unless otherwise indicated). These "*mean*" values depend also on the method employed and in some cases on the type of apparatus used; values obtained by different methods are therefore *not comparable*.

As far as possible the experimental methods employed in determining these "*mean*" values are indicated by Roman numerals as follows:

I. Method of steady state.
II. Second method of Graham (27, 93).
III. Method of Stefan-Schuhmeister (118).
IV. First method of Graham (114, 143).
V. Indicator method (2, 127).

$c = 0^*$ indicates diffusion in very dilute solution. Δ is then practically identical with Δ_∞ (diffusion coefficient for infinite dilution). Temperature coefficient $\alpha = \frac{\Delta_{t_1} - \Delta_{t_2}}{\Delta_{t_1}(t_1 - t_2)}$, where $t_1 > t_2$.

Units

Values of Δ are in cm²/sec. Values of c are in gram-moles per liter except in the case of electrolytes where they are in g-equiv. per liter.

Accuracy

The values following the ± sign indicate (*a*) in the case of the "true" Δ, the estimated *possible* error in the *absolute* value; resp. (*b*) in the case of the "mean" Δ, the *possible* deviation from the correct value for the experimental method employed. The actual errors will *probably* not exceed these values. The reliability of the Δ values is indicated in many cases as follows:

Symbol	A	B	C	D	E	F
Error probably < ±	2%	3%	5%	7%	10%	(?)

DIFFUSION IN WATER† (OR IN A GIVEN AQUEOUS SOLUTION)

1. Elementary Substances—𝔄-Table

Cl_2‡

t, °C	c_0 (resp. c^*)	$10^5\Delta$	Method	Lit.
12	0.1	1.4	II	(42)
16	0.12§	1.2_6‖		(74)
		Br_2		
12	0.1	0.9	II	(42)
		H_2; *cf.* (6, 43, 66)		
10	0*	$4._3$*F		(75)
16	0*	$4._7$*F		(74)
21	0*	$5._2$*F		(74)

I_2;¶ *cf.* (17, 42)

t, °C	c_0	$10^5\Delta$	C, KI	Method	Lit.
20	0.046	1.1_5A	1*N*	II	(90)
		1.2_5A	2*N*		
		1.3_1A	3*N*		
		1.3_5A	4*N*		

† For most of the radioactive substances, *v.* Vol. I, p. 364.

‡ Hydrolyzed! § Saturated at 1 atm. ‖ Probably too low.

¶ In KI. For Δ in solutions of NH_4Br, NH_4I, NaBr, NaI and KBr. *v.* (90).

of penetration," which is not identical with it, and similar empirical coefficients are found by Weiss (16) and by Bruni and Meneghini (3) for the systems Cu-Ni, Cu-Au, and Ag-Au.

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HEAT CAPACITY

MECHANICAL EQUIVALENT OF HEAT

T. H. Laby and E. O. Hercus

Data based upon electrical measurements have been recalculated to the basis of International ohm = 1.000 52 × 10^9 cgsm, International ampere (defined by silver voltameter) = 0.999 97 × 10^{-1} cgsm, International volt (defined by ampere and ohm) = 1.000 49 × 10^8 cgsm, Weston normal cell at 20°C = 1.0188 × 10^8 cgsm. Reduction to the 20°C, or the mean, calorie is by Callendar's formula (3).

$$c = 0.98536 + \frac{0.504}{t + 20} + 0.0084\,\frac{t}{100} + 0.009\left(\frac{t}{100}\right)^2$$

c = specific heat in gram-calories, t = °C.

Value of 1 G Calorie

Unit = 10^7 erg, w = weight assigned

Observer	w	20°C calorie	Mean calorie	Lit.
Rowland; Day*	6	4.182†		(4, 9)
Reynolds and Moorby*	2		4.1836‡	(7)
Rispail*	1	4.180¶		(8)
Griffiths‖	2	4.1904**		(5)
Schuster and Gannon‖	1	4.1898††		(10)
Callendar and Barnes‖	3	4.1795‡‡		(1)
Jaeger and Steinwehr‖	3	4.1821		(6)
Bousfield and Bousfield‖	1	4.1767		(2)
Henning-Sutton §§	1		4.1865‖‖	(11, 12)
Henning-Joly §§	1		4.1877	(11, 12)
Weighted mean		4.1818	4.1853	
Osborne, Stimson and Fiock‖			4.188¶¶	(13)
Laby and Hercus*		4.1809		(14)

* Direct method.
† As given by Day.
‡ Corrected from 1 to 100° to 0 to 100°.
‖ Electrical method.
¶ Reduced from 15 to 20° by Callendar's formula.
** Corrected to 20°, for displaced air (10), and to Clark cell 15°C = 1.4336 × 10^8 cgsm.
†† Assumed presence of filter paper increased deposit by 2 in 10 000.
‡‡ Calculated on basis of King's determination of their cells = 1.4334 International volt = 1.43410 × 10^8 cgsm, and Barnes value: 1.4335.
§§ Latent heat of steam.
‖‖ Used weights assigned by Henning.
¶¶ ±0.02 % according to the authors.

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(10) Schuster and Gannon, *62*, **186**: 415; 95. (11) Sutton, *3*, **35**: 27; 18. (12) Henning, *8*, **58**: 759; 19. (13) Osborne, Stimson and Fiock, *56*, **50**: 152; 28. (14) Laby and Hercus, *62*, **227**: 63; 27.

THE HEAT CAPACITY OF GASES AND VAPORS

A. Leduc

Contents

Conversion Factors

To convert joule g^{-1} deg^{-1} C into g-cal_{15} g^{-1} deg^{-1} C or into BTU_{60} $lb.^{-1}$ deg^{-1} F, multiply by 0.2389_5.

For conversion into other units, *v.* Vol. I, p. 24.

Abbreviations, Symbols and Units

c_p (resp. c_v) Heat capacity per gram at constant pressure (resp. at constant volume).

C_p (resp. C_v) Heat capacity per gram-mole at constant pressure (resp. at constant volume).

c_m (resp. C_m) Mean capacity.

δ $c_p - c_v$.

γ $c_p/c_v = C_p/C_v$.

Units: Throughout this section, unless otherwise indicated, the unit of heat energy is the joule, the unit of mass, the gram (or gram-mole) and the unit of temperature, the degree centigrade.

Matières

Facteurs de conversion

Pour convertir les C exprimées en joules g^{-1} deg^{-1} C en cal_{15}-g g^{-1} deg^{-1} C, ou en BTU_{60} $lb.^{-1}$ deg^{-1} F multiplier par $0{,}2389_5$.

Pour convertir en d'autres unités, *v.* Vol. I, p. 24.

Abréviations, symboles et unités

c_p (resp. c_v) Capacité calorifique par gramme sous pression constante et à volume constant respectivement.

C_p (resp. C_v) Capacité calorifique par molécule-gramme sous pression constante et à volume constant respectivement.

c_m (resp. C_m) Capacité moyenne.

δ $c_p - c_v$.

γ $c_p/c_v = C_p/C_v$.

Unités: Dans cette section, à moins d'indication contraire, l'unité d'énergie calorifique est le joule, l'unité de masse le gramme (ou la molécule-gramme), et la température est exprimée en degrés centigrades.

Inhaltsverzeichnis

Umrechnungsfaktoren

Um Joule g^{-1} $Grad^{-1}$ C in Gramm-cal_{15} g^{-1} $Grad^{-1}$ C umzurechnen multipliziere man mit $0{,}2389_5$.

Für Umrechnungen zu anderen Einheiten, *siehe* Bd. I, S. 24.

Abkürzungen, Zeichen und Einheiten

c_p (bezw. c_v) Wärmeinhalt pro Gramm bei konstantem Druck (bezw. bei konstantem Volumen).

C_p (bezw. C_v) Wärmeinhalt pro Gramm-Mol bei konstantem Druck (bezw. bei konstantem Volumen).

c_m (bezw. C_m) Mittlere Wärmeinhalt.

δ $c_p - c_v$.

γ $c_p/c_v = C_p/C_v$.

Einheiten: Wenn nichts besonderes angegeben, so ist durchgehend in diesem Abschnitt die Einheit der Wärmeenergie in Joule, die Einheit der Masse in Gramm (oder Gramm-Mol) und die Temperatureinheit in Centigraden, angegeben.

Indice

Fattori di conversione

Per convertire i joule g^{-1} $gradi^{-1}$ C in g-cal_{15} g^{-1} $gradi^{-1}$ C oppure in BTU_{60} $lb.^{-1}$ $gradi^{-1}$ F bisogna moltiplicare per $0{,}2389_5$.

Per le conversioni in altre unità, *vedi* Vol. I, p. 24.

Abbreviazioni, simboli e unità

c_p (oppure c_v) Capacità calorifica per grammi sotto pressione costante (oppure a volume costante).

C_p (oppure C_v) Capacità calorifica per grammimolecola sotto pressione costante (oppure a volume costante).

c_m (oppure C_m) Calore specifico medio.

δ $c_p - c_v$.

γ $c_p/c_v = C_p/C_v$.

Unità: In questo capitolo, a meno che non sia altrimenti indicato, l'unità di energia calorifica è il joule, l'unità di massa, il grammo (o la grammimolecola) e l'unità di temperatura, il grado centigrado.

INTRODUCTION

Each of the four quantities, c_p, c_v, δ and γ, is capable of independent experimental determination and it is sufficient to know any two in order to calculate the other two, but knowledge of a third serves as a valuable check.

The most accurate determinations of γ are based upon the measurement of the velocity of sound, V, and the relations:

$$V = \sqrt{\frac{E}{d}} = \frac{1}{d}\sqrt{-\gamma\frac{\partial p}{\partial v}} \qquad \text{(Laplace)}$$

and

$$V_{\text{obs.}} = V\left(1 - \frac{\mathrm{k}}{2r\sqrt{\pi N}}\right) \qquad \text{(Kirchhoff)}$$

where d is the density of the gas; v, the specific volume; $V_{\text{obs.}}$, the velocity as measured in a tube of radius $r \geq 2.5$ cm; N, the frequency; and k, a correction factor (= *ca.* 0.65) which depends in an unknown manner upon the properties of the gas (*e.g.*, upon the viscosity) and upon the nature of the tube.

The quantity δ is computed from the thermodynamic relation

$$\delta = T\left(\frac{\partial p}{\partial T}\right)_v\left(\frac{\partial v}{\partial T}\right)_p$$

In preparing the tables in this section the values of $\partial p/\partial T$, $\partial v/\partial T$ and $\partial p/\partial v$ required in the above equations were obtained by one (or more) of the following methods, preference being given in the order shown: (1) Accurate values based upon direct measurement; (2) values deduced from an equation of state known to correctly reproduce the observed p, v, T for the gas; (3) values deduced from a general equation of state obtained by the author. Method (3) was used in the majority of cases. For details, *v.* (29, 35).

Owing to the fact that the available data give, in many instances, opportunities for frequent cross-checks, it is not always possible to indicate, except partially, the source of all of the experimental data upon which the values given below are based. For a critique of the experimental data in this field and a discussion of the various corrections required, *v.* (35.5).

In all of the tables given below the quantity recorded is the total heat capacity, that is, it includes, for example, any "heat of dissociation" which may accompany the rise in temperature. Consequently a value given cannot be taken as the "true" specific heat of a molecular species unless it is known that a dissociation equilibrium is not involved.

THE COMMON GASES AT 15°C

$p = 1$ atm.

Gas	$C_p - C_v$	γ	C_p	Gas	$C_p - C_v$	γ	C_p
A	8.345	1.668	20.93	NO	8.353	1.400	29.25
Cl_2	8.934	1.355	34.11	NH_3	8.822	1.310	37.29
H_2	8.316	1.410	28.58	CO	8.349	1.404	29.04
N_2	8.349	1.404	29.04	CO_2	8.542	1.304	36.62
O_2	8.349	1.401	29.17	CN	9.081	1.256	44.57
HCl	8.609	1.41	29.59	CH_4	8.387	1.31	35.45
SO_2	9.136	1.29	40.64	C_2H_2	8.609	1.26	41.72
H_2S	8.755	1.32	36.12	C_2H_4	8.609	1.255	42.14
N_2O	8.579	1.303	36.91	C_2H_6	8.734	1.22	48.55

THE COMMON GASES AT LOW TEMPERATURES

See also p. 84

$p = 1$ atm. (53)

Gas	t, °C	γ	C_p	C_v	Sign of $\partial C_p/\partial t$
A	−180	1.76?	22.2	12.6	−
H_2	−76	1.453	26.6	18.3	+
	−181	1.597	22.3	14.0	+
He	−180	1.660	20.9	12.6	+
N_2	−181	1.47	30.0	20.4	−
O_2	−76	1.415	28.7	20.3	−
	−181	1.45	30.6	21.1	−
H_2S*	−45	1.30	39.8	30.7	−
	−57	1.29	41.7	32.4	−
N_2O	−30	1.31	36.8	28.1	+
	−70	1.34	35.0	26.1	+
NO*	−45	1.39	30.0	21.6	−
	−80	1.38	30.7	22.2	−
CO	−180	1.41	30.3	20.6	−
CO_2	−75	1.37	33.8	24.7	+
CH_4	−80	1.34	33.8	25.2	+
CH_4 (37.9)	−74	1.35	33.4	24.8	+
	−115	1.41	30.2	21.4	+
C_2H_2	−71	1.31	38.2	29.1	+
C_2H_4	−91	1.35	36.2	26.8	+
C_2H_6	−82	1.28	43.7	34.1	+

* Values doubtful.

VALUES OF $\gamma = c_p/c_v$

A-Table, Elementary Substances and Atmospheric Air

Formula	$p_{atm.}$	t, °C	γ	Lit.
A	1	0–100	1.67	(43)
Br	0.3–1.5	20–350	1.32	(59)
Cl	1	16	1.355	(23, 45)
	0.5	16	1.34	(23)
H_2 (*v.* p. 82)	1	17	1.407	(2.5)
	1	− 21	1.420	
	1	− 78	1.443	
	1	−118	1.480	
	1	−185	1.605	
Hg	0.5–1	360	1.67	(27)
I	1	185	1.30	(58)
K	1	850	1.77	(65)
	1	680–1000	1.69	(51)
Kr	1	19	1.68	(49)
Na	1	750–920	1.68	(51)
Ne	1	19	1.64	(49)
P	1	300	1.17	(56)
Xe	1	19	1.66	(49)
Air (*v.* p. 81)	100	− 79	2.20	(26)
	200	− 79	3.33	(26)
	3	20	1.41	(54)
	1	925	1.36	(22, 58)
	1	17	1.403	(2.5)
	1	− 78	1.408	
	1	−118	1.415	

B-Table, Chemical Compounds

Formula	$p_{atm.}$	t, °C	γ	Lit.
HCl	1	100	1.40	(59)
HBr	0.3–1.5	20	1.42	(59)
HI	1	20–100	1.40	(59)
ICl	1	100	1.31	(59)
SO_2	0.5	20	1.27	(54)
	2.5	20	1.35	(4, 60)
H_2S	1	18	1.30	(60)
	0.5	18	1.32	(60)
N_2O	1	0	1.32	(68)
	1	100	1.28	(68)
NH_3	1	15	1.31	(54)
	3.5	15	1.41	(54)
CS_2	satd. vap.	99.7	1.63	(28, 58)
$SiCl_4$	0.15	14	1.13	(4)

C-Table, C-Compounds

Formula	Name	$p_{atm.}$	t, °C	γ	Lit.
CCl_4	Carbon tetrachloride	0.1	20	1.13	(4, 62)
$CHCl_3$	Chloroform	0.15	20	1.15	(4)
		1	100	1.15	(58)
HCN	Hydrogen cyanide	1	65	1.31	(63)
		1	140	1.28	(63)
		1	210	1.24	(63)
CH_2Cl_2	Dichloromethane	0.2	18	1.22	(4)
CH_3Br	Methyl bromide	0.3–0.6	18	1.27	(4)
CH_3Cl	Methyl chloride	0.8	16	1.28	(4)
CH_3I	Methyl iodide	0.3	20	1.286	(4)
CH_4O	Methyl alcohol (C_p = 52.3)	1	77	1.203	(11)
C_2H_3Br	Bromoethylene	0.6	15	1.20	(4)
C_2H_4	Ethylene	1	100	1.18	(68)
$C_2H_4Cl_2$	1, 2-Dichloroethane	0.06	19	1.137	(4)
		0.2	23	1.134	(4)
C_2H_4O	Acetaldehyde	1	30	1.14	(68)
$C_2H_4O_2$	Acetic acid	1	136	1.15	(58)
C_2H_5Br	Ethyl bromide	0.3	14	1.19	(4)
C_2H_5Cl	Ethyl chloride	0.3–0.5	16	1.19	(4)
C_2H_6	Ethane	1	50	1.21	(10)
		1	100	1.19	(10)
C_2H_6O	Ethyl alcohol (C_p = 78.3)	1	90	1.13	(11, 42)
C_2H_6O	Methyl ether	1	6–30	1.11	(39)
C_3H_5Br	Allyl bromide	0.1	15	1.145	(4)
C_3H_5Cl	Allyl chloride	0.2	14	1.137	(4)
$C_3H_6O_2$	Methyl acetate	*ca.* 1	*ca.* 15	1.14	(4)
C_3H_7Br	Isopropyl bromide	0.23	12	1.13	(4)
C_3H_7Cl	*n*- and *iso*-Propyl chloride	0.1	21	1.13	(4)
C_3H_8	Propane	0.5	16	1.13	(4)
$C_3H_8O_2$	Methylal	1	13	1.06	(39)
		1	40	1.09	(39)
C_4H_{10}	Isobutane	*ca.* 1	*ca.* 15	1.11	(6)

ℭ-TABLE.—(*Continued*)

Formula	Name	$p_{atm.}$	t, °C	γ	Lit.
$C_4H_{10}O$	Ethyl ether (C_p = 116.3)	1	35	1.08	(30)
		1	80	1.08_6	(11, 42)
C_6H_{12}	Cyclohexane	1	80	1.08	(7)

			C_p	t	γ	Lit.
C_5H_{12}	n-Pentane	1 atm.	123.5	86	1.08_6	(11, 42)
C_6H_6	Benzene		106.3	90	1.10	(7, 11)
C_6H_{14}	n-Hexane		131.4	80	1.08	(11)

VALUES OF c_p AT t AND OF c_p, MEAN, BETWEEN t_1 AND t_2

ELEMENTS AND INORGANIC COMPOUNDS

Formula	$p_{atm.}$	t, °C	c_p	Lit.
Br	1	83–228	0.23_0	(50)
	1	19–388	0.23_0	(59)
I	1	206–377	0.141	(59)
HCl	1	10–190	0.774	(50)
HBr	1	11–100	0.343	(59)
ICl	1	100–203	0.21_3	(59)
SO_2	1	10–190	0.561	(50)
H_2S	1	10–190	1.01_7	(61)
SO_2Cl_2	1	19–98	0.477	(61.5)
N_2O	1	25–100	0.887	(50)
	1	25–200	0.937	(50, 66)
	11	30–94	1.01_7	(37)
	31	30–94	1.17_2	(37)
NO	1	10–180	0.971	(50)
NO_2; *v. also* (37.5)	1	27–67	6.78	(1.5)
	1	27–100	6.11	(1.5)
	1	27–150	4.666	(1.5)
	1	27–200	3.5_6	(1.5)
	1	27–300	2.6_8	(1.5)
PCl_3	1	110–250	0.565	(50)
$AsCl_3$	1	160–270	0.469	(50)
CCl_4	1	0	0.586	(38)
	1	30	0.552	(38)
	1	70	0.481	(38)
CS_2	1	80–190	0.657	(50)
	0.3	17	0.657	(60)
$SiCl_4$	1	90–230	0.552	(50)
$TiCl_4$	1	160–270	0.540	(50)
$SnCl_4$	1	149–273	0.39_3	(50)

ORGANIC COMPOUNDS

Formula	Name	$p_{atm.}$	t, °C	c_p	Lit.
$CHCl_3$	Chloroform	1	27–118	0.60_7	(66)
		1	120–230	0.65_7	(50)
CH_4	Methane	1	10–200	2.48_2	(9, 50)
		11	30–94	2.62_0	(37)
		31	30–94	2.90_9	(37)
CH_4O	Methyl alcohol	1	100–223	1.91_7	(50)
C_2H_4	Ethylene	1	15–100	1.6_7	(50, 66)
		1	25–200	1.8_0	(66)
		11	30–94	1.7_6	(37)
		31	30–94	1.8_8	(37)
$C_2H_4Cl_2$	1, 1-Dichloroethane	1	110–220	0.96_3	(50)
$C_2H_4Cl_2$	Ethylene chloride	1	111–221	0.9_6	(50)
$C_2H_4O_2$	Acetic acid	1	118–140	6.2_8	(1.5)
		1	140–180	5.3_1	(1.5)
		1	180–220	3.9_8	(1.5)
		1	220–260	2.6_7	(1.5)
C_2H_5Br	Ethyl bromide	1	28–116	0.67_4	(66)
		1	80–200	0.79_5	(50)

ORGANIC COMPOUNDS.—(*Continued*)

Formula	Name	$p_{atm.}$	t, °C	c_p	Lit.
C_2H_5Cl	Ethyl chloride	1	10–170	1.15_1	(50)
		1	15–100	1.02_1	(20)
C_2H_6O	Ethyl alcohol	1	100–223	1.90	(50)
C_3H_5N	Ethyl cyanide	1	114–223	1.78_3	(50)
C_3H_6O	Acetone	1	26–110	1.45_2	(50)
		1	130–230	1.72_4	(50)
$C_4H_8O_2$	Ethyl acetate	1	110–220	1.67_8	(50)
		1	35–189	1.55_3	(66)
		1	35–113	1.41_0	(66)
$C_4H_{10}O$	Ethyl ether	1	35	1.86_2	(30)
		1	27–189	1.93_3	(66)
		1	69–224	2.01	(50, 55)
		1	200–300	2.23_1	(55)
		0.28	16	1.92	(60)
		0.28	350	2.51	(60)
$C_4H_{10}S$	Diethyl sulfide	1	120–223	1.6_7	(50)
C_5H_{10}	Amylene		*ca.* 210	2.64	(14)
C_5H_{12}	Isopentane	1	58	1.88	(64)
		1	100	1.97	(8)
C_6H_6	Benzene	1	80	1.09	(30)
		1	34–115	1.2_6	(66)
		1	35–180	1.39	(66)
		1	100	1.39	(7)
		1	120–220	1.5_5	(50)
C_6H_{12}	Cyclohexane	1	100	1.73	(7)
$C_{10}H_{16}$	Terebenthene	1	180–250	2.12	(50)

SPECIAL TABLES

Atmospheric Air

EFFECT OF TEMPERATURE

p = 1 atm. (2, 9, 16, 46, 48)

t, °C	$c_p - c_v$	γ	c_p	c_m, 0 to t°
0	0.2883	1.403	1.004	1.004
100	0.2882	1.401	1.006	1.005
200	0.287_5	1.398	1.010	1.00_9
400	0.287_1	1.393	1.01_7	1.01_3
600	0.287_1	1.385	1.03_4	1.01_7
800	0.287_1	1.376	1.05_5	1.02_5
1000	0.287_1	1.365	1.07_6	1.03_4
1200	0.287_1	1.353	1.10_1	1.04_2
1400	0.287_1	1.341	1.13_0	1.05_0
1600	0.287_1	1.329	1.16_0	1.06_3
1800	0.287_1	1.316	1.19_3	1.07_6
2000	0.287_1	1.303	1.23_4	1.08_8

EFFECT OF PRESSURE

Values of c_p above 0° (52)

$p_{atm.}$	0°	50°	100°	150°	200°	280°
20	1.04_2	1.03_8	1.03_4	1.03_4	1.03_0	1.03_4
60	1.11_3	1.08_8	1.07_1	1.05_9	1.05_0	1.04_2
100	1.17_2	1.13_8	1.08_8	1.08_8	1.07_6	1.05_5
140		1.18_0	1.13_8	1.11_3	1.09_2	1.06_3
180		1.21_4	1.16_8	1.13_4	1.10_9	1.07_6
220		1.23_9	1.18_9	1.15_1	1.12_2	1.08_4

Values of c_p below 0° (67)

$p_{atm.}$	−50°	−100°	−120°	−140°
10	1.02_1	1.08_0	1.13_8	1.70_7
20	1.05_5	1.18_4	1.34_8	2.67_8
40	1.14_7	1.40_0	2.00_5	10.9_1
70	1.30_6	1.92_5	3.25_2	

	−78°	−185°	Lit.
1	1.01_7	1.05_5	(53)

Atmospheric Air.—(*Continued*)

VALUES OF γ

$p_{atm.}$	0°		−79.4°	
	(26)	(67)	(26)	(67)
25	1.47	1.47	1.57	1.58
50	1.53	1.53	1.77	1.79
75	1.59	1.58	2.00	2.06
100	1.65	1.64	2.20	2.30
125	1.69		2.40	
150	1.74		2.47 max.	
175	1.78		2.41	
200	1.83		2.33	

VALUES c_v, MEAN, 15–100° (21)

d, g/cm³	0.01	0.03	p = 1 atm.
c_v	0.719	0.721	0.717

H_2, Hydrogen; *cf.* (69)

t, °C (5, 48, 57)	C_p	γ	C_m, 0 − t°	t, °K (12)	C_v
0	28.58	1.410	28.58	35	12.47
100	28.92	1.404	28.75	50	12.60
200	29.21	1.398	28.92	65	12.72
400	29.80	1.387	29.21	80	13.14
600	30.38	1.377	29.50	90	13.64
800	30.97	1.367	29.80	100	14.31
1000	31.55	1.358	30.09	110	15.15
1200	32.14	1.349	30.38	196.5	18.37
1400	32.73	1.341	30.68	273.1	20.26
1600	33.31	1.333	30.97		
1800	33.90	1.325	31.26		
2000	34.48	1.318	31.55		

O_2, N_2 and CO

For best values at 0°, *v.* p. 81; *see also* Fig. 2. The following values are from Partington and Shilling (47):

t°, C	$C_p - C_v$	γ	C_p	C_m, 0 to t°
0	8.362	1.402	29.17	29.17
100	8.332	1.399	29.21	29.19
200	8.324	1.396	29.29	29.23
400	8.324	1.391	29.63	29.34
600	8.320	1.383	30.01	29.50
800	8.320	1.375	30.51	29.67
1000	8.316	1.365	31.14	29.92
1200	8.316	1.353	31.85	30.17
1400	8.316	1.342	32.64	30.47
1600	8.316	1.329	33.56	30.80
1800	8.316	1.316	34.61	31.18
2000	8.316	1.303	35.74	31.55

$$\text{For } N_2 \begin{cases} C_p = 6.815 + 3.17 \times 10^{-4}t + 5.3 \times 10^{-8}t^2 \text{ g-cal}_{15}\text{/mole.} \\ C_v = 4.82 + 3.3 \times 10^{-4}t + 4.7 \times 10^{-8}t^2 \text{ g-cal}_{15}\text{/mole.} \end{cases}$$

$$\text{For } O_2 \begin{cases} C_p = 6.98 + 1.88 \times 10^{-4}t + 6.7 \times 10^{-8}t^2 \text{ g-cal}_{15}\text{/mole.} \\ C_v = 4.98 + 2.1 \times 10^{-4}t + 5.5 \times 10^{-8}t^2 \text{ g-cal}_{15}\text{/mole.} \end{cases}$$

H_2O

VARIATION OF c_p WITH TEMPERATURE AND PRESSURE (17, 25)

t, °C	1 atm.	2 atm.	4 atm.	6 atm.	10 atm.	14 atm.	20 atm.
100	2.017						
120	1.996	2.093					
140	1.984	2.046					
160	1.975	2.021	2.155	2.356			
180	1.971	2.005	2.101	2.226	2.645		
200	1.971	1.996	2.067	2.151	2.381	2.808	
250	1.980	1.996	2.034	2.072	2.155	2.264	2.461
300	1.996	2.009	2.034	2.059	2.109	2.159	2.247

H_2O.—(*Continued*)

VARIATION OF c_p WITH TEMPERATURE AND PRESSURE.—(*Cont'd*)

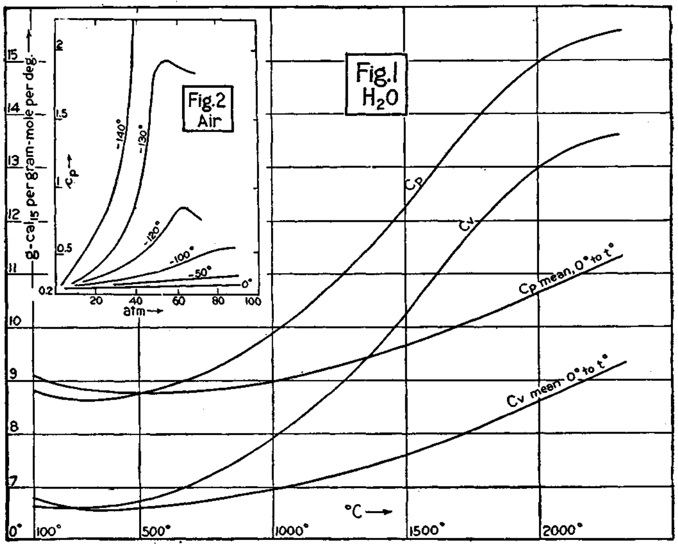
t, °C	1 atm.	2 atm.	4 atm.	6 atm.	10 atm.	14 atm.	20 atm.
350	2.021	2.025	2.051	2.067	2.109	2.147	2.214
400	2.051	2.059	2.076	2.093	2.122	2.155	2.205
450	2.084	2.093	2.113	2.118	2.139	2.164	2.201
500	2.122	2.126	2.134	2.143	2.159	2.176	2.201
550	2.156	2.159	2.164	2.168	2.180	2.189	2.210

VARIATION OF c_p WITH TEMPERATURE FOR $p = 1$ ATM. (15)

t, °C	200	400	600	800	1000	1200	1400
c_p	1.946 extrap.	1.980	2.055	2.172	2.335	2.544	2.796

"BEST" VALUES FOR $p = 1$ ATM. (47)

t, °C	$C_p - C_v$	γ	C_v	t, °C	$C_p - C_v$	γ	C_v
100	8.927	1.324	27.54	1000	8.328	1.252	33.06
200	8.550	1.310	27.58	1200	8.324	1.229	36.41
300	8.424	1.304	27.66	1400	8.320	1.206	40.47
400	8.378	1.301	27.83	1600	8.320	1.182	45.32
500	8.357	1.296	28.21	1800	8.320	1.163	42.56
600	8.345	1.290	28.80	2000	8.320	1.155	54.20
700	8.337	1.282	29.55	2200	8.320	1.148	56.29
800	8.332	1.273	30.55	2300	8.320	1.146	56.79
900	8.328	1.263	31.68				



MEAN C_p BETWEEN 100 AND t° (40)

t, °C	1000	1250	1500	1750	2000	2250	2500	3000
C_p, 100–t°	28.96	30.13	31.39	33.06	35.24	37.62	40.00	45.41

c_p FOR SLIGHTLY UNDER-SATURATED VAPOR* (17)

t, °C	99.1	119.6	142.9	169.6	187.1	200.5	211.4
p, kg/cm²	1	2	4	8	12	16	20
c_p	2.017	2.088	2.231	2.511	2.817	3.135	3.490

* These values are not in agreement with those calculated thermodynamically from the temperature coefficient of the latent heat.

"BEST" VALUES FOR THE SATURATED VAPOR

t, °C	c_p	c_v	γ
100	1.816	1.318	1.373*
120	1.871	1.356	1.378
140	1.971	1.422	1.380

* This is consistent with Neyreneuf's value of the velocity of sound (42).

"BEST" VALUES FOR THE SUPERHEATED VAPOR

p, atm.	t, °C	100	120	140	150	160
1	c_p	1.816	1.833	1.875	1.93	2.005
	γ		1.365	1.346	1.333	1.314

H_2O.—*(Continued)*

"BEST" VALUES FOR THE SUPERHEATED VAPOR.—*(Cont'd)*

p, atm.	*t*, °C	100	120	140	150	160
2	c_p		1.871	1.913	1.959	2.026
	γ		1.37*	1.36	1.344	1.326
3	c_p			1.959		
	γ			1.37	1.356	1.34
4	c_p				2.026	2.076
	γ		* At 130°		1.37	1.35

NH_3

VARIATION OF c_p WITH TEMPERATURE AND PRESSURE (44)

t, °C \ $p_{atm.}$	0	1	2	4	8	12	16	20
Satd.		2.340	2.483	2.701	3.030	3.300	3.561	3.843
−30	2.020	2.306						
−10	2.043	2.195	2.386					
0	2.057	2.173	2.314	2.657				
+20	2.085	2.159	2.244	2.446	2.988			
40	2.116	2.167	2.252	2.350	2.665	3.073		
60	2.149	2.186	2.226	2.313	2.515	2.759	3.058	3.448
80	2.184	2.212	2.242	2.305	2.445	2.605	2.789	3.008
100	2.220	2.214	2.265	2.312	2.415	2.528	2.652	2.792
120	2.256	2.274	2.293	2.330	2.409	2.492	2.582	2.679
150	2.294	2.327	2.340	2.368	2.422	2.481	2.540	2.603

VALUES OF c_p AT HIGH TEMPERATURES

Mean of (13 and 41) ±10%

t	309°	422°	523°
C_p	41.4	43.9	47.08
c_p	2.43	2.59	2.76

Nernst (41) gives $C_p = 8.62 + 0.002t + 7.2 \times 10^{-9}t^2$, g-cal$_{15}$/mole. Range 0 to 680°.

For very high temperatures Budde (3) gives the equation $C_p = 11.8 + 0.024 \times (t - 1400)$, g-cal$_{15}$/mole. This gives 11.8 at 1400° and 21.4 at 2200°.

CO, *v.* p. 86

CO_2

EFFECT OF TEMPERATURE AT p = 1 ATM. (2, 11, 15, 48)

$C_p = 6.63 + 5.54 \times 10^{-3}t - 2.47 \times 10^{-6}t^2 + 4.7 \times 10^{-10}t^3$, g-cal$_{15}$/mole (53)

t, °C	$C_p - C_v$	γ	C_p	C_m, 0–t°
0	8.600	1.310	36.33	36.33
100	8.429	1.281	38.38	37.37
200	8.374	1.263	40.18	38.25
300	8.349	1.247	42.18	39.09
400	8.337	1.235	43.82	39.92
500	8.328	1.225	45.24	40.76
600	8.324	1.217	46.60	41.43
700	8.324	1.210	47.86	42.27
800	8.320	1.204	49.01	42.98
900	8.320	1.200	50.01	43.69
1000	8.320	1.195	50.89	44.24
1100	8.320	1.192	51.68	44.78
1200	8.314	1.189	52.40	45.24
1300	8.314	1.186	53.02	45.73
1400	8.314	1.184	53.61	46.24
1500	8.314	1.181	54.20	46.75
1600	8.314	1.179	54.74	47.21
1700	8.314	1.177	55.28	47.75
1800	8.314	1.175	55.83	48.25
1900	8.314	1.173	56.33	48.76
2000	8.314	1.171	56.92	49.26

Between −75 and +20°, $C_p = 8.71 + 66 \times 10^{-4}t - 22 \times 10^{-7}t^2$ g-cal/mole (15).

CO_2.—*(Continued)*

VARIATION OF c_p WITH PRESSURE, $\frac{\partial c}{\partial p} > 0, \frac{\partial c}{\partial T} < 0$ (37.2)

For data near the critical point, *v.* (1)

$p_{atm.}$	13.2°	38°	67.6°	98.1°	114.9°
24.25		1.205	1.030		
54.1	3.06	1.364	1.151		
61.7	3.72	1.833	1.352	1.327	1.310
68.2	4.70	2.369			
75.8	6.16	3.059	2.026	1.93	1.611
85.4	8.83	4.164		2.498	2.226
86.9			2.691		

$p_{atm.}$ (19)	−10°	0°	+10°	20°	30°
20.5	1.201	1.159	1.117	1.071	1.030
27.3		1.381	1.289	1.193	1.058

VARIATION OF c_v WITH t AND d (21)

	d = 0.124 g/cm³			d = 0.18 g/cm³	
t, °C	10	50	100	50	100
c_v	0.933	0.824	0.795	0.866	0.862

d, g/cm³		0.0387	0.077	0.118	0.144
c_m, 12–100°		0.7173	0.7700	0.8119	0.8457

$c_v = 0.165 + 0.02125d + 0.340d^2$, g-cal$_{15}$/g.

CH_4, Methane (9)

t, °C	$C_p - C_v$	γ	C_p	C_m, 0–t°
0	8.403	1.307	35.78	35.78
100	8.353	1.232	44.36	40.05
200	8.337	1.188	52.61	44.36
300	8.328	1.160	60.47	48.42
400	8.324	1.139	68.01	52.40
500	8.324	1.125	75.12	56.25
600	8.320	1.113	81.90	59.97

CH_3Cl and C_2H_5Cl (20, 56)

VARIATION OF c_p WITH t AND p

t \ $p_{atm.}$	C_2H_5Cl			t \ $p_{atm.}$	CH_3Cl			
	0.137	1.37	2.74		0.68	2.72	5.46	8.2
−30	0.88			−30	0.84			
0	0.92			0	0.88			
+40	1.00	1.02	1.03	+30	0.90	0.93	0.96	1.01
80	1.06	1.09	1.13	70	0.95	0.96	1.00	1.04
110		1.13	1.17	110	0.97	1.00	1.03	1.07

SATURATED VAPORS

Values of c_s, the heat required to heat the vapor through 1°C and maintain it in the saturated condition, joule per g/deg C.

	H_2O			$(C_2H_5)_2O$	
t, °C	58	93	148	0	120
c_s	−5.9	−5.0	−0.33	0.485	0.557
	C_6H_6, Benzene			H_2	
t, °C	0	120	210	−257.24	−252.7
c_s	−7.34	0	0.48	−23.2	−15.8

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THERMODYNAMIC QUANTITIES: VALUES OF THE HEAT CAPACITY, ENTROPY, HEAT CONTENT AND "THERMODYNAMIC POTENTIAL" FOR PURE SUBSTANCES BETWEEN 0 AND 298°K

W. H. Rodebush and Esther Rodebush

Contents

Introduction

Unless otherwise indicated, the values given in this section apply in all cases to the form which is stable under 1 atm. pressure at the temperature in question.

In all cases, the mass unit is the gram-formula-weight, the energy unit is the joule, and the temperature unit is °K. The pressure is 1 atmosphere.

In all cases, the value of each of the quantities tabulated is assumed to be 0 at 0°K.

The number of units uncertain in a given place of significant figures is indicated by the number of bars over the figure in that place, one bar indicating ± 1 to 3 units, two bars, ± >3 units.

C_p Heat capacity per gram-formula-weight.

S Entropy.
H Heat content. Computed from heats of formation in the case of compounds.

Matières

Introduction

À moins d'une autre indication, les valeurs données dans cette section se rapportent dans tous les cas à la forme qui est stable sous une pression d'une atmosphère à la température en question. Dans tous les cas, l'unité de masse est le poids moléculaire, l'unité d'énergie est le joule, et l'unité de température est le degré K. La pression est 1 atmosphère.

Dans tous les cas, la valeur concernant chaque quantité mentionnée est supposée être 0 à 0°K.

Le nombre d'unités incertaines à une place donnée des chiffres significatifs est indiqué par le nombre de barres se trouvant sur le chiffre à cette place, une barre indiquant ± 1 à 3 unités, deux barres, ± > 3 unités.

C_p Capacité calorifique par molécule gramme.

S Entropie.
H Chaleur totale. Calculée à partir des chaleurs de formation dans le cas des composés.

Inhaltsverzeichnis

Einleitung

Wenn nichts anderes angegeben, so beziehen sich die gegebenen Werte dieses Abschnittes in allen Fällen auf die bei 1 Atm. und der fraglichen Temperatur, stabile Form.

In allen Fällen ist die Mengeneinheit das Grammformelgewicht, die Einheit der Energie ist Joule und die für die Temperatur ist °K. Der Druck ist 1 Atmosphäre.

In allen Fällen wird angenommen, dass jede Grösse, welche in der Tabelle angegeben ist, bei 0°K selbst Null ist.

Die Zahl der Einheiten die an einer gegebenen Stelle einer gewerteten Zahl unsicher sind, werden durch die Anzahl von Strichen über der Zahl an dieser Stelle angezeigt. Ein Strich bedeutet ± 1 bis 3 Einheiten, zwei Striche ± mehr wie 3 Einheiten.

C_p Wärmekapazität pro Grammformelgewicht.

S Entropie.
H Wärmeinhalt. Berechnet aus der Bildungswärme im Falle einer Verbindung.

Indice

Introduzione

I valori riportati in questo capitolo si riferiscono (a meno che non sia altrimenti indicato) alla forma stabile a pressione atmosferica e alla temperatura in questione.

In tutti i casi l'unità di massa è la grammimolecola, l'unità di energia il joule e l'unità di temperatura il °K. La pressione è 1 atmosfera.

In tutti i casi il valore delle quantità riportate nella tabella è supposto essere 0 a 0°K.

Le unità di cui è incerto un determinato numero significativo, sono indicate dal numero di linee stampate sopra la cifra stessa. Una linea indica ± da 1 a 3 unità, due linee ± > 3 unità.

C_p Calore specifico per un peso in grammi corrispondente alla formula.

S Entropia.
H Capacità termica. Computata, nel caso di composti, dai calori di formazione.

HEAT CAPACITY OF ELEMENTARY SUBSTANCES BETWEEN 0 AND 300°K

DEWAR'S VALUES OF MEAN ATOMIC HEAT CAPACITY BETWEEN 77.4 AND 20.35°K (3)

Joules per gram-atom per °C

As,	7.57	Cl,	13.40	Mn,	4.94	Rh,	5.4
Au,	12.4	Co,	4.77	Mo,	5.37	Ru,	4.35
B,	0.94	Cr,	2.76	Ni,	4.77	Se,	11.19
Ba,	18.8	Cs,	26.7	Os,	5.82	Sr,	18.84
Be,	0.49	"Di,"	18.14	Pd,	7.95	Te,	14.4
Bi,	17.75	Ir,	7.53	P(r),	5.23	Th,	17.95
Br,	14.15	La,	18.0	P(y),	9.37	Ti,	3.84
Ce,	18.18	Li,	5.27	Pt,	10.3	U,	12.9
				Rb,	23.65	Zr,	9.33

A-TABLE.—ELEMENTARY SUBSTANCES

Molecular heat capacity, joules per gram-formula-weight per °C

Argon

T, °K	C_p
Solid (6)	
15	$\bar{6}.3$
21	$1\bar{4}.7$
30	$1\bar{8}.8$
36	$2\bar{2}.8$
45	$2\bar{4}.7$
60	$2\bar{7}.6$
75	$3\bar{1}.4$
Liquid (6)	
84 to 88	$4\bar{4}.0$
Gas (12)	
90	$22.\bar{2}$
100	$22.\bar{2}$
150	$22.\bar{0}$
200	$21.\bar{7}$
250	$21.\bar{4}$
300	$21.\bar{1}$

Ag (9, 19, 20)

T, °K	C_p
20	$1.\bar{7}$
30	$4.\bar{3}5$
40	$8.\bar{0}5$
50	$11.\bar{1}$
60	$13.\bar{9}$
70	$15.\bar{9}$
80	$17.\bar{6}$
90	$19.\bar{0}$
100	$20.\bar{0}5$
150	$23.\bar{1}5$
200	$24.\bar{2}5$
250	$24.\bar{9}5$
300	$25.\bar{3}5$

Al (9, 20, 21)

T, °K	C_p
20	$0.\bar{3}$
30	$1.\bar{1}$
40	$2.\bar{2}$
50	$3.\bar{9}0$
60	$5.\bar{8}5$
70	$7.\bar{7}5$
80	$9.\bar{4}5$
90	$11.\bar{2}$
100	$12.\bar{9}$
150	$18.\bar{5}$
200	$21.\bar{5}5$
250	$23.\bar{2}$
300	$24.\bar{5}$

C, Graphite (19)

T, °K	C_p
20	$0.\bar{1}$
30	$0.\bar{2}5$
40	$0.\bar{4}$
50	$0.\bar{6}$
60	0.75
70	$1.\bar{0}$
80	$1.\bar{1}5$
90	$1.\bar{4}0$
100	$1.\bar{6}$
150	$3.\bar{2}$
200	$5.\bar{0}$
250	$6.\bar{8}5$
300	$8.\bar{6}$

C, Diamond (20)

T, °K	C_p
90	$0.0\bar{4}$
100	$.\bar{2}5$
125	$.\bar{8}$
150	$1.\bar{4}$
175	$2.\bar{0}$
200	$2.\bar{5}$
250	$4.\bar{2}$
300	$6.\bar{2}5$

Ca (4, 10)

T, °K	C_p
10	$0.\bar{7}5$
20	$2.\bar{1}$
30	$4.\bar{0}$
40	$7.\bar{1}5$
50	$1\bar{0}.25$
60	$1\bar{3}.1$
70	$1\bar{5}.5$
80	$1\bar{7}.8$
90	$1\bar{9}.1$
100	$2\bar{0}.4$
150	$2\bar{4}.0$
200	$2\bar{5}.35$
250	$2\bar{5}.65$
300	$2\bar{5}.9$

Cd (9, 25)

T, °K	C_p
20	$3.\bar{2}$
30	$6.\bar{9}$
40	$11.\bar{2}$
50	$15.\bar{0}$
60	$17.\bar{5}$
70	$19.\bar{3}5$
80	$30.\bar{6}5$
90	$21.\bar{6}$
100	$22.\bar{2}5$
150	$24.\bar{2}$
200	$25.\bar{1}5$
250	$25.\bar{7}5$
300	$26.\bar{2}$

Cl_2, Solid (7)

T, °K	C_p
22	$1\bar{0}.0$
30	$1\bar{7}.6$
35	$2\bar{1}.8$
40	$2\bar{6}.4$
45	$2\bar{9}.7$
52	$3\bar{2}.7$
80	$3\bar{9}.8$
90	$4\bar{1}.5$
100	$4\bar{3}.1$
110	$4\bar{4}.7$
150	$5\bar{3}.6$
155	$5\bar{4}.8$

Cl_2, Liquid (7)

T, °K	C_p
188 to 197	$6\bar{8}.0$

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Cu (9, 14, 20)

T, °K	C_p
20	$0.\bar{4}$
30	$1.\bar{7}$
40	$3.\bar{4}$
50	$5.\bar{8}6$
60	$8.\bar{1}$
70	$10.\bar{4}$
80	$12.\bar{5}$
90	$14.\bar{6}$
100	$16.\bar{3}$
150	$21.\bar{0}$
200	$22.\bar{7}$
250	$23.\bar{7}$
300	$24.\bar{6}$

Fe (9)

T, °K	C_p
30	$0.\bar{6}$
40	$2.\bar{2}$
50	$4.\bar{1}5$
60	$6.\bar{1}$
70	$7.\bar{8}$
80	$9.\bar{5}5$
90	$11.\bar{2}$
100	$12.\bar{9}$
150	$18.\bar{8}$
200	$21.\bar{8}$
250	$2\bar{3}.8$
300	$25.\bar{2}$

He (2.5)

H_2, Solid (16, 31)

T, °K	C_p
12	$4.\bar{\bar{1}}8$

H_2, Liquid (6, 16, 31)

T, °K	C_p
15 to 21	$1.\bar{\bar{3}}8 + 0.\bar{\bar{8}}60T$

H_2, Gas (5)

T, °K	C_p
30	$2\bar{0}.8$
40	$2\bar{0}.8$
50	$2\bar{0}.8$
60	$2\bar{0}.8$
70	$2\bar{1}.1$
80	$2\bar{1}.6$
90	$2\bar{2}.2$
100	$22.\bar{8}$
150	$25.\bar{3}$
200	$26.\bar{8}$
250	$28.\bar{0}$
300	$29.\bar{1}$

Hg, Solid (1, 22, 24, 28, 29)

T, °K	C_p
10	$4.\bar{8}$
20	$10.\bar{0}$
30	$15.\bar{7}$
40	$18.\bar{8}$
50	$20.\bar{9}$
60	$22.\bar{2}$
70	$23.\bar{0}$
80	$23.\bar{9}$
90	$24.\bar{1}$
100	$24.\bar{5}$
150	$26.\bar{0}$
200	$27.\bar{2}$

Hg, Liquid (33)

T, °K	C_p
235 to 298	$28.\bar{0}$

½I_2, Solid (17)

T, °K	C_p
15	$4.\bar{6}$
21	$9.\bar{8}5$
30	$12.\bar{8}$
36	$15.\bar{7}$
45	$17.\bar{6}$
60	$20.\bar{1}$
75	$21.\bar{8}$
90	$22.\bar{9}$
105	$23.\bar{4}$
120	$23.\bar{8}$
135	$24.\bar{1}$
150	$24.\bar{5}$
180	$25.\bar{1}$
200	$25.\bar{6}$
250	$26.\bar{8}$
300	$27.\bar{8}$

K (4)

T, °K	C_p
10	$6.\bar{0}7$
20	$1\bar{1}.0$
30	$1\bar{5}.2$
40	$1\bar{8}.35$
50	$2\bar{0}.8$
60	$2\bar{2}.05$
70	$2\bar{3}.75$
80	$2\bar{4}.6$
90	$2\bar{5}.1$
100	$2\bar{5}.35$
150	$2\bar{6}.6$
200	$2\bar{7}.8$
250	$2\bar{9}.0$
300	$3\bar{0}.2$

Mg (4, 21)

T, °K	C_p
20	$0.\bar{\bar{5}}0$
30	$1.\bar{\bar{8}}5$
40	$3.\bar{\bar{6}}0$
50	$6.\bar{\bar{1}}5$
60	$8.\bar{\bar{6}}$
70	$10.\bar{\bar{9}}5$
80	$13.\bar{1}5$
90	$15.\bar{1}$
100	$16.\bar{6}$
150	$21.\bar{4}5$
200	$23.\bar{3}5$
250	$24.\bar{4}$
300	$25.\bar{2}5$

N_2, Solid (6, 15)

T, °K	C_p
N_I	
15	$1\bar{2}.5$
21	$2\bar{5}.1$
30	$3\bar{0}.5$
N_{II}	
45	$3\bar{9}.7$
51	$4\bar{2}.3$
60	$4\bar{5}.2$

N_2, Liquid (6, 15)

T, °K	C_p
64 to 76	$5\bar{5}.6$

N_2, Gas (27)

T, °K	C_p
80	$30.\bar{2}$
90	$30.\bar{2}$
100	$30.\bar{1}$
150	$29.\bar{9}$
200	$29.\bar{7}$
250	$29.\bar{5}$
300	$29.\bar{1}$

Na (9, 11, 30)

T, °K	C_p
20	$2.\bar{\bar{5}}$
30	$5.\bar{\bar{2}}5$
40	$9.\bar{1}$
50	$1\bar{3}.4$
60	$1\bar{6}.75$
70	$1\bar{8}.95$
80	$2\bar{0}.6$
90	$2\bar{1}.55$
100	$2\bar{2}.25$
150	$2\bar{4}.8$
200	$2\bar{6}.3$
250	$2\bar{7}.4$
300	$2\bar{8}.55$

O_2, Solid (6)

T, °K	C_p
O_I	
15	$\bar{9}.20$
18	$1\bar{1}.25$
21	$1\bar{6}.7$
O_{II}	
30	$2\bar{7}.9$
36	$3\bar{6}.8$
39	$4\bar{1}.8$
O_{III}	
46	$4\bar{5}.2$

O_2, Liquid (6)

T, °K	C_p
57 to 73	$5\bar{3}.2$

O_2, Gas (27)

T, °K	C_p
90	$32.\bar{6}$
100	$32.\bar{4}$
150	$29.\bar{4}$
200	$29.\bar{7}$
250	$28.\bar{4}$
300	$29.\bar{4}$

Pb (8, 9, 13, 19)

T, °K	C_p
20	$11.\bar{1}$
30	$16.\bar{6}5$
40	$19.\bar{9}$
50	$22.\bar{0}$
60	$22.\bar{7}5$
70	$23.\bar{4}$
80	$23.\bar{9}$
90	$24.\bar{2}$
100	$24.\bar{4}5$
150	$25.\bar{1}$
200	$25.\bar{4}5$
250	$25.\bar{9}$
300	$26.\bar{4}$

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S, Rhombic (19)

T, °K	C_p
10	$1.\bar{3}$
20	$3.\bar{0}$
30	$4.\bar{8}$
40	$6.\bar{1}5$
50	$7.\bar{4}$
60	$8.\bar{7}$
70	$9.\bar{9}5$
80	$11.\bar{2}$
90	$12.\bar{3}$
100	$13.\bar{4}$
150	$17.\bar{2}$
200	$19.\bar{6}$
250	$21.\bar{4}5$
300	$23.\bar{3}$

S, Monoclinic (19)

T, °K	C_p
83	$1\bar{1}.55$
87	$1\bar{2}.15$
91	$1\bar{2}.4$
97	$1\bar{2}.45$
102	$1\bar{3}.2$
194	$2\bar{0}.6$
200	$2\bar{0}.95$

Sb (11)

T, °K	C_p
80.4	21.7
81.6	21.2
83.7	21.1
85.6	21.8
86.2	21.8
92.0	22.3
93.3	22.4
98.1	22.9

Si (21)

T, °K	C_p
20	$0.0\bar{8}$
30	$.\bar{5}0$
40	$1.\bar{1}$
50	$1.\bar{9}$
60	$2.\bar{8}5$
70	$3.\bar{0}$
80	$5.\bar{1}$
90	$6.\bar{4}5$
100	$7.\bar{9}$
150	$13.\bar{5}$
200	$16.\bar{2}$
250	$18.\bar{4}$
300	$20.\bar{3}5$

Sn, Gray (2, 17, 25)

10	$1.\bar{5}$
20	$3.\bar{5}5$
30	$6.\bar{4}$
40	$8.\bar{9}$
50	$11.\bar{2}$
60	$13.\bar{1}5$
70	$15.\bar{2}$
80	$16.\bar{9}$
90	$18.\bar{2}$
100	$19.\bar{5}8$
150	$23.\bar{0}5$
200	$24.\bar{4}$
250	$25.\bar{2}$
300	$25.\bar{8}5$

Sn, White (2, 17, 25)

T, °K	C_p
10	$1.\bar{9}$
20	$4.\bar{4}$
30	$8.\bar{6}$
40	$12.\bar{4}5$
50	$15.\bar{3}$
60	$17.\bar{3}$
70	$18.\bar{9}5$
80	$20.\bar{6}$
90	$21.\bar{5}5$
100	$22.\bar{5}$
150	$25.\bar{0}$
200	$25.\bar{9}5$
250	$26.\bar{5}5$
300	$26.\bar{9}5$

Ta, *v.* p. 94

Te, *v.* p. 94

Ti, *v.* p. 94

Tl (21)

20	$8.\bar{6}5$
30	$1\bar{5}.0$
40	$1\bar{8}.2$
50	$2\bar{0}.3$
60	$2\bar{1}.8$
70	$2\bar{2}.8$
80	$2\bar{3}.45$
90	$2\bar{3}.8$
100	$2\bar{4}.15$
150	$2\bar{5}.2$
200	$2\bar{5}.9$

Tl.—(*Cont'd*)

T, °K	C_p
250	$2\bar{6}.35$
300	$2\bar{6}.8$

W (17)

10	$0.\bar{1}$
20	$0.\bar{7}$
30	$1.\bar{7}$
40	$3.\bar{0}5$
50	$5.\bar{7}5$
60	$8.\bar{2}5$
70	$10.\bar{7}5$
80	$12.\bar{9}5$
90	$14.\bar{9}$
100	$16.\bar{5}5$
150	$21.\bar{0}$
200	$23.\bar{0}5$
250	$24.\bar{4}$
300	$25.\bar{5}5$

Zn (9, 19, 23)

30	$3.\bar{5}$
40	$7.\bar{2}0$
50	$10.\bar{3}5$
60	$13.\bar{1}$
70	$15.\bar{3}$
80	$17.\bar{1}$
90	$18.\bar{5}$
100	$19.\bar{8}$
150	$22.\bar{9}5$
200	$24.\bar{0}5$
250	$24.\bar{9}$
300	$25.\bar{4}$

𝔅-TABLE.—CHEMICAL COMPOUNDS; *v. also* p. 89.

Standard Arrangement (*v.* Vol. III, p. viii)

HCl, Solid (7); *cf.* (34)

T, °K	C_p
HCl_{I}	
25	$\bar{8}.95$
30	$1\bar{1}.95$
35	$1\bar{4}.25$
40	$1\bar{6}.9$
45	$1\bar{8}.85$
50	$2\bar{0}.5$
55	$2\bar{1}.95$
60	$2\bar{3}.35$
70	$2\bar{6}.35$
80	$2\bar{9}.0$
90	$3\bar{1}.9$
HCl_{II}	
105	$4\bar{0}.6$
110	$4\bar{1}.8$
135	$4\bar{6}.7$
145	$4\bar{8}.7$
155	$5\bar{0}.5$

HCl, Liquid (7); *cf.* (34)

165	$6\bar{2}.2$
175	$6\bar{3}.1$
185	$6\bar{4}.0$

HBr, Solid (7); *cf.* (35)

HBr_{I}	
22	$1\bar{2}.6$
25	$1\bar{5}.4$
30	$1\bar{7}.5$

HBr, Solid.—(*Cont'd*)

T, °K	C_p
HBr_{I}	
40	$2\bar{2}.55$
50	$2\bar{6}.15$
60	$2\bar{9}.25$
70	$3\bar{3}.8$
80	$4\bar{4}.6$
HBr_{II}	
95	$4\bar{3}.6$
105	$4\bar{8}.4$
110	$5\bar{1}.4$
HBr_{III}	
120	$4\bar{7}.7$
135	$4\bar{7}.7$

HBr, Liquid (7); *cf.* (35)

190 to 198	$6\bar{0}.7$

HI, Solid (7)

HI_{I}	
60	$3\bar{8}.95$
65	$5\bar{0}.0$
HI_{II}	
85	$4\bar{3}.2$
100	$4\bar{5}.0$
HI_{III}	
140	$4\bar{8}.0$
155	$4\bar{7}.3$
160	$4\bar{7}.1$

HI, Solid.—(*Cont'd*)

T, °K	C_p
HI_{III}	
170	$4\bar{7}.1$
180	$4\bar{6}.8$
200	$4\bar{7}.5$

HI, Liquid (7)

224 to 238	$6\bar{8}.6$

NO, Solid (7)

25	$1\bar{0}.1$
30	$1\bar{2}.6$
80	$3\bar{1}.5$
85	$3\bar{3}.1$
90	$3\bar{4}.4$
100	$3\bar{6}.4$

NO, Liquid (7)

115 to 117	$7\bar{2}.7$

NH_3, Solid (7)

25	$2.\bar{9}$
30	$4.\bar{6}$
40	$8.\bar{5}$
50	$1\bar{2}.6$
85	$2\bar{3}.5$
100	$2\bar{7}.7$
130	$3\bar{2}.2$
150	$4\bar{0}.7$
170	$4\bar{5}.3$
185	$4\bar{9}.0$

NH_3, Liquid (7)

T, °K	C_p
200	$7\bar{7}.0$
210	$7\bar{6}.4$
220	$7\bar{6}.1$

CO, Solid (6, 27)

CO_{I}	
10	$\bar{4}.8$
20	$1\bar{4}.2$
30	$2\bar{4}.7$
40	$3\bar{4}.4$
50	$4\bar{5}.4$
57	$5\bar{6}.5$
CO_{II}	
65	$5\bar{2}.8$

CO, Liquid (6)

67 to 83	$\bar{7}.2$

CO, Gas (27)

T, °K	C_p
83	$30.\bar{4}$
90	$30.\bar{3}$
100	$30.\bar{2}$
150	$30.\bar{0}$
200	$29.\bar{7}$
250	$29.\bar{5}$
300	$29.\bar{3}$

CH_4, Solid (7)

30	$2\bar{3}.1$
40	$2\bar{8}.5$
55	$3\bar{3}.95$
70	$3\bar{8}.1$
80	$4\bar{1}.2$
85	$4\bar{2}.7$

CH_4, Liquid (7)

96	$5\bar{7}.5$

CH_4, Liquid.—(*Cont'd*)

T, °K	C_p
100	$5\bar{6}.6$
105	$5\bar{6}.6$

C_6H_6 (18, 19, 32)

10	$2.\bar{5}$
20	$8.\bar{5}5$
30	$1\bar{7}.6$
40	$2\bar{6}.1$
50	$3\bar{2}.2$
60	$3\bar{8}.7$
70	$4\bar{3}.8$
80	$4\bar{9}.2$
90	$5\bar{3}.8$
100	$5\bar{7}.8$
150	$7\bar{8}.0$
200	$9\bar{5}.5$
250	$11\bar{2}.0$
300	$12\bar{7}.1$

CO_2 (6)

T, °K	C_p	T, °K	C_p
19.4	4.52	82.75	37.6
22.0	6.03	84.2	38.2
23.45	7.4	85.5	38.8
25.4	8.62	86.4	38.4
26.4	9.87	88.4	38.9
29.3	11.9	195.2	54.2
31.8	13.72	195.3	54.5
34.7	16.31	196.4	54.4
37.8	18.33	197.1	55.4
41.3	21.25	198.0	55.3
44.2	22.85	198.9	55.2
80.15	37.0	199.6	55.6
82.0	37.25	200.5	56.0

$(C_5H_8O)_x$, Ketone resin (28)

67.3	34.5	155.3	73.0
72.5	38.1	158.2	74.6
73.4	37.7	203.4	92.0
76.9	40.8	205.4	91.0
78.3	40.1	216.9	97.0
81.5	43.1	218.8	98.4
93.1	48.0	269.9	119.7
97.5	49.6	296.9	132.8
129.0	64.6	298.4	135.8
132.2	64.4		

$C_6H_{12}O_6$, Glucose (28)

19.9	4.96	90.6	42.1
23.4	6.74	100.6	46.3
26.9	8.78	102.1	46.3
31.4	11.71	105.4	48.1
36.0	14.36	114.1	51.1
39.2	16.3	130.9	58.4
44.2	18.16	153.7	67.6
48.8	21.75	158.0	69.6
51.8	23.5	200.1	86.9
56.0	25.9	202.5	88.7
60.9	28.8	231.5	101.8
66.5	31.4	251.9	110.0
69.8	32.6	269.9	119.5
79.2	37.0	287.2	126.2
84.6	39.6	296.2	135.0

PbI_2 (21)

T, °K	C_p	T, °K	C_p
22.3	29.5	89.4	71.5
26.2	32.85	95.6	72.3
38.2	44.9	235.0	784.0
50.6	55.2	332.0	823.0
62.1	61.8		

Hg_2SO_4 (24)

23.5	25.2	76.6	68.2
26.5	34.2	85.0	71.5
30.0	39.4	201.0	108.9
56.2	58.9	290.0	129.2

BeO (10)

76.8	0.85	79.7	1.02
78.1	.92	80.3	0.93
78.6	.82	82.6	0.99
79.3	.95	84.9	1.15

$Ca(OH)_2$ (21)

21.4	2.06	47.4	6.96
26.3	2.94	50.4	9.63
31.4	3.42	53.8	12.34
37.6	4.54	76.2	16.95
40.7	5.38	86.0	21.3

CaH_2 (10)

69.9	7.5	80.1	9.92
71.2	7.78	80.9	9.92
72.5	7.95	86.2	11.48
79.0	9.42		

$CaCO_3$, Aragonite (10)

23.3	0.97	38.6	4.05
26.8	1.16	41.7	5.34
29.7	1.53	47.7	7.7
31.9	2.18	50.5	9.3
34.1	2.86	52.6	10.42
35.9	3.54	56.2	10.85

$Al_2(SO_4)_3K_2SO_4.24H_2O$ (21)

25.7	116.5	41.7	252.3
28.3	136.1	46.0	302.5
30.0	144.2	50.6	350.0
31.2	158.8	54.0	368.5
32.8	175.5	71.9	503.0
34.7	181.8	84.4	592.0
36.0	210.0	90.5	693.0

ENTROPY, HEAT CONTENT AND THERMODYNAMIC POTENTIAL

A-TABLE.—ELEMENTARY SUBSTANCES

Argon (6, 12)

T, °K	C_p	S	H	F = H − TS
0	0	0	0	0
50	$2\bar{5}.85$	$2\bar{3}.4$	$7\bar{\bar{1}}2$	− $\bar{4}68$
100	$22.\bar{\bar{4}}$	$13\bar{0}.4$	3 $0\bar{\bar{3}}5$	−10 $\bar{\bar{0}}05$
150	$21.\bar{7}5$	$13\bar{9}.4$	4 $1\bar{\bar{4}}5$	−16 $\bar{\bar{7}}35$
200	$21.\bar{5}5$	$14\bar{5}.6$	5 $2\bar{\bar{4}}0$	−22 $\bar{\bar{8}}60$
250	$21.\bar{3}5$	$15\bar{0}.4$	6 $3\bar{\bar{2}}0$	−31 $\bar{\bar{2}}80$
273.1	$21.\bar{3}0$	$15\bar{2}.0$	6 $8\bar{\bar{0}}0$	−34 $\bar{\bar{7}}00$
298.1	$21.\bar{2}3$	$15\bar{4}.0$	7 $3\bar{\bar{4}}0$	−38 $\bar{\bar{5}}60$

Ag (9, 19, 20)

50	$11.\bar{\bar{3}}$	$5.\bar{9}1$	$19\bar{\bar{2}}$	− $1\overline{\bar{0}3}$
100	$20.\bar{\bar{2}}$	$\overline{17.2}$	1 $0\overline{\bar{1}2}$	− $\overline{708}$
150	$23.\bar{\bar{2}}$	$\overline{26.0}$	2 $0\overline{\bar{9}5}$	− 1 $\overline{805}$
200	$24.\bar{\bar{4}}$	$\overline{32.8}$	3 $\overline{\bar{2}80}$	− 3 $\overline{280}$
250	$25.\bar{\bar{0}}$	$\overline{38.3}$	4 $\overline{\bar{5}20}$	− 5 $\overline{060}$
273.1	$25.\bar{\bar{2}}$	$\overline{40.5}$	5 $\overline{\bar{1}00}$	− 5 $\overline{970}$
298.1	$25.\bar{\bar{3}}$	$\overline{42.7}$	5 $\overline{\bar{7}30}$	− 6 $\overline{\bar{9}90}$

Al (9, 20, 21)

0	0	0	0	0
50	$3.\bar{\bar{7}}5$	$1.\bar{2}3$	$5\bar{\bar{2}}.1$	− $\bar{\bar{9}}.4$
100	$1\bar{3}.1$	$6.\bar{\bar{8}}2$	$4\bar{\bar{6}}5.0$	− $2\bar{\bar{1}}7$
150	$1\bar{8}.63$	$1\bar{3}.22$	1 $\bar{2}72$	− $7\bar{\bar{1}}0$
200	$2\bar{1}.55$	$1\bar{8}.98$	2 $\bar{2}85$	− 1 $\bar{5}05$
250	$2\bar{3}.23$	$2\bar{3}.95$	3 $\bar{\bar{5}}00$	− 2 $\bar{\bar{4}}80$
273.1	$2\bar{3}.85$	$2\bar{6}.1$	4 $\bar{\bar{0}}40$	− 3 $\bar{\bar{0}}80$
298.1	$2\bar{4}.4$	$2\bar{8}.15$	4 $\bar{\bar{6}}30$	− 3 $\bar{\bar{7}}50$

C, Graphite (19)

0	0	0	0	0
50	$0.\overline{54}$	$0.\overline{29}$	$1\overline{1.9}$	− $\overline{2.8}$
100	$1.\overline{72}$	$1.\overline{\bar{0}4}$	$\overline{73.3}$	− $\bar{3}1$
150	$3.\overline{\bar{2}6}$	$1.\overline{\bar{9}7}$	$18\bar{9}$	− $1\overline{\bar{0}7}$
200	$5.\overline{\bar{1}0}$	$3.\overline{\bar{1}8}$	$3\overline{94}$	− $\overline{242}$
250	$6.\overline{\bar{9}4}$	$4.\overline{\bar{4}4}$	$6\overline{88}$	− $\overline{422}$
273.1	$7.\overline{\bar{8}2}$	$5.\overline{\bar{1}0}$	$8\overline{56}$	− $\overline{536}$
298.1	$8.\overline{\bar{6}6}$	$5.\overline{\bar{8}1}$	1 $0\overline{52}$	− $\overline{678}$

C, Diamond (20)

0	0	0	1 $\bar{2}82$	1 $\bar{2}82$
50	0	0	1 $\bar{2}82$	1 $\bar{2}82$
100	$0.\bar{2}9$	$0.0\bar{\bar{6}}3$	1 $\bar{2}82$	1 $\bar{2}76$
150	$1.\bar{\bar{1}}3$	$.\bar{3}4$	1 $\bar{3}26$	1 $\bar{2}76$
200	$2.\bar{\bar{3}}4$	$.\bar{8}0$	1 $\bar{4}26$	1 $\bar{2}66$
250	$4.\bar{\bar{1}}8$	$1.\bar{4}5$	1 $\bar{5}89$	1 $\bar{2}27$
273.1	$5.\bar{\bar{0}}2$	$1.\bar{8}2$	1 $\bar{6}98$	1 $\bar{2}07$
298.1	$6.\bar{\bar{1}}9$	$2.\bar{2}8$	1 $\bar{8}06$	1 $\bar{1}26$

Ca (4, 10)

T, °K	C_p	S	H	F = H − TS
50	11.46	5.58	189	− 90
100	20.70	17.1	983	− 727
150	24.0	26.2	2 110	− 1 810
200	25.3	33.3	3 340	− 3 310
250	25.8	39.1	4 620	− 5 150
273.1	25.88	41.3	5 220	− 6 060
298.1	25.97	43.5	5 860	− 7 120

Cd (9, 25)

0	0	0	0	0
50	15.4	8.12	285.5	− 121
100	22.45	22.7	1 290	− 980
150	24.18	32.15	2 460	− 2 360
200	25.15	39.2	3 700	− 4 140
250	25.65	44.3	4 960	− 6 130
273.1	25.9	46.7	5 560	− 7 190
298.1	26.1	48.9	6 210	− 8 390

Cu (9, 14, 20)

50	6.02	2.47	82.2	− 41
100	16.07	10.03	648.0	− 355
150	20.85	17.52	1 603	− 1 025
200	22.9	24.0	2 700	− 2 100
250	23.95	29.25	3 860	− 3 450
273.1	24.20	31.35	4 420	− 4 130
298.1	24.45	33.60	5 020	− 4 990

Fe (9)

0	0	0	0	0
50	3.77	1.30	50.2	− 15
100	13.1	6.78	484	− 192
150	18.82	13.27	1 292	− 698
200	21.85	19.12	2 302	− 1 522
250	23.85	24.20	3 455	− 2 595
273.1	24.45	26.4	4 010	− 2 190
298.1	25.1	28.6	4 630	− 3 900

½H_2 (5, 16, 31)

0	0	0	0	0
50	10.45	42.25	890	− 1 225
100	11.3	49.7	1 430	− 3 540
150	12.58	54.5	2 035	− 6 135
200	13.4	58.4	2 685	− 8 995
250	14.03	61.4	3 360	−11 990
273.1	14.3	62.5	3 690	−13 370
298.1	14.53	64.0	4 050	−15 050

Hg (1, 22, 24, 28, 29)

0	0	0	0	0
50	20.9	21.7	602	− 483
100	24.65	37.6	1 768	− 1 992
150	26.2	47.8	3 040	− 4 140
200	27.2	55.4	4 380	− 6 680
273.1	28.0	74.2	7 800	−12 500
298.1	27.6	76.5	8 500	−14 300

½I_2 (17)

T, °K	C_p	S	H	F = H − TS
0	0	0	0	0
50	18.41	16.30	495	− 320
100	23.2	31.05	1 578	− 1 527
150	24.4	40.7	2 770	− 3 330
200	25.65	47.8	4 030	− 5 520
250	26.9	53.7	5 340	− 8 060
273.1	27.35	55.9	5 960	− 9 330
298.1	27.8	58.4	6 650	−10 750

K (4, 30)

50	21.6	19.55	607	− 369
100	25.3	36.0	1 795	− 1 805
150	26.65	49.5	3 090	− 4 330
200	27.90	57.4	4 450	− 7 010
250	29.2	63.7	5 880	−10 020
273.1	29.6	66.3	6 560	−11 540
298.1	30.15	69.0	7 320	−13 280

Mg (4, 21)

50	6.27	2.47	90.5	− 33
100	16.5	10.4	680	− 360
150	21.2	17.95	1 650	− 1 040
200	23.6	24.3	2 780	− 2 090
250	24.95	29.6	3 970	− 3 430
273.1	25.2	31.8	4 540	− 4 140
298.1	25.45	34.0	5 170	− 4 980

½N_2 (6, 15, 27)

0	0	0	0	0
50	21.15	23.15	706	− 452
100	15.0	80.01	4 940	− 3 061
150	14.8	86.0	5 710	− 7 190
200	14.7	90.4	6 450	−11 610
250	14.65	93.5	7 180	−16 170
273.1	14.62	94.9	7 520	−18 380
298.1	14.6	96.1	7 890	−20 730

Na (9, 11, 30)

0	0	0	0	0
50	13.4	6.49	241	− 83
100	23.0	19.2	1 177	− 743
150	25.77	33.3	2 370	− 2 630
200	27.05	41.0	3 650	− 4 550
250	27.85	47.2	4 990	− 6 810
273.1	28.15	49.7	5 620	− 7 930
298.1	28.4	52.2	6 330	− 9 190

½O_2 (6, 27)

0	0	0	0	0
50	22.6	26.2	965	− 345
100	15.1	84.9	5 720	− 2 770
150	14.5	90.6	6 470	− 7 130
200	14.33	94.9	7 180	−11 810
250	14.43	98.0	7 890	−16 610
273.1	14.53	99.4	8 230	−18 870
298.1	14.63	100.5	8 600	−21 400

Pb (8, 9, 13, 19, 30)

T, °K	C_p	S	H	$F = H - TS$
0	0	0	0	0
50	$2\bar{1}.62$	$2\bar{1}.1$	$5\bar{7}7$	$-4\bar{\bar{7}}8$
100	$2\bar{3}.7$	$3\bar{7}.2$	$1\,7\bar{\bar{5}}3$	$-1\,\bar{9}67$
150	$2\bar{5}.4$	$4\bar{7}.3$	$2\,9\bar{\bar{8}}5$	$-4\,\bar{1}15$
200	$2\bar{5}.9$	$5\bar{4}.6$	$4\,\bar{2}50$	$-6\,\bar{6}50$
250	$2\bar{6}.25$	$6\bar{0}.5$	$5\,\bar{\bar{5}}40$	$-9\,\bar{5}80$
273.1	$26.\bar{\bar{3}}5$	$6\bar{2}.8$	$6\,\bar{\bar{1}}40$	$-10\,\bar{\bar{9}}90$
298.1	$26.\bar{5}$	$6\bar{5}.0$	$6\,\bar{\bar{8}}00$	$-12\,\bar{\bar{6}}00$

S, Orthorhombic (19)

0	0	0	0	0
50	$7.\overline{\bar{8}2}$	$6.\bar{\bar{2}}$	$1\overline{\bar{8}2}$	$-1\overline{\bar{2}8}$
100	$1\overline{2.85}$	$1\overline{3.2}$	$\overline{605}$	$-\overline{715}$
150	$1\overline{6.5}$	$1\overline{9.1}$	$1\,\overline{370}$	$-1\,\overline{490}$
200	$1\overline{9.12}$	$2\overline{4.3}$	$2\,\overline{290}$	$-2\,\overline{\bar{5}70}$
250	$2\overline{1.4}$	$2\overline{8.8}$	$3\,\overline{310}$	$-3\,\overline{\bar{8}90}$
273.1	$2\overline{2.17}$	$3\overline{0.2}$	$3\,\overline{810}$	$-4\,\overline{\bar{4}30}$
298.1	$2\overline{3.0}$	$3\overline{2.2}$	$4\,\overline{380}$	$-5\,\overline{\bar{2}20}$

Si (21)

0	0	0	0	0
50	$1.\bar{\bar{9}}3$	$0.\bar{7}1$	$2\bar{8}.15$	$-\bar{7}.4$
100	$\bar{7}.83$	$3.\bar{\bar{8}}1$	$2\bar{\bar{6}}5.5$	$-1\bar{\bar{1}}5.5$
150	$1\bar{2}.55$	$7.\bar{\bar{9}}1$	$8\bar{\bar{0}}1$	$-3\bar{\bar{8}}6$
200	$1\bar{5}.57$	$1\bar{1}.85$	$1\,\bar{5}58$	$-8\bar{\bar{1}}2$
250	$1\bar{8}.0$	$1\bar{5}.6$	$2\,\bar{3}90$	$-1\,\bar{5}10$
273.1	$1\bar{8}.9$	$1\bar{7}.3$	$2\,\bar{8}05$	$-1\,\bar{9}15$
298.1	$1\bar{9}.99$	$1\bar{9}.0$	$3\,\bar{3}00$	$-2\,\bar{\bar{3}}60$

Sn, White (2, 17, 25)

0	0	0	0	0
50	$15.\bar{\bar{3}}5$	$1\bar{1}.12$	$3\bar{\bar{5}}4$	$-2\bar{\bar{0}}2$
100	$22.\bar{\bar{4}}5$	$2\bar{4}.4$	$1\,\bar{3}24$	$-1\,\bar{1}16$
150	$25.\bar{\bar{0}}$	$3\bar{4}.0$	$2\,\bar{5}20$	$-2\,\bar{5}80$
200	$26.\bar{\bar{1}}$	$4\bar{1}.5$	$3\,\bar{8}10$	$-4\,\bar{\bar{4}}90$
250	$26.\bar{\bar{6}}$	$4\bar{7}.4$	$5\,\bar{1}40$	$-6\,\bar{\bar{7}}10$
273.1	$26.\bar{\bar{8}}$	$4\bar{9}.6$	$5\,\bar{7}60$	$-7\,\bar{\bar{7}}70$
298.1	$26.\bar{\bar{9}}$	$5\bar{2}.3$	$6\,\bar{4}40$	$-9\,\bar{\bar{1}}60$

Sn, Gray (2, 17, 25)

0	0	0	$-1\,\bar{5}50$	$-1\,\bar{\bar{5}}50$
50	$11.\bar{\bar{1}}3$	$8.\bar{\bar{1}}2$	$-1\,\bar{5}25$	$-1\,\bar{\bar{9}}30$
100	$19.\bar{\bar{6}}$	$18.\bar{\bar{7}}$	$-5\bar{1}0$	$-2\,\bar{\bar{3}}80$
150	$23.\bar{\bar{0}}$	$2\bar{7}.3$	$5\bar{\bar{6}}0$	$-3\,\bar{\bar{5}}40$
200	$24.\bar{\bar{6}}$	$3\bar{4}.8$	$1\,\bar{7}50$	$-5\,\bar{\bar{2}}00$
250	$25.\bar{\bar{4}}$	$4\bar{0}.5$	$2\,\bar{9}90$	$-7\,\bar{\bar{1}}30$
273.1	$25.\bar{\bar{5}}5$	$4\bar{2}.7$	$3\,\bar{5}70$	$-8\,\bar{\bar{0}}80$
298.1	$25.\bar{\bar{6}}$	$4\bar{4}.7$	$4\,\bar{1}80$	$-9\,\bar{\bar{1}}20$

Tl (21)

50	$2\overline{0.7}$	$1\overline{8.4}$	$5\overline{24}$	$-3\overline{96}$
100	$2\overline{4.05}$	$3\overline{4.2}$	$1\,6\overline{60}$	$-1\,\overline{760}$
150	$2\overline{5.2}$	$4\overline{4.2}$	$2\,8\overline{90}$	$-3\,\overline{740}$
200	$2\overline{5.85}$	$5\overline{1.5}$	$4\,1\overline{70}$	$-6\,\overline{130}$
250	$2\overline{6.3}$	$5\overline{7.5}$	$5\,\overline{470}$	$-8\,\overline{920}$
273.1	$2\overline{6.5}$	$5\overline{9.7}$	$6\,\overline{080}$	$-1\bar{0}\,\overline{200}$
298.1	$2\overline{6.65}$	$6\overline{2.2}$	$6\,\overline{750}$	$-1\bar{1}\,\overline{770}$

W (17)

T, °K	C_p	S	H	$F = H - TS$
50	$6.\bar{0}2$	$\bar{2}.43$	$8\bar{\bar{3}}.6$	$-\bar{\bar{3}}8$
100	$16.\bar{\bar{3}}2$	$1\bar{0}.09$	$6\bar{\bar{7}}2$	$-3\bar{\bar{3}}7$
150	$2\bar{1}.15$	$1\bar{7}.69$	$1\,\bar{6}25$	$-1\,\bar{0}25$
200	$2\bar{3}.55$	$2\bar{4}.1$	$2\,\bar{7}30$	$-2\,\bar{\bar{0}}90$
250	$2\bar{4}.9$	$2\bar{9}.6$	$3\,\bar{\bar{9}}20$	$-3\,\bar{\bar{4}}80$
273.1	$2\bar{5}.2$	$3\bar{1}.7$	$4\,\bar{\bar{4}}90$	$-4\,\bar{\bar{1}}60$
298.1	$2\bar{5}.55$	$3\bar{3}.90$	$5\,\bar{\bar{1}}20$	$-4\,\bar{\bar{9}}80$

Zn (9, 19, 23)

0	0	0	0	0
50	$10.\bar{\bar{2}}7$	$4.\bar{\bar{8}}2$	$1\bar{\bar{4}}1$	$-1\bar{\bar{0}}0$
100	$19.\bar{\bar{7}}5$	$1\bar{5}.38$	$9\bar{\bar{2}}4$	$-6\bar{\bar{1}}4$
150	$23.\bar{\bar{0}}$	$2\bar{3}.55$	$2\,\bar{0}10$	$-1\,\bar{5}20$
200	$24.\bar{\bar{3}}$	$3\bar{0}.3$	$3\,\bar{1}95$	$-2\,\bar{\bar{8}}65$
250	$24.\bar{\bar{9}}$	$3\bar{5}.85$	$4\,\bar{4}20$	$-4\,\bar{\bar{5}}40$
273.1	$25.\bar{\bar{1}}5$	$3\bar{8}.45$	$5\,\bar{0}00$	$-5\,\bar{\bar{5}}00$
298.1	$25.\bar{\bar{2}}5$	$4\bar{0}.6$	$5\,\bar{6}30$	$-6\,\bar{\bar{4}}70$

𝔅-TABLE.—CHEMICAL COMPOUNDS, STANDARD ARRANGEMENT

H_2O (24)

0	0	0	$-28\bar{2}\,600$	$-28\bar{2}\,600$
50	$8.\bar{\bar{5}}8$	$4.\bar{7}8$	$-28\bar{2}\,417$	$-28\bar{2}\,656$
100	$1\bar{6}.1$	$13.\bar{3}1$	$-28\bar{1}\,777$	$-28\bar{3}\,108$
150	$2\bar{1}.75$	$2\bar{\bar{0}}.8$	$-28\bar{0}\,825$	$-28\bar{3}\,945$
200	$2\bar{3}.85$	$2\bar{\bar{7}}.75$	$-27\bar{9}\,595$	$-28\bar{5}\,145$
250	$3\bar{4}.7$	$3\bar{\bar{4}}.65$	$-27\bar{8}\,060$	$-28\bar{6}\,720$
273.1	$38.\bar{\bar{2}}$	$3\bar{\bar{7}}.85$	$-27\bar{7}\,220$	$-28\bar{7}\,540$
298.1	$75.\bar{3}$	$6\bar{\bar{6}}.7$	$-26\bar{9}\,300$	$-28\bar{9}\,200$

HCl (34); **HBr** (35)

NH_4Cl (28)

0	0	0	$-28\bar{5}\,960$	$-28\bar{5}\,960$
50	$1\bar{4}.69$	$6.\bar{\bar{4}}9$	$-28\bar{5}\,706$	$-28\bar{6}\,031$
100	$3\bar{7}.7$	$2\bar{4}.2$	$-28\bar{4}\,360$	$-28\bar{6}\,780$
150	$5\bar{0}.2$	$4\bar{1}.5$	$-28\bar{2}\,100$	$-28\bar{8}\,320$
200	$6\bar{9}.4$	$5\bar{8}.8$	$-27\bar{9}\,070$	$-29\bar{0}\,830$
250	$7\bar{8}.9$	$8\bar{3}.1$	$-27\bar{4}\,130$	$-29\bar{4}\,930$
273.1	$8\bar{2}.4$	$9\bar{0}.2$	$-27\bar{2}\,320$	$-29\bar{6}\,920$
298.1	$8\bar{6}.6$	$9\bar{7}.6$	$-27\bar{0}\,230$	$-29\bar{9}\,430$

CO (6, 27)

0	0	0	$-12\bar{5}\,948$	$-12\bar{5}\,948$
50	$4\bar{5}.2$	$3\bar{\bar{0}}.75$	$-12\bar{4}\,918$	$-12\bar{6}\,458$
100	$32.\bar{\bar{0}}$	$15\bar{\bar{9}}.3$	$-11\bar{5}\,218$	$-13\bar{1}\,148$
150	$29.\bar{\bar{9}}$	$17\bar{\bar{1}}.9$	$-11\bar{3}\,718$	$-13\bar{9}\,518$
200	$29.\bar{\bar{6}}5$	$18\bar{\bar{0}}.0$	$-11\bar{2}\,228$	$-14\bar{8}\,228$
250	$29.\bar{\bar{4}}5$	$18\bar{\bar{6}}.5$	$-11\bar{0}\,748$	$-15\bar{7}\,348$
273.1	$29.\bar{\bar{4}}$	$18\bar{\bar{9}}.2$	$-11\bar{0}\,068$	$-16\bar{1}\,668$
298.1	$29.\bar{\bar{3}}5$	$19\bar{\bar{2}}.0$	$-10\bar{9}\,348$	$-16\bar{6}\,548$

C_6H_6 (18, 19, 32)

0	0	0	$4\bar{\bar{9}}\,050$	$4\bar{\bar{9}}\,050$
50	$3\bar{4}.65$	$2\bar{2}.8$	$4\bar{\bar{9}}\,656$	$4\bar{\bar{8}}\,516$
100	$5\bar{5}.8$	$5\bar{\bar{3}}.5$	$5\bar{\bar{2}}\,000$	$4\bar{\bar{6}}\,650$
150	$7\bar{3}.9$	$7\bar{\bar{9}}.5$	$5\bar{\bar{5}}\,390$	$4\bar{\bar{3}}\,490$

C_6H_6.—(*Continued*)

T, °K	C_p	S	H	$F = H - TS$
200	$10\bar{3}.0$	$10\bar{\bar{2}}.5$	$5\bar{\bar{9}}\ 670$	$3\bar{\bar{9}}\ 170$
250	$11\bar{0}.5$	$12\bar{\bar{4}}.4$	$6\bar{\bar{4}}\ 850$	$3\bar{\bar{3}}\ 750$
273.1	$11\bar{8}.8$	$13\bar{\bar{5}}.0$	$6\bar{\bar{7}}\ 500$	$3\bar{\bar{0}}\ 700$
298.1	$13\bar{3}.5$	$18\bar{\bar{1}}.0$	$8\bar{\bar{0}}\ 850$	$2\bar{\bar{6}}\ 850$

SiC (10, 21)

PbO (21)

0	0	0	$-21\bar{3}\ 660$	$-21\bar{3}\ 660$
50	$1\bar{6}.6$	$1\bar{2}.3$	$-21\bar{3}\ 250$	$-21\bar{3}\ 865$
100	$2\bar{8}.45$	$2\bar{7}.6$	$-21\bar{2}\ 110$	$-21\bar{4}\ 870$
150	$3\bar{6}.55$	$4\bar{3}.5$	$-21\bar{0}\ 485$	$-21\bar{7}\ 005$
200	$4\bar{1}.8$	$5\bar{4}.6$	$-20\bar{8}\ 540$	$-21\bar{9}\ 440$
250	$4\bar{4}.9$	$6\bar{4}.2$	$-20\bar{6}\ 390$	$-22\bar{2}\ 390$
273.1	$46.\bar{\bar{1}}$	$6\bar{8}.5$	$-20\bar{5}\ 320$	$-22\bar{4}\ 020$
298.1	$47.\bar{\bar{2}}$	$7\bar{2}.5$	$-20\bar{4}\ 140$	$-22\bar{5}\ 740$

$PbCl_2$ (19)

0	0	0	$-32\bar{9}\ 460$	$-32\bar{9}\ 460$
50	$4\bar{0}.9$	$2\bar{\bar{9}}.6$	$-32\bar{8}\ 556$	$-33\bar{0}\ 036$
100	$5\bar{9}.2$	$6\bar{\bar{4}}.9$	$-32\bar{5}\ 945$	$-33\bar{2}\ 435$
150	$6\bar{8}.0$	$9\bar{\bar{0}}.7$	$-32\bar{2}\ 700$	$-33\bar{6}\ 300$
200	$7\bar{2}.6$	$11\bar{\bar{1}}.0$	$-31\bar{9}\ 180$	$-34\bar{1}\ 380$
250	$7\bar{5}.4$	$12\bar{\bar{7}}.2$	$-31\bar{5}\ 540$	$-34\bar{7}\ 340$
273.1	$7\bar{6}.2$	$13\bar{\bar{4}}.1$	$-31\bar{3}\ 780$	$-35\bar{0}\ 380$
298.1	$7\bar{6}.9$	$14\bar{\bar{0}}.9$	$-31\bar{1}\ 880$	$-35\bar{3}\ 880$

PbS (4)

0	0	0	$-\ 9\bar{3}\ 860$	$-\ 9\bar{3}\ 860$
50	$2\bar{6}.8$	$1\bar{9}.5$	$-\ 9\bar{3}\ 254$	$-\ 9\bar{4}\ 229$
100	$3\bar{9}.6$	$4\bar{\bar{3}}.0$	$-\ 9\bar{1}\ 542$	$-\ 9\bar{5}\ 842$
150	$4\bar{4}.4$	$6\bar{\bar{0}}.0$	$-\ 8\bar{9}\ 420$	$-\ 9\bar{8}\ 420$
200	$4\bar{7}.5$	$7\bar{\bar{3}}.3$	$-\ 8\bar{7}\ 120$	$-10\bar{1}\ 770$
250	$4\bar{9}.7$	$8\bar{\bar{4}}.0$	$-\ 8\bar{4}\ 710$	$-10\bar{5}\ 710$
273.1	$5\bar{0}.4$	$8\bar{\bar{8}}.4$	$-\ 8\bar{3}\ 540$	$-10\bar{7}\ 640$
298.1	$5\bar{1}.4$	$9\bar{\bar{2}}.8$	$-\ 8\bar{2}\ 260$	$-10\bar{9}\ 960$

TlCl (24)

0	0	0	$-19\bar{1}\ 020$	$-19\bar{1}\ 020$
50	$33.\bar{\bar{9}}5$	$2\bar{7}.4$	$-19\bar{0}\ 163$	$-19\bar{1}\ 533$
100	$44.\bar{\bar{7}}$	$5\bar{4}.8$	$-18\bar{8}\ 136$	$-19\bar{3}\ 616$
150	$48.\bar{\bar{2}}$	$7\bar{\bar{3}}.6$	$-18\bar{5}\ 800$	$-19\bar{6}\ 800$
200	$50.\bar{\bar{3}}$	$8\bar{\bar{7}}.5$	$-18\bar{3}\ 350$	$-20\bar{0}\ 850$
250	$51.\bar{\bar{8}}$	$9\bar{\bar{9}}.9$	$-18\bar{0}\ 520$	$-20\bar{5}\ 520$
273.1	$52.\bar{\bar{4}}$	$10\bar{\bar{3}}.3$	$-17\bar{9}\ 320$	$-20\bar{7}\ 520$
298.1	$53.\bar{\bar{0}}$	$10\bar{\bar{8}}.0$	$-17\bar{8}\ 000$	$-21\bar{0}\ 200$

ZnS (10)

0	0	0	$-19\bar{0}\ 750$	$-19\bar{0}\ 750$
50	$1\bar{4}.59$	$\bar{7}.99$	$-19\bar{0}\ 465$	$-19\bar{0}\ 865$
100	$2\bar{5}.8$	$2\bar{1}.7$	$-18\bar{9}\ 376$	$-19\bar{1}\ 546$
150	$3\bar{3}.5$	$3\bar{\bar{3}}.4$	$-18\bar{7}\ 715$	$-19\bar{2}\ 715$
200	$3\bar{\bar{8}}.95$	$4\bar{\bar{3}}.8$	$-18\bar{5}\ 790$	$-19\bar{4}\ 540$
250	$4\bar{\bar{3}}.1$	$5\bar{\bar{2}}.8$	$-18\bar{3}\ 710$	$-19\bar{6}\ 910$
273.1	$4\bar{5}.0$	$5\bar{\bar{6}}.7$	$-18\bar{2}\ 680$	$-19\bar{8}\ 160$
298.1	$4\bar{6}.6$	$6\bar{\bar{0}}.6$	$-18\bar{1}\ 500$	$-19\bar{9}\ 500$

HgO (10)

T, °K	C_p	S	H	$F = H - TS$
0	0	0	$-\ 8\bar{3}\ 020$	$-\ 8\bar{3}\ 020$
50	$1\bar{8}.18$	$1\bar{2}.13$	$-\ 8\bar{2}\ 631$	$-\ 8\bar{3}\ 236$
100	$2\bar{9}.3$	$2\bar{8}.45$	$-\ 8\bar{1}\ 409$	$-\ 8\bar{4}\ 254$
150	$3\bar{6}.0$	$4\bar{1}.7$	$-\ 7\bar{9}\ 725$	$-\ 8\bar{5}\ 975$
200	$4\bar{0}.3$	$5\bar{2}.5$	$-\ 7\bar{7}\ 810$	$-\ 8\bar{8}\ 310$
250	$4\bar{3}.4$	$6\bar{1}.8$	$-\ 7\bar{5}\ 840$	$-\ 9\bar{1}\ 290$
273.1	$4\bar{4}.5$	$6\bar{5}.6$	$-\ 7\bar{4}\ 830$	$-\ 9\bar{2}\ 730$
298.1	$4\bar{5}.3$	$6\bar{9}.6$	$-\ 7\bar{3}\ 700$	$-\ 9\bar{4}\ 500$

HgCl (24)

0	0	0	$-11\bar{5}\ 500$	$-11\bar{5}\ 500$
50	$2\bar{8}.6$	$2\bar{1}.3$	$-11\bar{4}\ 814$	$-11\bar{5}\ 879$
100	$3\bar{9}.55$	$4\bar{5}.0$	$-11\bar{3}\ 075$	$-11\bar{7}\ 575$
150	$4\bar{5}.0$	$6\bar{\bar{2}}.3$	$-11\bar{0}\ 960$	$-12\bar{0}\ 300$
200	$4\bar{8}.0$	$7\bar{\bar{5}}.7$	$-10\bar{8}\ 660$	$-12\bar{3}\ 760$
250	$5\bar{0}.0$	$8\bar{\bar{6}}.5$	$-10\bar{6}\ 250$	$-12\bar{7}\ 850$
273.1	$50.\bar{\bar{5}}$	$9\bar{\bar{0}}.9$	$-10\bar{5}\ 090$	$-12\bar{9}\ 890$
298.1	$51.\bar{\bar{0}}$	$9\bar{\bar{5}}.4$	$-10\bar{3}\ 820$	$-13\bar{2}\ 220$

CuI (28)

0	0	0	$-\ 6\bar{8}\ 520$	$-\ 6\bar{8}\ 520$
50	$2\bar{8}.05$	$1\bar{9}.2$	$-\ 6\bar{7}\ 892$	$-\ 6\bar{8}\ 852$
100	$4\bar{1}.9$	$4\bar{\bar{3}}.7$	$-\ 6\bar{6}\ 080$	$-\ 7\bar{0}\ 450$
150	$4\bar{7}.1$	$6\bar{\bar{1}}.6$	$-\ 6\bar{3}\ 830$	$-\ 7\bar{3}\ 080$
200	$5\bar{0}.0$	$7\bar{\bar{5}}.5$	$-\ 6\bar{1}\ 420$	$-\ 7\bar{6}\ 520$
250	$5\bar{2}.1$	$8\bar{\bar{6}}.8$	$-\ 5\bar{8}\ 870$	$-\ 8\bar{0}\ 570$
273.1	$5\bar{3}.0$	$9\bar{\bar{1}}.4$	$-\ 5\bar{\bar{7}}\ 690$	$-\ 8\bar{2}\ 590$
298.1	$5\bar{3}.8$	$9\bar{\bar{6}}.0$	$-\ 5\bar{\bar{6}}\ 330$	$-\ 8\bar{4}\ 930$

AgCl (19, 21)

0	0	0	$-11\bar{4}\ 090$	$-11\bar{4}\ 090$
50	$2\bar{8}.15$	$2\bar{\bar{0}}.8$	$-11\bar{3}\ 408$	$-11\bar{4}\ 448$
100	$4\bar{1}.0$	$4\bar{\bar{5}}.0$	$-11\bar{1}\ 650$	$-11\bar{6}\ 150$
150	$4\bar{6}.0$	$6\bar{\bar{2}}.8$	$-10\bar{9}\ 490$	$-11\bar{8}\ 920$
200	$4\bar{9}.0$	$7\bar{\bar{6}}.4$	$-10\bar{7}\ 110$	$-12\bar{2}\ 390$
250	$5\bar{1}.4$	$8\bar{7}.5$	$-10\bar{4}\ 620$	$-12\bar{6}\ 495$
273.1	$53.\bar{\bar{1}}$	$9\bar{\bar{2}}.1$	$-10\bar{3}\ 410$	$-12\bar{8}\ 510$
298.1	$53.\bar{\bar{8}}$	$9\bar{\bar{6}}.7$	$-10\bar{2}\ 090$	$-13\bar{0}\ 890$

AgI (21)

0	0	0	$-\ 6\bar{3}\ 220$	$-\ 6\bar{3}\ 220$
50	$3\bar{1}.9$	$2\bar{8}.65$	$-\ 6\bar{2}\ 388$	$-\ 6\bar{3}\ 820$
100	$4\bar{5}.7$	$5\bar{\bar{5}}.7$	$-\ 6\bar{0}\ 390$	$-\ 6\bar{5}\ 960$
150	$5\bar{0}.8$	$7\bar{\bar{5}}.4$	$-\ 5\bar{8}\ 010$	$-\ 6\bar{9}\ 310$
200	$5\bar{2}.7$	$9\bar{\bar{0}}.0$	$-\ 5\bar{5}\ 480$	$-\ 7\bar{3}\ 480$
250	$5\bar{3}.8$	$10\bar{\bar{2}}.0$	$-\ 5\bar{2}\ 640$	$-\ 7\bar{8}\ 140$
273.1	$5\bar{4}.1$	$10\bar{\bar{6}}.4$	$-\ 5\bar{1}\ 440$	$-\ 8\bar{0}\ 540$
298.1	$5\bar{4}.4$	$11\bar{\bar{1}}.3$	$-\ 5\bar{0}\ 120$	$-\ 8\bar{3}\ 320$

FeS_2 (8)

0	0	0	$-14\bar{4}\ 750$	$-14\bar{4}\ 750$
50	$2.\bar{6}4$	$0.\bar{\bar{8}}3$	$-14\bar{4}\ 720$	$-14\bar{4}\ 761$
100	$1\bar{8}.84$	$\bar{7}.11$	$-14\bar{4}\ 226$	$-14\bar{4}\ 937$
150	$3\bar{6}.66$	$1\bar{\bar{8}}.4$	$-14\bar{2}\ 870$	$-14\bar{5}\ 630$
200	$4\bar{9}.59$	$3\bar{\bar{0}}.75$	$-14\bar{0}\ 680$	$-14\bar{6}\ 830$
250	$5\bar{7}.3$	$4\bar{\bar{2}}.7$	$-13\bar{7}\ 990$	$-14\bar{8}\ 640$
273.1	$60.\bar{\bar{0}}$	$4\bar{\bar{7}}.8$	$-13\bar{6}\ 630$	$-14\bar{9}\ 730$
298.1	$62.\bar{\bar{1}}$	$5\bar{\bar{3}}.0$	$-13\bar{5}\ 100$	$-15\bar{0}\ 900$

MgO (10, 26)

T, °K	C_p	S	H	$F = H - TS$
0	0	0	−600̅ 680	−600̅ 680
50	0.4̅2	0.2̅9	−600̅ 660	−600̅ 674
100	6̅.91	2.1̿8	−600̅ 497	−600̅ 715
150	19̅.3	7.4̿5	−599̅ 822	−600̅ 940
200	27̅.65	14̅.10	−598̅ 590	−601̅ 410
250	34̅.35	21̅.0	−597̅ 010	−602̅ 260
273.1	36̅.9	24̅.2	−596̅ 180	−602̅ 780
298.1	39̅.6	27̅.5	−595̅ 230	−603̅ 430

CaO (21)

0	0	0	−627̅ 740	−627̅ 740
50	2.8̿5	0.8̅8	−627̅ 705	−627̅ 749
100	16̅.4	6.5̿6	−627̅ 251	−627̅ 907
150	28̅.8	15̅.4	−626̅ 070	−628̅ 370
200	37̅.3	24̅.75	−624̅ 460	−629̅ 400
250	41̅.3	33̿.4	−622̅ 570	−630̅ 920
273.1	42̅.9	37̿.18	−621̅ 620	−631̅ 770
298.1	44̅.2	40̿.8	−620̅ 540	−632̅ 740

CaF_2 (8)

0	0	0		
50	4.2̿7	1.5̅9		
100	19.3̿	8.9̿9		
150	31̅.4	18̅.99		
200	38̅.1	29̅.95		
250	42̅.5	37̅.85		
273.1	44̅.0	41̅.7		
298.1	45.1̿	45̅.6		

$CaCO_3$, Calcite (21)

0	0	0	−1 191̅ 410	−1 191̅ 410
50	15.9̿	7.0̿7	−1 191̅ 118	−1 191̅ 468
100	41̅.1	25.7̿	−1 189̅ 690	−1 192̅ 260
150	57̅.4	45̅.8	−1 187̅ 260	−1 194̅ 140
200	68̅.1	63̅.6	−1 184̅ 250	−1 196̅ 950
250	75̅.6	79̅.2	−1 180̅ 710	−1 200̅ 510
273.1	78.2̿	85̅.9	−1 178̅ 990	−1 202̅ 390
298.1	80.4̿	92̅.6	−1 177̅ 000	−1 204̅ 600

LiH (11)

0	0	0		
50	0.8̅4	0.2̅5		
100	6̅.28	2.0̿9		
150	14̅.68	6̅.19		
200	23̅.3	11̅.68		
250	30̅.3	17̅.6		
273.1	32̅.35	20̅.45		
298.1	34̅.5	23̅.55		

NaCl (20)

T, °K	C_p	S	H	$F = H - TS$
0	0	0	−396̅ 520	−396̅ 520
50	15.0̿8	6.1̿5	−396̅ 263	−396̅ 570
100	34.9̿5	23̅.75	−394̅ 866	−397̅ 241
150	42.7̿	39̅.7	−392̅ 910	−398̅ 860
200	46.7̿	52̅.6	−390̅ 720	−401̅ 220
250	49.0̿	63̅.2	−388̅ 390	−404̅ 190
273.1	49.6̿	67̅.6	−387̅ 270	−405̅ 770
298.1	50.0̿	72̅.0	−386̅ 000	−407̅ 400

KBr (20)

0	0	0	−386̅ 190	−386̅ 190
50	29.5̿	16̅.14	−385̅ 587	−386̅ 397
100	42.6̿	42̅.1	−383̅ 675	−387̅ 885
150	46.8̿	60̅.2	−381̅ 440	−390̅ 490
200	48.9̿	74̅.1	−379̅ 090	−393̅ 890
250	50.6̿	85̅.0	−376̅ 660	−397̅ 860
273.1	51.3̿	89̅.5	−375̅ 480	−399̅ 880
298.1	51.8̿	94̅.2	−374̅ 220	−402̅ 220

KCl (20)

0	0	0	−421̅ 300	−421̅ 300
50	21.1̿	9.7̅1	−420̅ 914	−421̅ 399
100	39.6̿	31.0̿	−419̅ 319	−422̅ 419
150	45.1̿	50.2̿	−417̅ 190	−424̅ 720
200	47.7̿	63.5̿	−414̅ 860	−427̅ 560
250	49.4̿	74.2̿	−412̅ 400	−430̅ 900
273.1	50.1̅	78.6̿	−411̅ 280	−432̅ 700
298.1	50.6̅	83.1̿	−410̅ 000	−434̅ 780

$Al_2(SO_4)_3Cs_2SO_4.12H_2O$ (36)

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(For a key to the periodicals see end of volume)

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THERMAL EFFECTS ACCOMPANYING PHYSICAL AND CHEMICAL PROCESSES

LATENT HEATS OF FUSION

R. DE FORCRAND AND L. GAY

Scope of the Tables.—The data given in the following tables are based solely upon the best available direct calorimetric determinations and do not take into account the values, sometimes more reliable, which can be computed by indirect methods. For such values the reader should consult the appropriate sections of I. C. T. as indicated in the index under, "Fusion, heat of."

Calorimetric Methods. *A.*—m grams of the pure substance which has been in the crystalline state for a long period of time (hereafter referred to as the "stable" crystalline form) is taken at a temperature slightly below its fusion point t_F and is introduced into a calorimeter, the temperature of which is slightly above t_F. The final state of the substance is liquid. The total effect produced is composed of (*a*) the heat absorbed by the solid up to t_F, (*b*) the heat absorbed by the liquid between t_F and the final temperature, and (*c*) the heat of fusion. Knowing the two specific heats, the heat of fusion, L_F, at the M. P., is obtained by difference.

B.—As in Method *A*, but in the reverse order, the liquid substance slightly above its fusion point is introduced into the calorimeter, where it crystallizes. This experiment gives directly the heat of solidification, L_D, rather than the heat of fusion, L_F. The heat of solidification is sometimes less than the heat of fusion, because at the moment of solidification the substance does not always liberate its entire heat of fusion. The determination of L_F is therefore preferable.

C.—Two samples of the pure substance are employed, one in the "stable" crystalline form, the other in the form of the supercooled liquid, and both at the same temperature, which is substantially that of the calorimeter. In two separate experiments the substance is brought to the same final state which may be anything, but is the same for the two samples. The difference between the two values found gives directly the heat of fusion. In this case there is no difference between L_F and L_D if the crystalline sample employed is in the "stable" form. In most cases the final state in such an experiment is a solution in the calorimetric liquid, but obviously it might be any state. The value finally obtained by Method *C* is the heat of fusion at the temperature of the calorimeter and is identical with the heat of fusion at the melting point only in case the calorimeter is operated in the neighborhood of this temperature.

D.—The super-cooled substance is maintained in the calorimeter until temperature equilibrium is secured, and crystallization is then produced by seeding. This method gives L_D.

E.—In this method (Wigand) the "stable" crystalline substance is melted in the calorimeter by means of a measured amount of electrical energy. This method gives L_F directly, but requires a calorimetric liquid with a melting point lower than t_F.

F.—The method of thermo-analysis (W. Plato) gives reliable results in cases where L_F is known for an analogous substance having approximately the same melting point. The method is a relative one.

G.—In the method of L. Meyer, a Bunsen calorimeter is employed, the calorimetric liquid being the pure substance at its melting point. The determination consists in measuring the variation in volume, ΔV, which accompanies the fusion of 1 g of the substance. In a second experiment, a known quantity of heat Q is introduced into the calorimeter electrically and the accompanying volume change $\Delta V'$ is measured. $\Delta V'/\Delta V$ gives the mass m of the substance melted. The heat of fusion is then

$$\frac{Q}{m} = \frac{Q}{\Delta V'}\Delta V.$$

The temperature t_F being constant, a knowledge of the specific heats is unnecessary.

H.—Special methods, for which see the literature cited.

I.—Method not given by the author.

Conversion Factors.—1 Kilojoule per g = 238.9 cal$_{15}$ g^{-1} = 430.1 BTU$_{60}$ lb.$^{-1}$ = 9.869 l-atm. g^{-1} = 2.778 × 10^{-4} kw hr g^{-1}. For other factors, *v.* Vol. I, p. 24.

NON-METALLIC ELEMENTARY SUBSTANCES*

Formula	M. P., °C	Joule per g	Kilojoule per g-atom	Method	Lit.
A	−190	28.1	1.12	*A*	(18)
O	−219	13.8	0.221	*A*	(18)
H		63 ± 6	0.063	*E*	(42)
		58.6 ± 0.3	0.0591	*A*	(70)
Cl	−103.5	96.$_1$	3.40$_8$	*A, E*	(17, 18.5)
Br	− 7.32	67.7 ± 0.7	5.41$_0$	*A*	(62)
S	115	39.21$_5$	1.257	*B*	(54)
	118.95	43.6 ± 1.2	1.40	*E*	(84)
	119	55.2	1.77	*B*	(40)
		37.05	1.188	*E*	(74)
Te	446				(90)
N	−210	25.5	0.36	*A*	(18)
P	44.2	21.07	0.6538	*B*	(54)

* For heats of fusion of metallic elementary substances, *v.* Vol. II, p. 458.

𝔅-TABLE.—CHEMICAL COMPOUNDS (STANDARD ARRANGEMENT) (*v.* Vol. III, p. viii)

Formula	M. P., °C	Joule per g	Kilojoule per g-formula-wt.	Method	Lit.
H_2O	0	333.6 ± 0.33	6.0099	*E*	(14.1)
H_2O_2	−1.7	310 ± 1.25	10.5 ± 0.04	*A*	(47)
HBr	−86	32.1	2.60	*E*	(18.5)
	−86.8	29.7	2.41	*E*	(87)
HCl	−114	58	2.11	*E*	(18.5)
	−114	54.6	1.99	*E*	(86)
$HCl.2H_2O$	−18.5	144.6$_5$	10.48$_5$	*C*	(8)
HI	−53	23.7$_6$	3.0$_4$	*E*	(18.5)
ICl(α)	27.2	68.75 ± 1.0	11.16 ± 0.16	*A*	(73)
ICl(β)	15.2 ± 1.3	58.6 ± 0.65	9.52 ± 0.1	*C, A*	(6, 73)
SO_3	−30	99.4	7.96	*C*	(30)
H_2SO_4	10.352	100.6 ± 0.7	9.865 ± 0.07	*A*	(57)
H_2SO_4.—(*Cont'd*)		95.$_5$	9.3$_6$	*A*	(43)
	10.49	108.7$_5$	10.66$_5$	*A*	(11)
$H_2SO_4.H_2O$	8.56*	163.6 ± 3.0	19 ± 0.35	*A*	(11, 46, 57)
$H_2S_2O_7$	35	75.0 ± 4	1.35	*D*	(1.5)
NO	−163	77	2.32	*E*	(18.5)
N_2O_4	−10.14	135 to 155.5	12.4 to 14.35	*A*	(61)
N_2O_5	29.5?	320.9$_5$?	34.66$_5$?	*I*	(3)
NH_3	−75	452.$_5$	7.7	*A*	(49)
	−77.6	35$_1$	5.9$_8$	*E*	(18.5)
HNO_3	−47	39.9$_5$	2.51$_5$	*C*	(3)
H_3PO_2	17.4	146.5	9.68	*C*	(78)
$POCl_3$	2	83	12.7	*A*	(81)
$AsBr_3$	31	37.4	11.75	*B*	(79)
$SbCl_3$	73.2	55.6$_5$	12.69	*B*	(79)
$SbBr_3$	94	40.8$_5$	14.77	*B*	(79)
Sb_2S_3	540	73.5	24.9	*B*	(35, 41)
CO	−206	33.5	0.094	*A*	(18)
CO_2	−56.2	189.6	8.35	*A*	(47.5)
For other C-compounds, *v.* 𝕮-Table					
$SiCl_4$	70.3	45.4$_2$	7.7$_5$	*E*	(44)
$TiCl_4$	−25	49.2$_7$	9.348	*E*	(44)
$SnCl_4$	−33	35.16 ± 0.8	9.160	*E*	(44)
$SnBr_4$	25.5	26.2 ± 0.1	11.5	*B, C*	(5, 79)
$PbCl_2$	485	87.5 ± 1.8	24.3	*B*	(16)
				F	(58)
	498	77.$_5$	21.5	*B*	(31)
$PbBr_2$	490	51.65 ± 1.5	18.96 ± 0.55	*B*	(16)
	488	41.5	15.2	*B*	(31)
PbI_2	375	48.1 ± 1.2	22.2 ± 0.55	*B*	(16)
TlCl	427	69.$_5$	16.7	*B*	(31)
TlBr	460	53	15.1	*B*	(31)
$TlOC_2H_5$		4.4	1.1	*C*	(26.5)
$Zn(NO_3)_2.6H_2O$	36.4	130	38.6	*B*	(63)
$Cd(NO_3)_2.4H_2O$	59.5	106	32.7	*B*	(63)
$HgBr_2$	235	53.6	19.32	*B*	(34)
HgI_2	250	41	18.6	*H*	(33)
$Cu(NO_3)_2.6H_2O$	24.4	123	36.4	*B*	(63)
AgCl	451	128.$_5$	18.4	*B*	(64)
	455	89	12.8	*B*	(31)
AgBr	430	52.$_5$	9.9	*B*	(31)
$AgNO_3$ *cf.*(89)	208	74.25 ± 0.75	12.6 ± 0.1	*H*	(33)
	218	63.$_5$	10.8	*B*	(31)
OsO_4	40.1	56.6 ± 1	14.4 ± 0.2	*G*	(81.5)
$Mn(NO_3)_2.6H_2O$	25.8	120.$_5$	34.6	*B*	(63)
$Co(NO_3)_2.6H_2O$		126.$_5$	36.8	*B*	(63)
$Ni(NO_3)_2.6H_2O$	56.7	152.$_5$	44.3	*B*	(63)
$MgCl_2.6H_2O$	116.7	172.$_5$	35.1	*B*	(63)
$Mg(NO_3)_2.6H_2O$	90	160	41	*B*	(63)
$CaCl_2$	773.9	227.15 ± 1.35	25.21 ± 0.14	*F*	(58, 67)
$CaCl_2.6H_2O$	29 ± 0.5	170.5	37.3	*B*	(55)
$Ca(NO_3)_2.4H_2O$	42.1 ± 0.1	142.2 ± 2.2	33.6 ± 0.5	*A*	(57)
				I	(76)
$SrCl_2$	872.3	106.5 ± 0.5	16.85 ± 0.05	*F*	(58)
$BaCl_2$	958.9	115	24	*F*	(58)
$LiNO_3$	250	370.$_5$	25.5$_5$	*B*	(31)
Li_2SiO_3		335.$_5$	30.2	*F*	(68)
$Li_2SiO_3.Li_2O$		260	31.1	*F*	(68)
NaOH	318.4	167.$_5$	6.7	*F*	(37)
NaF	992.2	779	32.71	*F*	(58.1)
NaCl	804.3	517	30.2	*F*	(58)
$NaClO_3$	255	205.0 ± 2.5	21.825 ± 0.27	*B*	(23, 31)
$Na_2SO_4.10H_2O$	31	214.$_5$	69	*B*	(12)
	31.5	239	77.0	*B*	(45)
$Na_2S_2O_3.5H_2O$		200.0 ± 0.5	49.65 ± 0.15	*B*	(45)
$NaNO_3$	333	189.$_5$	16.1	*B*	(31)
$Na_2HPO_4.12H_2O$	36.1	279.$_5$	100.1	*B*	(55)
$Na_2CrO_4.10H_2O$	23 to 30	164.0 to 150.8	56.12 to 51.59	*C*	(5)
KOH	360.4	119.$_5$	6.72	*F*	(37)
KF	859.9	452	26.3	*F*	(58.1)
KCl	772.3	310 ± 50	23.1 ± 3.7	*F*	(58)
KNO_3	308	106.$_5$	10.8	*B*	(31)
$K_2Cr_2O_7$	397	124.$_5$	36.7	*B*	(31)
RbOH	301	66	6.7$_5$	*F*	(37)
RbCl		159	19.2	*F*	(58)
CsOH	272.3	45	6.7	*F*	(37)

* ±0.06.

ℭ-Table
The ℭ-Arrangement (*v.* Vol. III, p. viii)

Formula	Name	M. P., °C	Joule per g	Kilojoule per g-formula-wt.	Method	Lit.
CCl_4	Carbon tetrachloride	−24	17.4 ± 0.25	2.68	*E*	(44)
CH_2N_2	Cyanamide	42.9	208.5 ± 3	11.27	*B*	(60)
CH_2O_2	Formic acid	8.0 ± 0.6	246.5 ± 1.9	11.34	*A, B*	(32, 56)
CH_4	Methane	−182.6	60.8	0.974	*E*	(18.5)
CH_4O	Methyl alcohol	−97	68.6	2.20	*A*	(48)
		−97.8	92.2	2.95	*E*	(53.5)
$C_2HCl_3O_2$	Trichloroacetic acid	59.1	36	5.9	*B*	(57)
$C_2H_2Cl_2O_2$	Dichloroacetic acid	10.8	$59._5$	7.6_5	*B*	(57)
$C_2H_3Br_3O_2$	Bromal hydrate	46	70.7_5	21.1_5	*B*	(10)
$C_2H_3ClO_2$	Chloroacetic acid (α)	61.2	130	12.3	*B*	(57)
	Chloroacetic acid (β)	56	147	13.8	*B*	(57)
$C_2H_3Cl_3O_2$	Chloral hydrate		138.9	22.97	*C*	(4)
$C_2H_4Br_2$	Ethylene dibromide	9.55	56.62	10.637	*B*	(14)
$C_2H_4O_2$	Acetic acid	16.58 ± 0.04	187.1 ± 6.7	11.23	*B**	(46, 56)
		16.7	181	10.9	*E*	(53.7)
C_2H_6O	Ethyl alcohol	−114.4	104.2 ± 3.7	4.80	*A, E*	(29, 53.5)
$C_2H_6O_2$	Glycol	−11.5	181.1	11.24	*A*	(24)
		−12.3	174	10.8	*E*	(53.5)
$C_3H_4O_2$	Acrylic acid	13	155	11.2	*I*	(66)
$C_3H_5N_3O_9$	Trinitroglycerol	12.3	96.3_5	21.88	*B*	(52)
	Stable form		21.8†	4.95†	*D*	(38)
	Metastable form	13	138.9†	31.5†	*D*	(38)
C_3H_6O	Acetone	−95.5	98	5.69	*E*	(53.7)
		−94.6	82	4.76	*B*	(48)
$C_3H_7NO_2$	Urethane	48.7	171	15.2	*B*	(19)
C_3H_8O	Isopropyl alcohol	−88.5	88	5.34	*E*	(53.7)
$C_3H_8O_3$	Glycerol	18	198.8	18.3	*B*	(28)
$C_4H_4N_2$	Succinonitrile	54.5	49	3.9_2	*I*	(76)
$C_4H_4O_3$	Succinic anhydride	119	204	20.4	*I*	(76)
$C_4H_6O_2$	Crotonic acid$_{(\alpha)}$	67.4	106.0	9.11	*B*	(10)
	Crotonic acid$_{(\alpha)}$	71.4	$152._4$ ± 4	13.1	*B*	(46.5)
	Crotonic acid$_{(cis)}$	71.23	146.1_5	12.57_5	*B*	(9.1)
$C_4H_6O_4$	Methyl oxalate	49.5	$178._5$	21.0_5	*B*	(10)
$C_4H_7Cl_3O_2$	Chloral alcoholate	9	100.6	19.45_5	*C*	(7)
$C_4H_8N_2S$	Thiosinamine	77	140	16.2_5	*B*	(89)
$C_4H_8O_2$	*n*-Butyric acid	−5.7	126	11.1	*E*	(53.6)
$C_4H_{10}O$	*n*-Butyl alcohol	89.2	125.3 ± 0.2	9.280	*E*	(53.5)
	tert.-Butyl alcohol	25.45	87.8	6.50_5	*C*	(25)
	tert.-Butyl alcohol	25.4	91.6	6.78	*E*	(53.6)
$C_5H_8O_3$	Levulinic acid	33	79.4	9.21_5	*C*	(8)
$C_5H_8O_4$	Glutaric acid	99.3	$156._5$	20.6_5	*B*	(36)
$C_5H_{12}O$	*tert.*-Amyl alcohol		$52._5$	4.6_5	*I*	(76)
$C_6H_3Br_3O$	2, 4, 6-Tribromophenol	93	56	18.5_5	*B*	(89)
C_6H_4BrCl	*o*-Bromochlorobenzene	−12.6	$64._5$	12.3_5	*I*	(51)
	m-Bromochlorobenzene	−21.2	64	12.2_5	*I*	(51)
	p-Bromochlorobenzene	64.6	98	18.7_5	*I*	(51)
C_6H_4BrI	*o*-Bromoiodobenzene	21	51	14.4_5	*I*	(51)
	m-Bromoiodobenzene	−9.3	43	12.2	*I*	(51)
	p-Bromoiodobenzene	90.1	$69._5$	19.6_5	*I*	(51)
$C_6H_4Br_2$	*o*-Dibromobenzene	18	53.5	12.6	*I*	(51)
	m-Dibromobenzene	−6.9	56	13.2	*I*	(51)
	p-Dibromobenzene	86 ± 1	86 ± 1	20.3	*B*‡	(9, 10)
$C_6H_4Br_2O$	2, 4-Dibromophenol	12	$58._5$	14.7_5	*C*	(83)
$C_6H_4Br_3N$	2, 4, 6-Tribromoaniline	122	$70._5$	23.2_5	*B*	(64)
$C_6H_4ClNO_2$	*m*-Chloronitrobenzene	43.8	123	19.4	*B*	(10)
		44.16	131.9	20.775	*B*	(9)
	p-Chloronitrobenzene	82	$89._5$	14.1	*B*	(10)
$C_6H_4Cl_2$	*o*-Dichlorobenzene	−17.5	88	12.9	*I*	(51)

* Also *C* (25, 80) and *G* (50). † Heat of crys. at 0°. ‡ Also *I* (51).

Formula	Name	M. P., °C	Joule per g	Kilojoule per g-formula-wt.	Method	Lit.
$C_6H_4Cl_2$	*m*-Dichlorobenzene	−24.4	86	12.6	*I*	(51)
	p-Dichlorobenzene	52.7 ± 0.2	124.2 ± 0.8	18.25	*B*	(10)
					I	(51)
$C_6H_4I_2$	*o*-Diiodobenzene	23.4	42.$_5$	14.1	*I*	(51)
	m-Diiodobenzene	34.2	48.3$_5$	15.9$_5$	*I*	(51)
	p-Diiodobenzene	129	67.8	22.4	*I*	(51)
$C_6H_4N_2O_4$	*o*-Dinitrobenzene	116.93	135.0 ± 4	22.84	*B*	(1.4)
	m-Dinitrobenzene	90.08	103.$_4$ ± 4	17.3$_6$	*B*	(1.4)
	p-Dinitrobenzene	173.5	167.$_4$ ± 4	28.1	*B*	(1.4)
$C_6H_4O_2$	Quinone	112.85 ± 0.5	171.$_0$ ± 4	18.4$_6$	*B*	(46.5)
C_6H_5BrO	*p*-Bromophenol	64	85.8 ± 1.3	14.85	*C*	(83)
$C_6H_5NO_2$	Nitrobenzene	5.72 ± 0.10	94.25 ± 0.25	11.6	*G, I*	(50, 76)
$C_6H_5NO_3$	*o*-Nitrophenol	42.8	112	15.6	*B*	(10)
		44.51	129.3$_5$	17.98	*B*	(9)
C_6H_6	Benzene	5.42 ± 0.02	127.0 ± 1.4	9.91	*A**	(9, 14) (22, 48)
		5.40	126.$_5$ ± 4	9.88	*B*	(1.4)
C_6H_6ClN	*p*-Chloroaniline	69	155.$_5$	19.8$_3$	*B*	(10)
$C_6H_6N_2O_2$	*o*-Nitroaniline	69.3	116.$_7$	16.1$_2$	*B*	(1.4)
	m-Nitroaniline	111.8	171.$_5$	23.7$_0$	*B*	(1.4)
	p-Nitroaniline	147.5	152.$_6$	21.1$_0$	*B*	(1.4)
C_6H_6O	Phenol	25.37	121.$_5$	11.4	*E*	(74)
$C_6H_6O_2$	*o*-Dihydroxybenzene	104.3	206.8	22.7$_6$	*B*	(1.4)
	m-Dihydroxybenzene	109.65 ± 0.5	193.$_4$	21.2$_9$	*B*	(1.4, 67)
	p-Dihydroxybenzene	172.3	246.$_0$	21.7$_0$	*B*	(1.4)
C_6H_7N	Aniline	−7.03	87.7	8.16	*A*	(25)
$C_6H_8N_2$	Phenylhydrazine	22.1	152.0 ± 0.6	16.43	*A*	(46)
$C_6H_8O_4$	Methyl fumarate	102	242.$_5$	34.9$_5$	*B*	(53)
$C_6H_{10}O_4$	Methyl succinate	18	149.5$_5$	21.84	*B*	(53)
$C_6H_{10}O_6$	*dl*-Dimethyl tartrate	87	147	26.2	*F*	(77)
	d-Dimethyl tartrate	49	90	16	*F*	(77)
$C_6H_{12}O$	Cyclohexanol	23.2 ± 0.8	17.55 ± 0.3	1.756	*B, C*	(26, 85)
$C_6H_{12}O_3$	Paraldehyde	12.6	104.7$_5$	13.83	*A*	(46)
$C_7H_5ClO_2$	*o*-Chlorobenzoic acid	140.2	164.$_5$ ± 4	25.7$_6$	*B*	(46.5)
	m-Chlorobenzoic acid	154.25	152.4 ± 4	23.8$_6$	*B*	(46.5)
	p-Chlorobenzoic acid	239.7	206 ± 4	32.3	*B*	(46.5)
$C_7H_5NO_4$	*o*-Nitrobenzoic acid	145.8	167.$_7$ ± 4	28.0$_2$	*B*	(46.5)
	m-Nitrobenzoic acid	141.1	115.$_5$ ± 4	19.3$_0$	*B*	(46.5)
	p-Nitrobenzoic acid	239.2	221.$_0$ ± 4	36.9$_0$	*B*	(46.5)
$C_7H_5N_3O_6$	2, 4, 6-Trinitrotoluene	79	93.5 ± 3.5	21.23	*I*	(14.2, 76)
$C_7H_6N_2O_4$	2, 4-Dinitrotoluene	70	110.$_5$	20.1	*I*	(76)
$C_7H_6O_2$	Benzoic acid	121.8	141.$_9$ ± 4	17.3	*B*	(46.5)
C_7H_7Br	*p*-Bromotoluene	27.6 ± 1.2	87.3 ± 3	14.93	*B*	(56)
					A	(46)
C_7H_7I	*p*-Iodotoluene	34	78.$_5$	17.1	*I*	(76)
$C_7H_7NO_2$	*o*-Aminobenzoic acid	145	148.$_5$ ± 4	20.3$_8$	*B*	(1.4)
	m-Aminobenzoic acid	180	159.$_2$ ± 4	21.8$_3$	*B*	(1.4)
	p-Aminobenzoic acid	188.5	152.$_6$ ± 4	20.9$_1$	*B*	(1.4)
C_7H_8O	*p*-Cresol	34	110	11.9	*B*	(10)
$C_7H_8O_2$	Dimethyl-γ-pyrone	132	235	29	*B*	(59)
C_7H_9N	*p*-Toluidine	40.01 ± 0.12	167.0 ± 2.4	17.88	*B*	(2, 14)
$C_8H_6Cl_4$	*o*-Tetrachloroxylene	86	88	21.4$_5$	*I*	(13)
	p-Tetrachloroxylene	95	92.5	22.5$_5$	*I*	(13)
$C_8H_8Br_2$	*o*-Xylene dibromide	95	101.5	26.79	*I*	(13)
	m-Xylene dibromide	77	89.8	23.7	*I*	(13)
$C_8H_8Cl_2$	*o*-Xylene dichloride	55	121.$_5$	21.2$_5$	*I*	(13)
	m-Xylene dichloride	34	111.5	19.5$_5$	*I*	(13)
	p-Xylene dichloride	100	137	23.9$_5$	*I*	(13)
$C_8H_8O_2$	Phenylacetic acid	74.9	106.$_5$	14.4$_5$	*B*	(10)
		76.58	125.6	17.09	*B*	(9)
		77	134	18.2	*B*	(64)

* *Also I*(21), *G*(50), *B*(53), *A*(9).

Formula	Name	M. P., °C	Joule per g	Kilojoule per g-formula-wt.	Method	Lit.
$C_8H_8O_2$	*o*-Toluic acid	103.7	148.2 ± 4	20.18	*B*	(1.4)
	m-Toluic acid	108.75	115.5 ± 4	15.74	*B*	(1.4)
	p-Toluic acid	179.6	167 ± 4	22.71	*B*	(1.4)
$C_8H_9NO_2$	Hydroxyacetanilide	91.3 ± 0.1	140.6	21.26	*B*	(1.4)
C_8H_{10}	*p*-Xylene	16	164.5	17.45	*I*	(13)
$C_8H_{10}O_2$	Veratrol	22.7	114.9 ± 1.25	15.87	*B, A*	(46, 64)
$C_8H_{16}O_2$	*n*-Caprylic acid	16.34	148.2	21.36	*B*	(27)
$C_9H_8O_2$	Allocinnamic acid	58	114.5	17		(65)
$C_9H_8O_2$	Cinnamic acid	133	152.85	22.635	*B*	(53)
$C_9H_{10}O_2$	Hydrocinnamic acid	48	117.75	32.74	*B*	(53)
$C_9H_{18}O_2$	*n*-α-Pelargonic acid	12.35	128.2	20.27	*B*	(27)
	n-β-Pelargonic acid		163.4	25.84	*B*	(27)
$C_{10}H_7NO_2$	α-Nitronaphthalene	56	106.5	18.43	*B*	(2)
$C_{10}H_8$	Naphthalene	79.9 ± 1.1	148.9 ± 0.4	19.07	*B*	(1, 2, 46.5, 53, 57)
$C_{10}H_8O$	α-Naphthol	95	163 ± 4	23.5	*B*	(46.5)
	β-Naphthol	120.6	131 ± 4	18.8	*B*	(46.5)
$C_{10}H_8O_2$	Methyl phenylpropiolate	18	95.75	15.325	*B*	(53)
$C_{10}H_9N$	α-Naphthylamine	47.5	93.5	13.35	*B*	(10)
		48.9	92.05	13.17	*B*	(14)
		50.1	107.1 ± 0.8	15.33	*B*	(71)
$C_{10}H_{10}$	1, 4-Dihydronaphthalene	150	21.85	2.84	*I*	(76)
$C_{10}H_{10}O_2$	Methyl cinnamate	34.5 ± 1.5	111 ± 1.5	17.99	*I, B*	(53, 76)
$C_{10}H_{12}O$	Anethole	21.5	108.0 ± 1.3	16 ± 0.19	*B*	(46)
$C_{10}H_{14}O$	Thymol	48.5	115	17.3	*B*	(19)
$C_{10}H_{15}BrO$	Bromocamphor		174	40.2	*B*	(2)
$C_{10}H_{15}NO$	*d*-Carvoxime	71.5	97.5	16.1	*F*	(77)
	l-Carvoxime	71	98	16.15	*F*	(77)
	dl-Carvoxime	91	103	17.0	*F*	(77)
$C_{10}H_{20}O$	*l*-α-Menthol	42	78 ± 1	12.2	*B*	(10)
$C_{10}H_{20}O_2$	*n*-Capric acid	31.2	162.7	28.01	*B*	(27)
$C_{11}H_{22}O_2$	*n*-Undecylic acid$_{(\alpha)}$	28.25	134.8	25.09	*B*	(27)
	n-Undecylic acid$_{(\beta)}$		179.6	33.43	*B*	(27)
$C_{12}H_9N$	Carbazole	236	176	29.45	*I*	(76)
$C_{12}H_{10}$	Diphenyl	71	109.2 ± 0.6	16.84	*B*	(82)
$C_{12}H_{10}N_2$	Azobenzene	69.1	121	22.1	*B*	(19)
		66	117	21.25	*B*	(10)
		68	135.6	24.69	*B*	(53)
$C_{12}H_{10}N_2O$	Azoxybenzene	34.6	90.5	17.9	*B*	(10)
$C_{12}H_{11}N$	Diphenylamine	53.4 ± 0.6	105.6 ± 5.3	17.86	*B*	(9, 71)
$C_{12}H_{12}N_2$	Hydrazobenzene	134	95.75	17.63	*I*	(76)
$C_{12}H_{14}O_4$	Apiol	29.26	108.0 ± 0.2	23.99	*B*	(75)
$C_{12}H_{24}O_2$	*n*-Lauric acid	43.85 ± 0.15	183 ± 2	36.63	*B*	(72)
					B	(27)
$C_{13}H_{10}O$	Benzophenone	48.25 ± 0.25	98.5 ± 0.55	17.95	*B*	(10, 75)
$C_{13}H_{12}$	Diphenylmethane	26.3	105.5	17.7	*I*	(76)
$C_{13}H_{13}N$	Benzylaniline	36	91.5	16.75	*I*	(76)
$C_{14}H_8O_2$	Anthraquinone	282	156.9 ± 1.2	32.64	*B*	(39)
$C_{14}H_{10}$	Anthracene	216.55	162 ± 0.4	28.85	*B*	(39)
$C_{14}H_{10}$	Phenanthrene	98.2 ± 1.8	101.5 ± 2.5	18.1	*B*	(64)
$C_{14}H_{10}$	Tolane	60	120.05	21.38	*B*	(53)
$C_{14}H_{10}O_2$	Benzil	94.94	92.7	19.45	*B*	(9)
$C_{14}H_{12}$	Dihydrophenanthrene	94	73.45	13.25	*B*	(53)
$C_{14}H_{12}$	Stilbene	124	167	30.2	*I*	(76)
$C_{14}H_{14}$	Dibenzyl	51	129.85	23.645	*I*	(76)
$C_{14}H_{28}O_2$	Myristic acid		198.75	45.35	*B*	(72)
$C_{16}H_{32}O_2$	Palmitic acid	55	164	42.05	*B*	(10)
$C_{16}H_{34}O$	Cetyl alcohol	47	141.5	34.25	*I*	(76)
$C_{18}H_{14}O_3$	Cinnamic anhydride	48	117.75	32.74	*B*	(53)
$C_{18}H_{34}O_2$	Elaidic acid	47	218	61.55	*I*	(76)
$C_{18}H_{36}O_2$	Stearic acid	64	199	56.5	*B*	(10)
$C_{19}H_{16}$	Triphenylmethane	92.3	74.5 ± 0.8	18.2	*B*	(39)
$C_{57}H_{110}O_6$	Tristearin	56	191	170	*I*	(76)

LITERATURE

(For a key to the periodicals see end of volume)

(1) Alluard, *6*, **57**: 438; 57. (1.4) Andrews, Lynn and Johnston, *1*, **48**: 1274; 26. (1.5) Auerbach, *7*, **121**: 337; 26. (2) Battelli, *24*, **3**: 1781; 84. Battelli and Martinetti, *22*, **1**: 621; 85. (3) Berthelot, *6*, **6**: 145; 75. (4) Berthelot, *6*, **12**: 559; 77. (5) Berthelot, *34*, **87**: 573; 78. *6*, **15**: 185; 78. (6) Berthelot, *6*, **21**: 370; 80. (7) Berthelot, *6*, **27**: 389; 82. (8) Berthelot, *B73*. (9) Bogojawlenski, in *B57*. (9.1) Bogojawlenski, *185*, **1905 II**: 945.

(10) Bruner, *25*, **27**: 2102; 94. (11) Brönsted, *7*, **68**: 693; 09. (12) Cohen, *7*, **14**: 53; 94. (13) Colson, *34*, **104**: 428; 87. (14) Demerliac, *51*, **7**: 591; 98. (14.1). Dickinson and Osborne, *31A*, **12**: 49; 15. (14.2) E. I. Dupont de Nemours & Co., Wilmington, Del., *0*. (15) Efremov, *134*, **13**: 765; 19. (16) Ehrhardt, *8*, **24**: 215; 85. (17) Estreicher and Staniewski, *180*, **1910A**: 349. (18) Eucken, *88*, **18**: 4; 16. (18.5) Eucken and Karwat, *7*, **112**: 467; 24. (19) Eijkmann, *7*, **4**: 497; 89.

(20) Favre and Silbermann, *6*, **37**: 406; 53. (21) Ferche, *Diss.*, Halle, 1890. *8*, **44**: 265; 91. (22) Fischer, *8*, **28**: 400; 86. (23) Foote and Levy, *11*, **37**: 494; 07. (24) de Forcrand, *34*, **132**: 569; 01. (25) de Forcrand, *34*, **136**: 945, 1034; 03. (26) de Forcrand, *34*, **154**: 1767; 12. (26.5) de Forcrand, *34*, **182**: 1191; 26. (27) Garner and Randall, *4*, **125**: 881; 24. (28) Gibson and Giauque, *1*, **45**: 93; 23. (29) Gibson, Parks and Latimer, *1*, **42**: 1542; 20.

(30) Giran, *27*, **13**: 1049; 13. (31) Goodwin and Kalmus, *2*, **28**: 1; 09. (32) Guillot, *B59*. (33) Guinchant, *34*, **145**: 68, 320; 07. (34) Guinchant, *34*, **149**: 479; 09. (35) Guinchant and Chrétien, *34*, **138**: 1269; 04. (36) Hess, *8*, **35**: 410; 88. (37) Hevesy, *7*, **73**: 667; 10. (38) Hilbert and Fuller, *1*, **35**: 978; 13. (39) Hildebrand, Duschak, Foster and Beebe, *1*, **39**: 2293; 17.

(40) Iitaka, *159*, **8**: 99; 19. (41) Jaeger, *64V*, **20**: 497; 11. (41) Jaeger and van Klooster, *93*, **78**: 245; 12. (42) Keesom and Onnes, *168*, No. **153a**; 18. *64P*, **20**: 1000; 18. (43) Knietsch, in Hantzsch, *7*, **61**: 257; 08. (44) Latimer, *1*, **44**: 90; 22. (45) Leenhardt and Boutaric, *34*, **154**: 113; 12. *27*, **13**: 651; 13. (46) Louguinine and Dupont, *27*, **9**: 219; 11. (46.5) Lynn, *Thesis*, Yale, 1925. (47) Maass and Thatcher, *1*, **42**: 2548; 20. (47.5) Maass and Barnes, *5*, **111**: 224; 26. (48) Maass and Waldbauer, *1*, **47**: 1; 25. (49) Massol, *34*, **134**: 653; 02.

(50) Meyer, *7*, **72**: 225; 10. (51) Narbutt, *9*, **24**: 339; 18. **25**: 51; 19. (52) Nauckhoff, *92*, **18**: 11; 05. (53) Padoa, *22*, **28 II**: 239; 19. (53.5) Parks, *1*, **47**: 338; 25. (53.6) Parks and Anderson, *1*, **48**: 1506; 26. (53.7) Parks and Kelley, *1*, **47**: 2089; 25. (54) Person, *6*, **21**: 295; 47. (55) Person, *6*, **27**: 250; 49. (56) Pettersson, *52*, **24**: 129, 293; 81. (57) Pickering, *5*, **49**: 11; 91. (58) Plato, *7*, **55**: 721; 06. (58.1) Plato, *7*, **58**: 350; 07. (59) Poma, *36*, **41 II**: 518; 11.

(60) Pratolongo, *22*, **22 II**: 716; 13. (61) Ramsay, *7*, **5**: 221; 90. (62) Regnault, *6*, **26**: 278; 49. (63) Riesenfeld and Milchsack, *93*, **85**: 401; 14. (64) Robertson, *4*, **81**: 1233; 02. (65) Roth, in Meyer, *9*, **17**: 976; 11. (66) Riiber and Schetelig, *7*, **48**: 345; 04. (67) Sackur, *7*, **78**: 550; 11. (68) Schwarz and Sturm, *25*, **47**: 1730; 14. (69) Shükarev, *7*, **71**: 90; 10.

(70) Simon and Lange, *96*, **15**: 312; 23. (71) Stillmann and Swain, *7*, **29**: 705; 99. (72) Stohmann and Wilsing, *52*, **32**: 80; 85. (73) Stortenbeker, *7*, **10**: 183; 92. (74) Stratton and Partington, *3*, **43**: 436; 22. (75) Tammann, *7*, **29**: 51; 99. (76) Tammann, *188*, **1913**: 335. *7*, **85**: 273; 13. (77) Tammann, *7*, **87**: 357; 14. (78) Thomsen, *B23*, **II**: 212. (79) Tolloczko, *165*, **1901A**: 1.

(80) de Visser, *70*, **12**: 101; 93. (81) Walden, *93*, **68**: 307; 10. (81.5) Wartenberg, *13*, **440**: 97; 24. (82) Washburn and Read, *197*, **1**: 191; 15. (83) Werner, *6*, **3**: 567; 84. (84) Wigand, *7*, **63**: 273; 08. (85) Cauquil, *34*, **180**: 1208; 25. (86) Giauque and Wiebe, *1*, **50**: 101; 28. (87) Giauque and Wiebe, *1*, **50**: 2193; 28. (88) Magnus and Oppenheim, *93*, **168**: 305; 28. (89) Robertson, *182*, **18**: 139; 03.

(90) Umino, *47*, **28**: 381; 28.

LATENT HEAT OF VAPORIZATION

The values recorded in this section are based upon direct calorimetric determinations. For values based upon vapor pressure data, *see* the vapor pressure sections of Vol. III, p. 201, 204, 207, 213, 215, 302, and for metals, *v.* Vol. II, p. 458; Vol. III, p. 204.

CONVERSION FACTORS

1 joule = 0.2392 g-cal$_{20}$; = 0.2389 g-cal$_{15}$; = 2.778×10^{-7} kw. hr; = 0.7376 ft. lb.; = 9.870×10^{-3} l-atm.; = 9.482×10^{-4} BTU$_{60}$.

ELEMENTARY SUBSTANCES AND ATMOSPHERIC AIR*

Arthur Whitmore Smith

Symbol	l, g-cal$_{15}$ per g	L, kj per g-atom	At t, °C or p, mm	Lit.
A	37.6	6.28	−186°	(**10, 14**)
Br	43.7(?)	14.6(?)	+ 63°	(**6, 19**)
H_2	108	0.455	−252.8°	(10)
H_2	108	0.455	760 mm	(13)
H_2	109.2	0.460	600 mm	(14)
H_2	110.8	0.467	400 mm	(17)
H_2	112.2	0.473	200 mm	(22)
He	6	0.100	−268.6°	(**15, 16**)
I_2	24(?)	12.7	+184°	(11)
N_2	47.6	2.79_0	−195.55°	(1)
N_2	48.3	2.83_0	−198°	(10)
N_2	49.4	2.90_0	−202°	(14)
N_2	50.5	2.96_0	−206°	
N_2	51.6	3.02_5	−210°	
O_2	50.9	3.41_0	−182.9°	(1)
O_2	52.0	3.48_0	−188°	(2)
O_2	53.2	3.56_0	−194°	(10)
O_2	54.5	3.65_0	−200°	(13)
O_2	55.5	3.72_0	−205°	
P	130	17.0	+287°	(12)
S				(1.5)

* For metals, *v.* Vol. II, p. 458; Vol. III, p. 204.

Oxygen-Nitrogen Mixtures under One Atmosphere

The quantity recorded below is the difference in heat content between the liquid at its boiling point and a vapor of the same composition at its initial condensation temperature. Accuracy: 0.2 % absolute, 0.1 % relative (7.5).

% O_2 in liq	0	5	10	15	20	25	30
l, joule/g	119.8	201.1	202.4	203.7	204.9	206.2	207.4
% O_2 in liq	35	40	45	50	55	60	65
l, joule/g	208.5	209.5	210.4	211.2	212.0	212.7	213.3
% O_2 in liq	70	75	80	85	90	95	100
l, joule/g	213.7	214.1	214.4	214.4	214.1	213.9	213.4

LITERATURE

(For a key to the periodicals see end of volume)

(1) Alt, *8*, **19**: 739; 06. (1.5) Awbery, *67*, **39**: 417; 27. (2) Barschall, *9*, **17**: 345; 11. (3) Baxter and Grose, *1*, **37**: 1061; 15. (4) Baxter, Hickey and Holmes, *1*, **29**: 127; 07. (5) Beckmann and Liesche, *93*, **85**: 31; 14. (6) Berthelot and Ogier, *6*, **30**: 410; 83. (7) Crommelin, *64P*, **16**: 477; 13. *168*, No. **138c**; 13. (7.5) Dana, *65*, **60**: 241; 25. (8) Dewar, *182*, **14**: 241; 99. (9) Dodd, *1*, **42**: 1579; 20.

(10) Eucken, *26*, **18**: 4; 16. (11) Favre and Silbermann, 6, **37**: 406; 53. (12) Kaye and Laby, *Physical and chemical constants and some tables of mathematical functions*, New York, Longmans, 1921. (13) Keesom, *168*, No. **137e**; 11. (14) Mathias, Crommelin and Onnes, *34*, **176**: 939; 23. (15) Onnes, *64P*, **13**: 1093; 11. *168*, No. **119**: 11. (16) Onnes, *B3*, p. 1475. (17) Onnes and Keesom, *64P*, **16**: 440: 13. *168*, No. **137d**; 13. (18) Pellaton, *42*, **13**: 426; 15. (19) van der Plaats, quoted by (12).

(20) Richards, *143*, **187**: 581; 19. (21) Shearer, *2*, **17**: 469; 03. (22) Simon and Lange, *96*, **15**: 312; 23.

CHEMICAL COMPOUNDS

Farrington Daniels and J. Howard Mathews

l_v = latent heat of vaporization, joules per gram, at t, °C to produce saturated vapor at t°, the liquid being under its own vapor pressure during evaporation.

The values marked with an asterisk (*) were obtained by measuring the heat of condensation. All other values were obtained by measuring the input of electrical energy necessary to evaporate a given weight of liquid.

The results by condensation methods (*) are usually too low on account of premature condensation and are unreliable also, because the specific heat of the liquid is usually not accurately known. Most of the results published before 1900 may be too low by 10 joules or more.

For the substances marked with a dagger (†) the value given is taken from the detailed tables of the next section, p. 138.

Parentheses ( ) around the temperature indicate that the temperature was not recorded in the original communication and that the normal boiling point has been taken. The corresponding value of Trouton's ratio is also enclosed in parentheses.

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l_v = chaleur latente de vaporisation, joules par g à t, °C nécessaires pour produire la vapeur saturée à $t°$, le liquide étant sous sa propre tension de vapeur pendant l'évaporation.

Les valeurs marquées d'un astérisque (*) ont été obtenues en mesurant la chaleur de condensation. Toutes les autres valeurs ont été obtenues en mesurant l'apport d'énergie électrique, nécessaire pour évaporer un poids donné de liquide.

Les résultats obtenus par les méthodes de condensation (*) sont ordinairement trop faibles par le fait d'une condensation prématurée et sont aussi moins digne de confiance par le fait que la chaleur spécifique du liquide n'est généralement pas connue d'une façon précise. La plupart des résultats publiés avant 1900 peuvent être trop faibles de 10 joules et plus.

Pour les substances marquées d'une croix (†), la valeur donnée est extraite des tables détaillées de la section suivante, p. 138.

La température marquée entre parenthèses ( ) indique que la température n'a pas été mentionnée dans le mémoire original et que le point d'ébullition normal a été choisi. La valeur correspondante du rapport de Trouton est aussi mise entre parenthèses.

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l_v = latente Wärme der Verdampfung, in Joule pro Gramm bei t, °C für die Erzeugung von gesättigten Dampf bei $t°$. Während der Verdampfung befindet sich die Flüssigkeit unter ihrem eigenen Dampfdruck.

Die mit einem Stern (*) bezeichneten Werte sind durch Messung der Kondensations-Wärme erhalten worden. Alle anderen Werte sind durch Messung der angewandten elektrischen Energie erhalten, die notwendig ist, eine gegebene Gewichtsmenge Flüssigkeit zu verdampfen.

Die nach der Kondensationsmethode (*) erhaltenen Werte sind gewöhnlich zu niedrig, einmal wegen der vorzeitigen Kondensation, dann aber auch deshalb, weil die spezifische Wärme der Flüssigkeit gewöhnlich nicht genau bekannt ist. Viele der Werte die vor dem Jahre 1900 publiziert worden sind, dürften deshalb um etwa 10 oder mehr Joule zu niedrig sein.

Für die mit einem Schwert (†) bezeichneten Stoffe ist der angegebene Wert einer besonderen Tabelle des folgenden Abschnittes, S. 138, entnommen.

Die in Klammer ( ) gesetzten Temperaturen bedeuten, dass diese nicht in der Originalmitteilung angegeben ist und der normale Siedepunkt genommen ist. Der entsprechende Trouton'sche Quotient ist ebenfalls in Klammer gesetzt.

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l_v = calore latente di vaporizzazione, joules per g necessari a t, °C per produrre vapore saturo a $t°$, supponendo il liquido durante l'evaporazione sotto la sua tensione di vapore.

I valori segnati con un asterisco (*) sono stati ottenuti misurando il calore di condensazione. Tutti gli altri sono stati ricavati dal consumo di energia elettrica necessaria ad evaporare un dato peso di liquido.

I risultati ottenuti con il metodo di condensazione (*) sono per lo più troppo bassi a causa di una condensazione prematura e sono incerti anche perchè il calore specifico dei liquidi in genere, non è esattamente conosciuto. La massima parte dei risultati pubblicati prima del 1900, possono essere più bassi di 10 joules o anche più.

Per le sostanze segnate con (†) il valore dato è preso dalle tabelle riportate nella sezione seguente a p. 138.

Le temperature chiuse tra parentesi ( ) significano che non trovandosi indicata la temperatura nella memoria originale si è preso il punto di ebollizione normale. Il valore corrispondente del rapporto di Trouton è anche chiuso tra parentesi.

$$\text{Trouton's ratio, } \frac{L_v}{T} = \frac{Ml_v}{273.1 + t}$$

𝔅-Table

Formula	t, °C	l_v at t, °C, joule per gram	Trouton's ratio, L_v/T	Lit.
H_2O†	100	2258	109.0	*v.* p. 138
HF	17	151$_0$	104	(33)*
HCl	− 84.3	413.$_1$	79.8	(23)
	− 85.0	443.1	85.8	(28.5)
HBr	− 69.9	203.$_6$	81.2	(23)
	− 66.72	217.7	85.3	(81)
HI	− 37.2	142.$_0$	77.1	(23)
SO_2†	− 10.08	397	96.7	*v.* p. 138
SO_3	53	496	122.1	(29)*
H_2S	− 61.4	552.$_2$	88.9	(23)
H_2SO_4	326	51$_1$	83.7	(65)*
S_2Cl_2	138	20$_7$	67.6	(62)*
	138	267	87.7	(33.5)
$SOCl_2$	82	22$_8$	76.4	(62)*
SO_2Cl_2	69.1	206.$_9$	81.6	(74)*
$S_2O_5Cl_2$	140	25$_6$	133.3	(63)*
$ClSO_3H$	151	46$_1$	126.7	(63)*
NH_3†	− 33.4	1369	98.1	*v.* p. 138
HNO_3	86.0	48$_1$	84.4	(6)*
N_2O†				*v.* p. 138
N_2O_4	18	39$_1$	123.6	(14)*
NH_4Cl (solid)	350	33$_0$		(53)*
PCl_3	78	21$_5$	84.2	(1)*
$Si(OCH_3)_4$	121	194	75.0	(40)
$Si(OC_2H_5)_4$	156	141	42.5	(61)*
CO	(−192)	211.1	(73.0)	(24)
CO_2†				*v.* p. 138
$SiCl_4$	57	151	77.7	(40)
$SnCl_4$	112	12$_7$	85.9	(1)*
BCl_3	10	16$_0$	66.3	(8)*

ℭ-Table—ℭ-Arrangement (*v.* Vol. III, p. viii)

Formula	Name	t, °C	l_v at $t°$	Lv/T	Lit.
CClN	Cyanogen chloride	13	56$_5$	121.4	9)*
CCl_4†	Carbon tetrachloride	76.75	194.3	85.4	*v.* p. 138
CS_2†	Carbon disulfide	46.25	352	83.8	*v.* p. 138
$CHCl_3$†	Chloroform	61.5	247	87.9	*v.* p. 138
CHN	Hydrocyanic acid	20	88$_0$	81.1	(9)*
CH_2Cl_2	Methylene chloride	40.5	329	89.1	(57)
CH_2O_2	Formic acid	101	502	61.8	(15)
CH_3Cl	Methyl chloride	− 23.8	428	75.1	(72)
		+ 15.0	402		(79.5)
		20.0	399		(79.5)
		25.0	396		(79.5)
CH_3I	Methyl iodide	(42)	192	(86.5)	(54)
CH_3NO_2	Nitromethane	99.9	565	92.5	(57)
CH_4	Methane	−159	578	81.0	(67)
CH_4O†	Methyl alcohol	64.7	1100	104.3	*v.* p. 138
C_2Cl_4	Tetrachloroethylene	120.7	209.5	88.2	(57)
C_2N_2	Cyanogen	0	43$_1$	82.1	(19)*
C_2HCl_3	Trichloroethylene	85.7	239.6	87.8	(57)
C_2HCl_3O	Chloral		22$_6$		(7)*
$C_2H_2Cl_2O_2$	Dichloroacetic acid	194.4	323	89.1	(47)*
$C_2H_2Cl_4$	1, 1, 2, 2-Tetrachloroethane	145.0	230.5	92.6	(57)
C_2H_3ClO	Acetyl chloride	(51)	33$_0$	(79.9)	(11)*
$C_2H_3Cl_3O_2$	Chloral hydrate	96	55$_2$	274.4	(7)*
C_2H_3N	Acetonitrile	80	72$_7$	84.5	(38)*
$C_2H_4Br_2$	Ethylene bromide	130.8	193.5	90.0	(57)
$C_2H_4Cl_2$	Ethylene chloride	0.0	357		(36)*
		82.3	323.7	90.1	(57)
$C_2H_4Cl_2$	Ethylidene chloride	0.0	321		(36)*
		(60)	28$_1$	(83.5)	(13)*
C_2H_4O	Acetaldehyde	(21)	57$_0$	(85.3)	(4)*
C_2H_4O	Ethylene oxide	13	58$_0$	89.3	(10)*
$C_2H_4O_2$†	Acetic acid	118.3	405	62.1	*v.* p. 138
$C_2H_4O_2$	Methyl formate	31.3	470.3	92.8	(57)

C-TABLE.—(*Continued*)

Formula	Name	t, °C	l_v at $t°$	L_v/T	Lit.
C_2H_5Br	Ethyl bromide	38.4	250.8	87.8	(76)
C_2H_5Cl	Ethyl chloride	4.7	389	90.3	(37)
		15.0	387	86.6	(79.5)
		20.0	386		(79.5)
		25.0	385		(79.5)
C_2H_5ClO	2-Chloroethyl alcohol	126.5	514.6	103.7	(57)
C_2H_5I	Ethyl iodide	71.2	190.9	86.5	(57)
C_2H_6	Ethane	0	314		(19.5)
		− 10	341		(19.5)
		− 20	364		(19.5)
		− 30	386		(19.5)
		− 40	408		(19.5)
		− 90	10_{80}	177.3	(67)
C_2H_6O†	Ethyl alcohol	78.3	855	112.0	*v.* p. 138
$C_2H_6O_2$	Glycol	197	800	105.6	(48)*
C_2H_7N	Ethylamine	(15)	61_1	(95.5)	(28)*
C_3H_5N	Propionitrile	97	562	83.6	(47)*
C_3H_6O†	Acetone	56.1	521	91.9	*v.* p. 138
C_3H_6O	Allyl alcohol	(96)	684	(107.5)	(46)*
$C_3H_6O_2$	Ethyl formate	53.3	406.8	92.3	(57)
$C_3H_6O_2$	Methyl acetate	0.0	477		(36)*
		56.3	410.6	92.3	(57)
$C_3H_6O_2$	Propionic acid	139.3	413.6	74.3	(57)
$C_3H_6O_3$	Dimethyl carbonate	90	369	91.5	(46)*
C_3H_8	Propane	20	349		(19.5)
		+ 10	362		(19.5)
		0	375		(19.5)
		− 10	387		(19.5)
		− 20	399		(19.5)
		− 30	410		(19.5)
C_3H_8O†	*n*-Propyl alcohol	97.2	688	111.6	*v.* p. 138
C_3H_8O†	Isopropyl alcohol	82.3	667	118.4	*v.* p. 138
$C_3H_8O_2$	Methylal	42	37_6	90.8	(12)*
C_4H_4O	Furane	31	399	89.3	(57.2)
$C_4H_6O_3$	Acetic anhydride	137	27_7	68.9	(4)*
$C_4H_7ClO_2$	*β*-Chloroethyl acetate	141.5	338	99.9	(57)
C_4H_7N	*n*-Butyronitrile	117.4	481	85.1	(49)*
C_4H_8O	Methyl ethyl ketone	78.2	443.4	91.0	(57)
$C_4H_8O_2$	*n*-Butyric acid	163.5	477	96.2	(15)
$C_4H_8O_2$	Isobutyric acid	154	467	96.3	(15)
$C_4H_8O_2$	Ethyl acetate	0.0	427		(36)*
$C_4H_8O_2$	Methyl propionate	79.0	366.5	91.7	(57)
$C_4H_8O_2$	*n*-Propyl formate	80.0	368.9	92.0	(57)
C_4H_9I	*n*-Butyl iodide	129.5	192.1	87.8	(57)
C_4H_9NO	Methyl ethyl ketoxime	182	485	92.8	(49)*
C_4H_{10}	Butane	20	366		(19.5)
		10	376		(19.5)
		0	383	81.4	(19.5)
C_4H_{10}	Isobutane	20	333		(19.5)
		+ 10	345		(19.5)
		0	356		(19.5)
		− 10	366	80.8	(19.5)
$C_4H_{10}O$	*n*-Butyl alcohol	116.8	$591._8$	112.4	(57)
$C_4H_{10}O$	Isobutyl alcohol	106.9	578	112.7	(57)
$C_4H_{10}O$	*sec.*-Butyl alcohol	98.1	$562._5$	112.3	(57)
$C_4H_{10}O$	*tert.*-Butyl alcohol	83	546	113.6	(15)
$C_4H_{10}O$†	Ethyl ether	34.6	351	84.5	*v.* p. 138
$C_4H_{11}N$	Diethylamine	58	381	84.1	(59)*
$C_5H_4O_2$	Furfural	160.5	450	99.6	(57)
C_5H_5N	Pyridine	114.1	449.4	91.8	(57)
C_5H_9N	*n*-Valeronitrile	129	403	83.3	(39)*
C_5H_{10}	Amylene	12.5	31_4	77.1	(5)*
$C_5H_{10}O$	Diethyl ketone	101	380	87.5	(46)*
$C_5H_{10}O$	Methyl isopropyl ketone	92	376	88.7	(46)*
$C_5H_{10}O_2$	*n*-Butyl formate	105.1	363.1	98.0	(57)
$C_5H_{10}O_2$	Isobutyl formate	97.0	328.6	90.7	(57)
$C_5H_{10}O_2$	Ethyl propionate	97.6	335.2	92.3	(57)
$C_5H_{10}O_2$	Methyl *n*-butyrate	102.6	334	90.8	(15)
$C_5H_{10}O_2$	Methyl isobutyrate	91.1	$327._0$	91.7	(57)
$C_5H_{10}O_2$	*n*-Propyl acetate	100.4	336.0	91.9	(57)
$C_5H_{10}O_2$	*n*-Valeric acid	184.6	432	96.4	(15)
$C_5H_{10}O_2$	Isovaleric acid	176.3	423	96.1	(15)
$C_5H_{10}O_3$	Diethyl carbonate	126	306	90.6	(47)*
$C_5H_{11}Br$	*n*-Amyl bromide	129	20_2	(75.9)	(9)*
$C_5H_{11}I$	*n*-Amyl iodide	155	19_9	(92.1)	(9)*
$C_5H_{11}N$	Piperidine	106	374	84.0	(47)*
C_5H_{12}	Isopentane	13	371	93.5	(78)
$C_5H_{12}O$	*n*-Amyl alcohol	131	503	109.7	(68)*
$C_5H_{12}O$	Isoamyl alcohol	130.2	501.4	109.3	(57)
$C_5H_{12}O$	*tert.*-Amyl alcohol	102	443	104.1	(16)
$C_5H_{12}O$	Ethyl propyl ether	60.0	346	91.5	(60)
$C_5H_{13}N$	*n*-Amylamine	95	413	97.8	(38)*
C_6H_5Br	Bromobenzene	155.9	241.1	88.2	(57)
C_6H_5Cl	Chlorobenzene	130.6	$324._8$	90.5	(57)
$C_6H_5NO_2$	Nitrobenzene	210	331	84.3	(49)*
C_6H_6†	Benzene	80.2	394.8	87.2	*v.* p. 138
C_6H_7N	Aniline	183	434	88.6	(2.5)
C_6H_7N	*α*-Picoline	129	380	88.0	(39)*
C_6H_{10}	Cyclohexene	81.6	371.2	85.9	(57)
$C_6H_{10}O$	Mesityl oxide	128	359	87.8	(46)*
$C_6H_{10}O_4$	Diethyl oxalate	185	283	90.3	(48)*
$C_6H_{11}Cl$	Cyclohexyl chloride	142.0	313	89.4	(60)
$C_6H_{11}N$	Capronitrile	156	369	83.5	(47)*
C_6H_{12}	Cyclohexane	80.0	358.3	85.4	(57)
C_6H_{12}	Hexylene	0	388.3		(36)*
$C_6H_{12}O$	Cyclohexanol	161.1	453	104.5	(60)
$C_6H_{12}O$	Methyl *n*-butyl ketone	127	345	86.3	(46)*
$C_6H_{12}O_2$	*n*-Butyl acetate	124.0	309	90.4	(15)
$C_6H_{12}O_2$	Ethyl *n*-butyrate	118.9	312.6	92.6	(57)
$C_6H_{12}O_2$	Ethyl isobutyrate	109.2	301.6	91.6	(57)
$C_6H_{12}O_2$	Isoamyl formate	123	308	90.3	(15)
$C_6H_{12}O_2$	Isobutyl acetate	115.5	308.7	92.3	(57)
$C_6H_{12}O_2$	Methyl *n*-valerate	116	29_8	87.4	(69)*
$C_6H_{12}O_2$	Methyl isovalerate	116	303	90.4	(15)
$C_6H_{12}O_2$	*n*-Propyl propionate	120.6	306.2	90.3	(57)
C_6H_{14}	*n*-Hexane	0	373		(36)*
		66.9	342.1	86.7	(75)
		68	332	83.8	(52)*
$C_6H_{14}O$	Ethyl isobutyl ether	79.0	313	90.8	(60)
$C_6H_{14}O_2$	Acetal	102.9	277	87.0	(46)*
$C_6H_{15}N$	Di-*n*-propylamine	108	317	84.2	(39)*
C_7H_5N	Benzonitrile	189	367	81.9	(38)*
C_7H_6O	Benzaldehyde	179	362	84.9	(48)*
$C_7H_6O_2$	Salicylaldehyde	196	313	81.5	(50)*
C_7H_7Cl	*o*-Chlorotoluene	158.1	304	89.2	(57)
C_7H_7Cl	*p*-Chlorotoluene	160.4	306.1	89.4	(57)
C_7H_8	Toluene	109.6	362.2	87.2	(57)
C_7H_8O	Phenyl methyl ether	153	341	86.5	(49)*
C_7H_8O	Benzyl alcohol	204.3	470	106.4	(57)
C_7H_8O	*m*-Cresol	202	421	95.8	(47)*
C_7H_9N	Methylaniline	194	400	91.7	(49)*
C_7H_9N	*o*-Toluidine	198	398	90.5	(49)*
		198	382	86.8	(45)*
C_7H_{14}	Dimethylcyclopentane	91	339	91.4	(52)*
C_7H_{14}	Methylcyclohexane	99.9	321.9	84.7	(57)
$C_7H_{14}O$	Dipropylketone	143.5	317	86.9	(46)*
$C_7H_{14}O$	Methyl *n*-amyl ketone	149.2	346	93.6	(57.2)
$C_7H_{14}O_2$	*n*-Butyl propionate	144.9	300.3	82.0	(57)
$C_7H_{14}O_2$	Isobutyl propionate	137	27_6	76.8	(69)*
$C_7H_{14}O_2$	Ethyl *n*-valerate	98	32_3	99.3	(69)*
$C_7H_{14}O_2$	Ethyl isovalerate	144	284	77.7	(15)
$C_7H_{14}O_2$	Isoamyl acetate	143.6	289	79.2	(15)
$C_7H_{14}O_2$	*n*-Propyl *n*-butyrate	143.6	286	78.3	(15)
$C_7H_{14}O_2$	*n*-Propyl isobutyrate	134	26_7	74.9	(69)*
C_7H_{16}	*n*-Heptane	97.5	319.4	86.3	(57)
$C_7H_{16}O$	*n*-Heptyl alcohol	176	439	113.5	(15)
C_8H_8O	Acetophenone	203.7	323	81.4	(47)*
C_8H_{10}	Ethylbenzene	135.2	339.6	88.3	(57)
C_8H_{10}	*o*-Xylene	141.4	346.9	88.8	(57)
C_8H_{10}	*m*-Xylene	138.5	342.6	88.3	(57)
C_8H_{10}	*p*-Xylene	137.1	339.1	87.7	(57)
$C_8H_{11}N$	Dimethylaniline	193	338	87.8	(49)*
C_8H_{16}	Dimethylcyclohexane	$118._5$	300	85.9	(52)*
$C_8H_{16}O$	Methyl hexyl ketone	173	310	89.1	(48)*
$C_8H_{16}O_2$	Isoamyl propionate	161	273	90.7	(15)
$C_8H_{16}O_2$	Isobutyl *n*-butyrate	157	270	90.5	(15)
$C_8H_{16}O_2$	Isobutyl isobutyrate	148	265	90.7	(15)
$C_8H_{16}O_2$	*n*-Propyl isovalerate	156	270	90.7	(16)
C_8H_{18}	4-Methylheptane	117.2	296.5	86.7	(57)
C_8H_{18}	*n*-Octane	125	297	85.2	(52)*
$C_8H_{18}O$	*n*-Octyl alcohol	196	408	113.2	(15)
C_8H O	*dl-sec.*-Octyl alcohol	180	395	113.5	(15)
$C_8H_{19}N$	Diisobutylamine	134	275	87.3	(38)*
$C_9H_{10}O_2$	Ethyl benzoate	(213)	270	(83.5)	(44)*
C_9H_{12}	Mesitylene	165	311	85.3	(16)
C_9H_{12}	*n*-Propylbenzene	157	30_1	84.1	(69)*
C_9H_{12}	Pseudocumene	(169)	308	(83.8)	(45)*
$C_9H_{18}O_2$	Isoamyl *n*-butyrate	169	259	92.7	(15)

ℭ-Table.—(*Continued*).

Formula	Name	*t*, °C	l_v at *t*°	L_v/T	Lit.
$C_9H_{18}O_2$	Isoamyl isobutyrate	168	24_1	86.5	(69)*
$C_9H_{18}O_2$	Isobutyl *n*-valerate	169	24_2	86.6	(69)*
$C_9H_{18}O_2$	Isobutyl isovalerate	169	253	90.5	(15)
$C_{10}H_8$	Naphthalene	218	$316._0$	82.4	(60)
$C_{10}H_{12}O$	*p*-Anethole	232	299	87.7	(51)*
$C_{10}H_{14}$	*p*-Cymene	176	283	84.5	(16)
$C_{10}H_{14}O$	Carvacrol	237	285	83.9	(51)*
$C_{10}H_{16}$	Limonene	165	291	90.4	(68)*
$C_{10}H_{16}$	Turpentine	156	28_7	91.1	(68)*
$C_{10}H_{20}O_2$	Ethyl caprylate	207	253	90.7	(15)
$C_{10}H_{20}O_2$	Isoamyl *n*-valerate	187	23_5	88.0	(69)*
$C_{10}H_{22}$	*n*-Decane	160	252	82.7	(46)*
$C_{10}H_{22}O$	*n*-Amyl ether	(170)	29_1	(104)	(26)*
$C_{11}H_{22}O_2$	Ethyl nonylate	227	243	90.5	(15)

SPECIAL TABLES

Arthur Whitmore Smith

l, joule/g; normal boiling points in bold-face type

H_2O (18, 21, 31, 34, 42, 56, 66, 73)

t, °C	*l*
0	2494
5	2482
10	2471
15	2459
20	2448
25	2436
30	2425
35	2413
40	2402
45	2390
50	2379
55	2368
60	2357
65	2345
70	2333
75	2321
80	2309
85	2297
90	2284
95	2271
100	2258
	±0.1 %
105	2244
110	2230
115	2215
120	2200

Continued below

SO_2 (17, 22, 23, 57.5, 58, 71, 80)

−60	550(?)
−10.08	397
	±2 %
−10	397
0	382
+10	367
20	352
30	338
40	323
50	309
60	294
157	0.0

N_2O (17, 55, 57.5, 58, 80)

t, °C	*l*
−30	284
−20	276
−10	263
0	246
+10	217
20	171
30	96
37	0.0

NH_3 (23, 30, 35, 64)

−45	1401
−40	1388
−35	1373
−33.4	1369
	±0.2 %
−30	1359
−25	1344
−20	1329
−15	1313
−10	1296
− 5	1280
0	1262

Continued below

CO_2 (2, 3, 17, 43, 51.5, 57.5, 58, 80)

−78.5	577*
	±2 %
−60	365
−50	349
−40	333
−30	312
−20	288
−10	263
0	234

* For the solid.

Continued below

C_6H_6 (15, 16, 32, 57, 58, 60, 69, 73.5, 79)

0	447.8
20	434.4
40	421.4

C_6H_6.—(*Cont'd*)

t, °C	*l*
60	408.0
80	394.2
80.2	394.8
	±0.1 %
100	379.1
120	362.8
140	345.7
160	328.5
180	310.1
200	286.6
220	259.9
240	226.4
260	183.3
280	114.7
288.5	0.0

CH_4O (15, 16, 54, 57, 58, 75, 79, 80)

Methyl alcohol

0	1190
20	1170
40	1140
60	1110
64.7	1100
	±2 %
80	1060
100	1010
120	950
140	890
160	810
180	730
200	620
220	460
240	0.0

$C_2H_4O_2$ (15, 16, 25, 55, 58)

Acetic acid

20	365?
60	390?
100	400?
118.3	405
	±3 %
140	395
180	370
220	340
321	0.0

C_2H_6O (15, 16, 46, 55, 57, 58, 75, 79, 80)

Ethyl alcohol

t, °C	*l*
0	920
20	910
40	900
60	880
78.3	855
	±4 %
80	850
100	810
120	760
140	710
160	650
180	570
200	480
220	360
240	160
243	0.0

C_3H_6O (58, 77, 79, 80)

Acetone

0	564
20	552
40	536
56.1	521
	±2 %
60	517
80	495
100	472
235	0.0

C_3H_8O (15, 16, 58, 70)

n-Propyl alcohol

0	810
80	721
97.2	688

C_3H_8O.—(*Cont'd*)

t, °C	*l*
	± 1 %
100	683
120	637
140	593
160	537
180	484
200	426
220	355
240	264
260	139
261	0.0

C_3H_8O (15, 16, 46, 57)

Isopropyl alcohol

82.3	667
	±2 %
238	0.0

$C_4H_{10}O$ (15, 16, 41, 57, 58, 77)

Ethyl ether

0	387
20	366
34.6	351
	±2 %
40	346
60	326
80	303
100	282
120	257
140	228
160	186
180	125
190	0.0

CCl_4 (54, 57, 58, 75, 79)

0	217.9
76.75	194.3

CCl_4.—(*Cont'd*)

t, °C	*l*
	±0.3 %
80	193.3
100	185.5
120	176.8
140	167.7
160	159.4
180	148.7
200	137.0
220	123.7
240	107.4
260	84.3
280	43.8
283.1	0.0

$CHCl_3$ (54, 57, 58, 75, 79)

0	271
20	263
40	255
60	247
61.5	247
	±1 %
80	239
100	231
260	0.0

CS_2 (57, 58, 79)

0	374
20	366
40	356
46.25	352
	±0.3 %
60	344
80	331
100	316
120	300
140	282
273	0.0

H_2O, NH_3 AND CO_2 UP TO THE CRITICAL POINT

Oscar C. Bridgeman

H_2O (34)

t, °C	*l*
120	2199
125	2185
130	2170
135	2155
140	2139
145	2123
150	2107
155	2091
160	2074
165	2057
170	2039
175	2021
180	2003

NH_3 (23, 27.5, 34, 64, 65.7, 78.2)

−20	1239
−15	1313
−10	1297
− 5	1280

NH_3.—(*Cont'd*)

t, °C	*l*
0	1263
+ 5	1245
10	1226
15	1207
20	1187
25	1167
30	1146
35	1124
40	1101
45	1076
50	1051
132.5	0

CO_2* (19, 36.5, 57.7, 65.5)

−56.6	339
−55	337
−50	330
−45	323
−40	316

CO_2.*—(*Cont'd*)

t, °C	*l*
−35	308
−30	299
−25	290
−20	280
−15	269
−10	257
− 5	244
0	230
+ 5	214
10	195
15	174
20	147
25	112
30	50
31.1	0

* This table is based primarily upon the data of (37.5) while the table given above is in agreement with the data of (51.5) and the older literature.

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HEATS OF ADSORPTION AND OF WETTING

H. R. Kruyt and J. G. Modderman

HEAT OF ADSORPTION

Abbreviations and Units

A Total amount of gas adsorbed per g of adsorbent, expressed in cm³ reduced to *NTP*, unless otherwise indicated.

Q Total heat evolved by the adsorption of *A*, joules.

Gases on Charcoal

A, cm³/g	Q, joule	P, range mm Hg	$\Delta Q/\Delta A$
Coconut C, heated to 550°, and out-gassed at 400° (d = 1.86) (14)			
N_2, 0°C			
0.258	0.35_6	0–10.7	1.38_1
2.210	2.12_2	10.7–91.6	0.90_4
4.169	3.75_4	91.6–178.9	0.83_3
7.237	6.46_3	178.9–342.2	0.88_3
10.052	8.93_4	342.2–524.4	0.87_9
13.049	11.58_9	524.4–748.9	0.88_7
NH_3, 0°C			
5.407	11.38_9	0–2.9	2.10_6
30.157	50.87_7	2.9–28.8	1.59_5
60.394	96.43_0	28.8–78.7	1.50_7
90.290	140.18_1	78.7–161.0	1.46_3
115.725	177.65_2	161.0–319.2	1.47_3
127.045	195.33_2	319.2–490.0	1.56_5
132.387	203.97_1	490.0–636.4	1.61_5
135.873	209.63_8	636.4–746.7	1.62_8
Coconut C, heated to 550°, and out-gassed at 400° (d = 1.86) (14)			
CO_2, 0°C			
2.286	3.30_0	0–2.2	1.44_3
11.310	15.54_2	2.2–18.7	1.35_7
22.556	29.91_6	18.7–55.1	1.27_8
33.416	43.53_9	55.1–122.1	1.25_4
43.904	56.43_6	122.1–229.3	1.23_0
50.850	64.92_1	229.3–337.7	1.22_2
56.937	(71.69_3)	337.7–471.3	(1.11_4)
61.639	77.34_5	471.3–605.5	1.19_9
65.112	81.46_7	605.5–730.9	1.18_7
Active coconut C, out-gassed at 350° (11)			
CCl_4, 0°C			
23.56	$70._6$	0– << 4	2.9_9
39.50	$111._4$	<< 4– < 4	2.5_6
60.94	$174._6$	< 4–4	2.9_5
78.32	$215._6$	4–10	2.3_6
CS_2, 0°C			
23.91	$58._3$	0– << 3	2.4_4
48.40	$111._8$	<< 3– << 3	2.1_8
70.02	$157._5$	<< 3– < 3	2.1_1
97.94	$215._2$	< 3–3	2.0_7
127.67	$273._7$	3–12	1.9_7
153.19	$321._7$	12–40	1.8_8

Gases on Charcoal.—(*Continued*)

A, cm³/g	Q, joule	P, range mm Hg	$\Delta Q/\Delta A$
Active coconut C, out-gassed at 350° (11)			
$CHCl_3$, 0°C			
22.30	62.4	0–<<7	2.80
45.49	123.1	<<7–<7	2.62
78.36	204.4	<7–7	2.47
107.10	274.2	7	2.43
CH_3OH, 0°C			
21.67	56.0	0–<<13	2.59
47.42	115.7	<<13–<<13	2.32
75.27	179.0	<<13–<13	2.27
103.27	240.4	<13–13	2.193
127.40	293.3	13–18	2.192
C_2H_5Cl, 0°C			
29.10	67.2	0–<<15	2.31
42.66	96.3	<<15–<<15	2.15
67.01	145.6	<<15–<15	2.02
102.81	214.3	<15–15	1.92
124.80	255.4	15–52	1.87
C_2H_5Br, 0°C			
48.90	124.9	0–<10	2.56
91.73	219.9	<10–10	2.22
120.48	281.0	10–37	2.13
C_2H_5I, 0°C			
34.42	90.9	0–<2	2.64
67.52	173.3	<2–2	2.49
99.17	251.0	2–5	2.46
124.72	310.2	5–39	2.32
C_2H_5OH, 0°C			
4.59	15.15	0	3.30
8.40	26.24		2.91
14.23	42.64		2.81
27.83	79.98		2.75
46.91	129.8		2.61
$HCO_2C_2H_5$, 0°C			
32.30	91.9	0–<<10	2.85
62.88	168.5	<<10–<10	2.50
96.73	249.8	<10–10	2.40
120.15	305.5	10–35	2.38
$(C_2H_5)_2O$, 0°C			
18.10	56.0	0–<<<10	3.10
37.68	109.1	<<<10–<<10	2.71
58.07	163.5	<<10–<10	2.67
86.77	225.1	<10–10	2.15
99.34	253.7	10–63	2.28
C_6H_6, 0°C			
28.37	80.2	0–<2	2.83
54.70	150.2	<2–2	2.649
81.03	219.9	2–3	2.647
102.04	273.3	3–13	2.54
Inactive coconut C, out-gassed at 350° (11)			
CCl_4, 0°C			
24.33	68.6	0–<21	2.82
36.27	94.4	<21–21	2.16
CH_3OH, 0°C			
32.65	83.5	0–<2	2.56
60.95	149.0	<2–2	2.32
88.35	211.0	2–4	2.26
117.09	274.7	4–14	2.22
C_6H_6, 0°C			
18.48	55.9	0–<4	3.02
36.28	106.5	<4–4	2.84
47.93	138.8	4–9	2.77

A, cm³/g	Q, joule	P, range mm Hg	$\Delta Q/\Delta A$
SO_2 on blood C (puriss. Merck) out-gassed at 450°C (d = 1.63); measurements at −10°C (16)			
21.4	41.9	0–1.0	1.956
54.2	97.3	1.0–3.6	1.691
87.4	151.3	3.6–9.2	1.626
123.5	205.2	9.2–16.4	1.492
159.2	256.7	16.4–(31.1)	1.445
193.8	304.0	(31.1)–45.0	1.366
226.5	353.4	45.0–(71.8)	1.510
256.8	398.3	(71.8)–(103.2)	1.483
283.2	437.2	(103.2)–136.4	1.472
323.4	493.9	136.4–(246.3)	1.411
352.1	533.3	(246.3)–397.3	1.371
369.7	556.4	397.3–533.0	1.315
386.4	575.2	533.0–(653.2)	1.125
409.9	600.4	(653.2)–720.5	1.073
439.9	631.6	720.5–755.0	1.039
466.3	659.5	755.0–764.0	1.059
C from the wood of *Evonymus europaeus*, out-gassed at red heat (3)			
Air, 0°C			
7.44	3.37	0–705	0.453
CH_3Cl, 0°C			
32.17	65.47	0–3.77	2.035
62.16	124.5	3.77–147.81	1.968
72.31	144.8	147.81–675.4	1.997
Active C de-ashed and out-gassed at 900°C (8)			
O_2, 0°C			
0.403	5.23		12.98
0.806	8.87		9.03
2.24	12.56		2.57
5.17	15.48		1.00
10.19	19.96		0.89
H_2O, 0°C*			
0.921	32.89		35.7
2.710	112.37		44.4
4.56	194.27		44.3
6.42	275.71		43.8
Cl_2, 0°C			
0.31	1.80		5.81
0.74	3.77		4.58
5.52	27.79		5.02
NH_3, 0°C			
3.70	9.37		2.53
14.92	26.11		1.51
24.75	40.93		1.51
34.45	55.03		1.45
CO_2, 0°C			
3.80	5.69		1.50
12.04	16.15		1.27
31.06	40.47		1.28
$(C_2H_5)_2O$, 0°C			
6.92	21.93		3.17
14.04	42.39		2.87
22.21	63.15		2.54
29.93	82.48		2.50
37.04	94.41		1.68
47.36	107.6		1.28
CCl_3NO_2, Chloropicrin, 0°C*			
0.307	20.84		67.9
0.672	42.48		59.3
1.012	59.89		51.2

* A in millimoles per gram.

A, cm^3/g	Q, joule	P, range mm Hg	$\Delta Q/\Delta A$
Activated C dried at 150° and out-gassed at 100° (15)			
O$_2$, 0°C			
4.39	3.22	0–370	0.733
8.54	6.13	370–802	0.702
CO, 0°C			
4.84	4.01	0–233.1	0.83
9.40	7.60	233.1–540.1	0.79
CH$_4$, 0°; P corr. for N$_2$ (10%) present			
4.71	4.61	0–63.0	0.98
9.23	8.95	63.0–169.2	0.96
13.57	12.81	169.2–320.3	0.89
17.72	16.27	320.3–517.0	0.83

O$_2$ on "Norit" out-gassed at 900°C (2)

°C	A	Q	P, range	Q/A
15	0.216	2.59	0–	12.0
200†	0.302	6.43	0–2	21.3
310	0.158	5.07	0–2.7	32.1
450	0.133	5.55	0–3.4	41.7

† Above 200° CO$_2$ is formed and a correction has been applied for this heat of reaction.

Various gases on coconut C at −185°C; A is cm^3 of gas adsorbed per cm^3 (0.5–1 g) of charcoal from 0 to *ca.* 760 mm (4)

Gas	A	Q	Q/A
A	175	104.6	0.598
He	15	8.37	0.558
O$_2$	230	142.3	0.619
H$_2$	135	38.9	0.288
N$_2$	155	106.7	0.688
CO	190	115.1	0.606
2H$_2$ + O$_2$	150	71.1	0.474
2CO + O$_2$	195	144.4	0.740

Gases on various kinds of charcoal at room temperature and from 0 to *ca.* 760 mm; A and Q vary with the nature of the charcoal but the ratio is approx. constant (5)

Gas	HCl	HBr	HI	N$_2$O
Q/A	0.429	0.692	0.984	0.332

Gases on Metals

H$_2$ on Ni catalysts at 0° (7)

A, cm^3	Q	$\Delta Q/\Delta A$
Catalyst I. Prepared by heating NiCO$_3$ at 300–320° for 120 hr and out-gassing at 300°; adsorbs 0.9 cm^3 H$_2$ per g at *NTP*		
0.0396	0.1895	4.77
0.0772	0.3086	3.18
0.114	0.4184	2.93
0.180	0.5949	2.68
0.260	0.7936	2.49
0.795	2.0296	2.34
Catalyst II. Reduced for 60 hr; contained 13.5% ThO$_2$; adsorbs 0.72 cm^3 H$_2$ per g at *NTP*		
0.0315	0.0804	2.56
0.0612	0.2325	5.11
0.0918	0.4187	6.08
0.1211	0.5832	5.57
0.2082	1.0143	4.95
0.2453	1.1646	4.01
0.332	1.3581	2.23
0.722	2.1933	2.14
CO$_2$ on Ni catalyst at 0° (7)		
Catalyst III. Reduced from the oxide for 260 hr at 300–320°; contained 4% Ce$_2$O$_3$		
0.082	0.271	3.29
0.619	1.04	1.43
0.874	1.24	0.789

H$_2$ on Ni and Cu at room temperature. The H$_2$ contained an unknown but negligible amount of N$_2$ (1)

A, cm^3	Q	P, range	$\Delta Q/\Delta A$
On Ni reduced from NiO at 300°; results are greatly affected by previous treatment of the Ni			
0.403	0.998	0–2.7	2.48
0.865	2.086	2.7–8.7	2.35
1.123	2.792	8.7–703.4	2.73
On Cu reduced from CuO by H$_2$ at 145°			
0.438	0.786	0–760	1.793

Gases on Ni at 0° and from 0 to 760 mm (6)

H$_2$

Out-gassed at t, °C	A	Q	Q/A
304	5.2	15.70	3.03
240	3.7	10.98	2.97
196	2.9	8.56	2.95
145	2.1	5.49	2.61
120	1.8	4.28	2.38
90	1.5	3.22	2.15
0	0.54	1.16	2.15

Gas	A	Q	Q/A
C$_2$H$_4$	0.88	1.04	1.18
C$_2$H$_6$	0.75	0.78	1.05

H$_2$ and O$_2$ on Pt-black at 0° and from 0 to 760 mm (12); for H$_2$ on Pt-black carefully freed from O$_2$, $A = 0.87$ cm^3 and $\Delta Q/\Delta A = 2.58$; for O$_2$ the values of Q/A vary from 6 to 18 joule/cm^3. The authors consider 6.6 as the best value.

Gases on SiO$_2$ and on Meerschaum

On meerschaum (d = 2.76) (3)

A	Q	P, range	$\Delta Q/\Delta A$
SO$_2$, 0°			
24.24	46.82	0–98.9	1.932
46.14	74.13	98.9–377.1	1.247
67.75	96.99	377.1–687.4	1.058
NH$_3$, 0°			
24.23	92.95	0–0	3.84
48.26	150.07	0–5	2.38
72.29	201.11	5–37.1	2.12
95.26	239.64	29.3–214.96	1.68
116.74	270.22	214.96–575.6	1.42
CH$_3$Cl, 0°			
20.96	41.07	0–34.9	1.959
39.59	66.78	34.9–484.9	1.380
41.72	69.67	484.9–561.9	1.355

On SiO$_2$ gel dried at 300° for 2 hr and out-gassed at 250°; contained 3.5–5.5% H$_2$O (13)

A	Q	P, range	$\Delta Q/\Delta A$
SO$_2$, 0°			
19.80	41.85	0–4.2	2.113
32.42	64.87	4.2–11.8	1.824
56.43	108.0	11.8–40.1	1.796
80.71	145.6	40.1–102.5	1.549
123.1	211.8	102.5–388.8	1.562
142.3	233.5	388.8–611.2	1.130
H$_2$O on the same gel, 0°; A in millimoles			
1.826	113.0	0–0.3	61.88
6.361	349.0	0.3–0.8	52.04
12.85	657.0	0.8–2.1	47.46
15.35	771.7	2.1–3.4	45.88
19.94	975.1	3.4–4.6	44.31

From Aqueous Solutions

Crystal violet on wetted blood charcoal (Merck) at room temp.; A in millimoles (9)

A	Q	$\Delta Q/\Delta A$
0.31	13.42	43.3
0.42	14.03	5.55

Salts on wetted blood charcoal (Merck) at room temp.; A in millimoles (10)

Salt	A	Q	Q/A
On Charcoal I. Heat of wetting = 25.11 J			
$LiNO_3$	0.214	5.36	25.0
$NaNO_3$	0.270	7.11	26.4
$CsNO_3$	0.354	12.05	34.1
On Charcoal II. Heat of wetting = 35.15 J			
$LiNO_3$	0.202	7.53	37.2
KNO_3	0.248	10.80	43.5
$CsNO_3$	0.336	16.49	49.0

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(For a key to the periodicals see end of volume)

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HEAT OF WETTING

Except as otherwise indicated the values given represent heat of *complete* wetting, Q, in joules per **g** of the dry material.

Index.—The numbers are table numbers except those in ( ) which are literature references (*v.* p. 143).

Liquid	Fibers	Soils	Colloids	$PbSO_4$
H_2O	6 (12, 20, 28, 34)	(1, 6, 7, 8, 9, 10, 11, 15, 26, 30, 35)	10, 11	18

	Charcoal	SiO_2	Clays and earths	Starch, cellulose, etc.
H_2O	1, 2, 6, 12 to 16	1, 3, 4, 5, 6, 11, 12	1, 2, 11, 13	1, 6, 8, 9
CS_2, Carbon disulfide	1, 2, 15	1	1, 2	1
CCl_4, Carbon tetrachloride	1, 2	1, 3	1, 2	1
C_2Cl_4, Tetrachloroacetylene	15			
$CHCl_3$, Chloroform	1, 2	1, 7	1, 2	1
Hydrocarbons				
C_5H_{10}, Amylene			2	
C_5H_{12}, Pentane	1	1	1	1
C_6H_6, Benzene	1, 2, 15, 16	1, 3, 4	1, 2	1
C_6H_{10}, Cyclohexene			2	
C_6H_{12}, Hexamethylene	2		2	
C_6H_{14}, Hexane	1, 2	1	1, 2	1
C_7H_8, Toluene		4, 7		
$C_{10}H_{16}$, Pinene	2		2	
Alcohols				
CH_3OH, Methyl	1, 2, 15	1	1, 2	1
C_2H_5OH, Ethyl	1, 2, 15	1, 3	1, 2	1
C_3H_7OH, Propyl	1	1	1	1
$C_5H_{11}OH$, Amyl	1, 2	1, 7	1, 2	1
$C_6H_5CH_2OH$, Benzyl	1	1	1	1

Liquid	Charcoal	SiO_2	Clays	Starch
Ethers, esters, ketones, acids				
C_3H_6O, Acetone	1, 2	1	1, 2	1
$C_4H_8O_2$, Ethyl acetate	2		2	
$C_4H_{10}O$, Ether	1, 15	1, 7	1, 2	1
Fatty acids	1	1	1	1
Naphthenic acids			2	
N compounds				
C_5H_5N, Pyridine		4, 7		
$C_6H_5NH_2$, Aniline		3	2	
$C_6H_5NO_2$, Nitrobenzene		4		
Miscellaneous				Cu
Petroleum products	2		2	17
Vegetable oils				17

TABLE 1.—POWDERS DRIED AT 100°

Experiments at 12–13° (14)

Liquid	Clay	Amorph. silica	Starch	Sugar charcoal
H_2O	52.7	64.0	85.4	16.3
CH_3OH	46.0	64.0	23.4	48.1
C_2H_5OH	45.2	61.5	20.5	28.9
C_3H_7OH	42.7	56.5	29.3	23.4
$C_5H_{11}OH$	42.3	56.5	13.0	15.5
$C_6H_5CH_2OH$	38.9	56.5	17.6	15.5
$HCOOH$	50.2	60.7	33.5–41.8	50.2 ±
CH_3COOH	38.9	56.5	12.6–16.7	25.1
C_3H_7COOH	32.6	56.5	12.6–16.7	25.1
CH_3COCH_3	33.5	56.5	8.4	15.1
$CHCl_3$	37.7	33.5	8.4	9.6
$C_2H_5OC_2H_5$	24.3	35.2	9.2	5.0
C_6H_6	24.3	33.9	5.0	17.6
CCl_4	7.5	33.9	7.1	6.3
CS_2	7.1	15.1	2.1	16.7
C_5H_{12}–C_6H_{14}	5.0	13.0	1.26	1.67

TABLE 2 (17)

Liquid		Clay	"Floridin"	Bone charcoal
Amylene		329.8	239.0	
H_2O			126.0	77.4
Cyclohexene			117.6	
CH_3COCH_3			114.2	80.8
Pinene		86.2		72.0
CH_3OH		115.5	91.2	73.7
$CH_3CO_2C_2H_5$			77.4	69.1
C_2H_5OH		102.5	72.0	69.1
$C_6H_5NH_2$			56.1	
$C_5H_{11}OH$		85.4	45.6	44.4
$C_2H_5OC_2H_5$			43.9	
$CHCl_3$		65.7	35.2	58.6
C_6H_6		45.2	23.4	46.5
CCl_4		41.4	19.3	35.2
CS_2		39.3	17.6	58.2
Hexamethylene			17.6	38.5
C_6H_{14}		30.1	16.3	37.2
Petroleum fractions*	B. P., 220–225°		22.2	56.1
	B. P., 150–155°		18.8	49.4
Gasoline, B. P., 80–85°			17.6	39.8
Naphthenic acids†	Mol. wt., 405		59.4	
	Mol. wt., 298		56.5	
	Mol. wt., 221		53.6	

* Treated with fuming H_2SO_4 to remove unsaturated and aromatic hydrocarbons. † Diluted with 20 vol. % of gasoline to decrease viscosity.

TABLE 3 (31)

Liquid	SiO_2 gel
H_2O	80.4
C_2H_5OH	94.7
C_6H_6	46.6
CCl_4	35.2
$C_6H_5NH_2$	73.4

TABLE 4.—SiO_2 OUT-GASSED AT RED HEAT (25)

Liquid	Mean diam., cm	
	5×10^{-4}	9.6×10^{-4}
H_2O	57.8	28.9
$C_6H_5NO_2$	46.2	26.2
$C_6H_5CH_3$	35.6	20.3
C_6H_6	17.1	17.1
C_5H_5N	50.8	20.8

TABLE 5.—SiO_2 WITH H_2O (29)

Specimen SiO_2	Q at 7°	Diam., cm $\times 10^{-4}$	Joule/m²
SiO_2 (glass wool)	3.85	17.5	46.0
SiO_2 (fine gray sand)	0.96	100.	41.8
SiO_2 I (precipitated)	47.3	2.5	43.5
SiO_2 II (precipitated)	30.1	4.0	43.9
SiO_2 II (precipitated)	31.6 (Q at 24°)		

Heat of Complete Wetting per g Dry Material (Q_i)

Powders containing varying initial amounts of hygroscopic moisture, i = mg H_2O per g dry powder.

TABLE 6.—WITH H_2O

Powder	i	Q_i	i	Q_i
Cellulose (22, 23); dried *in vacuo* at 116°	14	33.9_0	74	10.8_9
	41	19.6_7	261	4.6_1
	54	16.7_4		
Animal charcoal at 0° (22, 23)	0	87.5_1	563	13.0_6
	49	73.9_1	659	6.6_6
	90	64.2_0	718	4.5_6
	218	49.3_4	753	1.2_1
	350	33.0_7	930	0
	437	25.3_2		
SiO_2 gel at 0° (4)	23	77.5_9	275	22.5_7
	57	50.9_3	399	15.4_8
	87	38.5_0	565	6.9_5
	129	32.1_4	769	0.8_0
	188	27.2_0		
Wood fiber (12)	?	67		

TABLE 7.—SiO_2 GEL WITH VARIOUS LIQUIDS (4)

Liquids	i	Q_i	Liquids	i	Q_i
$C_6H_5CH_3$	23	32.7_3	$C_5H_{11}OH$	17	51.3_5
$CHCl_3$	13	32.5_2	$C_2H_5OC_2H_5$	31	68.5_9
C_5H_5N	18	60.0_5	$C_2H_5OC_2H_5$	276	37.0_4
$C_5H_{11}OH$	27	55.8_7			

TABLE 8.—STARCH WITH H_2O AT 0° (HEAT OF SWELLING)

The starch has been dried for 21 days in partial vacuum above H_2SO_4, Q = 110.5 joule/g (32).

TABLE 9.—DEXTRIN WITH H_2O

Q = 67.6 joule/g (33).

TABLE 10.—HEAT OF SWELLING AND OF SOLUTION, PER G MATERIAL (36)

Material	Amount	$+H_2O$	Q
Gelatin			
t = 42.5°	1 g	5 g	+13.0
t = 42.5°	1 g + 100% H_2O	4 g	− 4.18
t = 34.3°	1 g + 200% H_2O	3 g	− 4.18
t = 25°	1 g + 300% H_2O	2 g	0
Gum arabic	1 g	5 g	+37.6
	1 g + 50% H_2O	2 g	− 2.5
Gum tragacanth	1 g	5 g	+43.1

TABLE 11.—COLLOIDS WITH H_2O (9)

Colloid	Q	Colloid	Q
$Al(OH)_3$	89.6	Silica gel	101.5
$Fe(OH)_3$	39.3	Fuller's earth	88.9
Quartz	1.88		

TABLE 12.—SILICA AND ANIMAL CHARCOAL, WITH WATER (13)

	Q
Silica (dried at 200°)	55.41
Charcoal (puriss.)	59.55

TABLE 13.—WITH H_2O (18, 19)

Coconut charcoal (out-gassed)	43.9	Bone charcoal	77.4
Coconut charcoal (containing 0.04 g H_2O)	14.6	Fuller's earth	134

TABLE 14.—WITH H_2O

Graphite preheated *in vacuo*. Q = 2.85 joule/g (27).

TABLE 15.—"BAYER" CHARCOAL AT ROOM TEMPERATURE (2)

Liquid	Q	Liquid	Q
$C_2H_5OC_2H_5$	118.4	CH_3OH	126.4
C_6H_6	123.0	C_2Cl_4	137.3
CS_2	125.6	H_2O	51.5*
C_2H_5OH	118.9		

* With 0.66 cm³ H_2O per g. Possibly incomplete wetting.

TABLE 16.—VARIOUS CHARCOALS WITH H_2O AND C_6H_6

The activity, a, is taken as proportional to the adsorptive power for H_2 (21). d is approximate.

a	d	H_2O	C_6H_6	a	d	H_2O	C_6H_6
10		20.9	25.1	75	1.87	154.8	209.0
20		41.8	54.4	90		188.3	251.1
25	1.45	50.2	71.1	98	2.00	205.1	272.0
50		104.6	138.1	100		209.0	280.4

TABLE 17.—CU WITH OILS

All samples (except kerosene) diluted 1:2 with C_6H_6; Q for C_6H_6 taken as 0 (3)

Oil	Q	Oil	Q
Castor oil	0.51	Paraffin oil	0.16
Linseed oil	0.58	Kerosene	0.24
Lubricating oil, distillate	0.60	Kerosene + 1% oleic acid	0.89
Lubricating oil, refined	0.26		

For temperature rise on wetting charcoal with oils, v. (3.5).

TABLE 18.—$PbSO_4$ WITH ITS SATURATED AQUEOUS SOLUTION

For total surface of 5840 to 32 400 cm²/g, Q = 0 (24).

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THERMAL EFFECTS ACCOMPANYING PRESSURE CHANGES IN HOMOGENEOUS SYSTEMS (JOULE-THOMSON AND RELATED EFFECTS)

J. R. Roebuck

JOULE-THOMSON EFFECT $\mu = \left(\frac{\partial T}{\partial P}\right)_h$, $h = U + pv$

𝔄-Table, Elementary Substances and Atmospheric Air

Values of μ in °C/atm. (11)

°C	0	20	40	60	80	100
H_2...........	−0.013	0.018	0.023	0.028	0.033	−0.039
He...........	*v.* (17)					
N_2...........	+0.333	0.291	0.250	0.215	0.187	+0.159
O_2...........	+0.366	0.328	0.289	0.255	0.224	+0.193

Air, values of 10^3a and 10^5b in the equation, $\mu = a - bp$, for p in kg/cm², and μ in °C/kg cm⁻² (14)

°C	−55	−34	−0.6	+49.2	99.5	149.7	199.3	249.9
10^3a	448	375	272	197	138	84	52	18
10^5b	176	129	81	56	36	18	13	10

Air, values of $10^3\mu$, unit, °C/atm. (20); *cf.* (9)

p, atm.	0°	50°	100°	150°	200°	250°	280°C
1	266	189	133	93	62.5	40.2	29.7
20	249	178	124	86	56.4	34.6	24.6
60	214	153	106	71	44.7	25.1	16.1
100	178	128	89	59	34.7	16.4	7.8
140	145	105	72	46.7	25.8	9.3	+ 1.1
180	113	83	58	36.6	18.5	+2.7	− 5.4
220	81	63	45	28.6	12.7	−2.0	−11.0

Air, values of $10^3\mu$, unit, °C/atm. (25)

°C / p, atm.	−25	−50	−75	−100	−110	−120	−130	−140	−150
1	317	378	462	576	637	710	807	936	1100
20	297	358	442	562	627	710	819	967	1200
40	276	336	417	534	598	577	776	245	52
60	255	309	378	472	541	527	362	106	40
80	232	275	335	386	367	299	141	67	34
100	211	248	288	284	242	158	87	43	21
120	187	214	242	203	158	102	57	28	+11
140	164	172	192	142	108	69	38	17	0
160	143	155	147	103	76	47	+22	+ 3	−12
180	125	130	116	75	52	28	8	− 8	−22
200	108	110	82	48	29	+13	− 3	−17	−29
220	93	91	69	31	+14	− 2	−15	−28	−42

Air, values of μ in °K/atm. (8)

p, atm.	p, kg/cm²	90°	120°	132.6°*	150°	180°	210°	240°	270°	300°K
0	0	2.045	1.265	1.046	0.833	0.602	0.459	0.361	0.285	0.227
25	25.84	−0.005	0.059	1.065	0.847	0.619	0.458	0.345	0.266	0.212
37.17†	38.40	−0.010	0.028	0.723	0.787	0.599	0.443	0.332	0.254	0.204
50	51.67	−0.014	0.013	0.136	0.641	0.555	0.420	0.315	0.244	0.195
75	77.50	−0.020	0.000	0.036	0.266	0.436	0.362	0.282	0.221	0.178
100	103.33	−0.026	−0.010	0.010	0.130	0.299	0.295	0.247	0.196	0.159
125	129.18	−0.031	−0.020	−0.005	0.062	0.203	0.233	0.211	0.172	0.142
150	155.00	−0.035	−0.026		0.025	0.135	0.182	0.175	0.148	0.124
175	180.83	−0.038	−0.032		0.000	0.079	0.130	0.139	0.124	0.106
200	206.7	−0.041	−0.036		−0.017	0.029	0.080	0.101	0.099	0.089

* Critical temperature. † Critical pressure.

𝔅-Table, Chemical Compounds

CO₂, unit, °C/atm. (2)

Temp., °K	Pressure in atmospheres								
	0	1	10	20	40	60	72.9	80	100
Vapor phase above line									
400.0	0.6475	0.6440	0.6210	0.5950	0.5375	0.4790	0.4410	0.4225	0.3635
390.0	0.6755	0.6725	0.6485	0.6200	0.5595	0.4965	0.4560	0.3850	0.3235
380.0	0.7080	0.7045	0.6780	0.6475	0.5835	0.5165	0.4742	0.4505	0.3855
370.0	0.7415	0.7335	0.7100	0.6775	0.6160	0.5405	0.4952	0.4705	0.3995
360.0	0.7790	0.7750	0.7455	0.7110	0.6420	0.5685	0.5200	0.4930	0.4155
350.0	0.8195	0.8150	0.7850	0.7500	0.6780	0.6020	0.5500	0.5210	0.4340

CO_2.—(*Continued*)

Temp., °K	Pressure in atmospheres								
	0	1	10	20	40	60	72.9	80	100
340.0	0.8640	0.8595	0.8290	0.7950	0.7205	0.5425	0.5872	0.5550	0.4500
330.0	0.9140	0.9095	0.8795	0.8450	0.7720	0.6925	0.6331	0.5945	0.4490
325.0	0.9425	0.9375	0.9075	0.8745	0.8025	0.7230	0.6605	0.6165	0.4220
320.0	0.9710	0.9665	0.9380	0.9050	0.8360	0.7570	0.6900	0.6380	0.3570
315.0	1.0020	0.9985	0.9705	0.9395	0.8735	0.7970	0.7223	0.6500	0.2210
310.0	1.0360	1.0320	1.0055	0.9765	0.9160	0.8435	0.7554	0.6100	0.1585
305.0	1.0710	1.0675	1.0445	1.0155	0.9640	0.9000	0.7468	0.2690	0.1270
304.1	1.0775	1.0740	1.0505	1.0240	0.9735	0.9100	0.6050	0.2420	0.1215
300.0	1.1070	1.1045	1.0840	1.0600	1.0175	0.9675	0.2147	0.1650	0.1005
295.0	1.1480	1.1455	1.1270	1.1090	1.0805	0.1990	0.1324	0.1134	0.0794
290.0	1.1920	1.1900	1.1750	1.1635	1.1525	0.1156	0.9999	0.0815	0.0619
285.0	1.2395	1.2385	1.2280	1.2245	1.2400	0.0761	0.06355	0.0586	0.0478
280.0	1.2900	1.2900	1.2845	1.2915	1.3470	0.0515	0.0454	0.0425	0.0364
275.0	1.3455	1.3455	1.3470	1.3645	0.0414	0.0355	0.0324	0.0309	0.0275
270.0	1.4050	1.4060	1.4155	1.4455	0.0274	0.0246	0.0228	0.0221	0.0202
260.0	1.5375	1.5405	1.5735	1.6375	0.0106	0.0101	0.00973	0.0096	0.0090
250.0	1.6885	1.6954	1.7570	0.0_3735	0.0_3733	0.0_3731	0.0_3730	0.0_3729	0.0_3727
240.0	1.860	1.870	1.974	−0.00723	−0.00742	−0.00761	−0.00774	−0.00781	−0.00801
230.0	2.060	2.070	−0.0168	−0.0171	−0.0177	−0.0183	−0.0187	−0.0190	−0.0195
220.0	2.2855	2.3035	−0.0294	−0.0304	−0.0323	−0.0341	−0.0353	−0.0359	−0.0375

Liquid phase below line

Supplementary values at graphically determined intersections of isotherms and isobars of μ with the saturation curve

p	1	5	10	15	20	30	40	50	60	65	70	72.9
T	(193.5)	216.2	233.4	245.05	254.1	268.15	279.0	288.0	295.7	299.15	302.35	304.1
μ_v	(3.055)	2.510	2.135	1.922	1.773	1.545	1.371	1.211	1.043	0.937	0.801	0.6050
μ_l	(?)	−0.0346	−0.0083	−0.0031	+0.0046	0.0245	0.0575	0.1182	0.2225	0.2985	0.418	0.6050
T	216.9	220.0	230.0	240.0	250.0	260.0	270.0	280.0	285.0	290.0	295.0	300.0
p	5.15	5.95	8.8	12.65	17.6	23.9	31.55	41.0	41.0	52.55	59.0	61.3
μ_v	2.475	2.410	2.200	2.020	1.841	1.675	1.515	1.354	1.354	1.174	0.961	0.914
μ_l	−0.3375	−0.0290	−0.0167	−0.0074	+0.0007	0.0115	0.0285	0.0625	0.0938	0.1386	0.2095	0.3235

Values below correspond to regions of rapid rates of change of μ along isotherms

T	220.0	230.0	304.1	304.1	304.1	304.1	304.1	310.0	310.0	315.0	315.0	315.0
p	5.0	5.0	70.0	72.0	74.0	76.0	90.0	85.0	90.0	85.0	90.0	95.0
μ	2.387	2.132	0.822	0.767	0.382	0.310	0.159	0.360	0.250	0.569	0.443	0.312

μ as a function of p along isenthalpic (or total heat) curves

Pressures in atmospheres; temperatures in °K; μ in °K per atm.

p	0	1	20	40	60	72.9	80	100
Vapor isenthalps								
T	379.94	380.63	393.12	404.56	414.39	420.00	422.88	430.22
μ	0.7080	0.7029	0.6118	0.5284	0.4564	0.4154	0.3944	0.3407
T	356.30	357.10	370.92	383.40	394.00	400.00	403.05	410.74
μ	0.7924	0.7860	0.6748	0.5745	0.4892	0.4410	0.4165	0.3546
T	331.40	332.30	347.99	361.90	373.52	380.00	383.27	391.43
μ	0.9054	0.8974	0.6582	0.6348	0.5317	0.4742	0.4452	0.3728
T	304.30	305.35	323.77	339.76	352.85	360.00	363.57	372.35
μ	1.0760	1.0655	0.8816	0.7220	0.5914	0.5200	0.4844	0.3967
T	272.42	273.88	297.03	316.46	331.83	340.00	344.00	353.64
μ	1.3750	1.3590	1.0885	0.8620	0.6826	0.5872	0.5405	0.4280
T	226.91	229.09	263.56	290.42	310.15	320.00	324.63	335.27
μ	2.1272	2.0948	1.5620	1.1470	0.8422	0.6900	0.6184	0.4540
T	208.69	211.26	[252.26]	282.91	304.56	315.00	319.82	330.59
μ	2.5786	2.5338	[1.8181]	1.2826	0.9046	0.7223	0.6381	0.4501

CO_2.—(*Continued*)

p	0	1	20	40	60	72.9	80	100
T	181.28	[184.70	237.43	274.42]	298.85	310.00	314.97	325.60
μ	3.4295	[3.3588	2.2620	1.4928]	0.9850	0.7533	0.6500	0.4290
T	157.40	[161.24	226.49	269.35	295.97]	307.50	312.48	322.77
μ	4.343	[4.2514	2.6950	1.6727	1.0380]	0.7630	0.6442	0.3998
T	120.90	[126.80	212.44	264.32	293.71]	305.50	310.36	319.77
μ	6.000	[5.832	3.400	1.926	1.091]	0.7560	0.6179	0.3508
T	76.00	[81.40	198.40	260.85	292.77]	304.50	309.09	317.42
μ	8.396	[8.114	4.288	2.1915	1.1200]	0.7264	0.5724	0.2926
Critical isenthalp								
T	0.00	[13.38	182.77	260.56	293.70	304.10]	307.80	313.82
μ	13.580	[13.01	5.783	2.463	1.049	0.6050]	0.4470	0.1906
Liquid isenthalps								
T	[195.21	198.25	251.57	281.51	297.44]	303.50	305.92	310.43
μ	[3.7974	3.6800	2.0194	1.0744	0.5716]	0.3804	0.3041	0.1618
T	[245.42	247.07	271.83	287.94	297.79]	302.00	303.81	307.48
μ	[1.6720	1.6312	1.0210	0.6239	0.3812]	0.2774	0.2329	0.1423
T	[265.03	265.92	280.04	290.11	296.87]	300.00	301.41	304.45
μ	[0.9102	0.8924	0.6108	0.4099	0.2751]	0.2127	0.1846	0.1239
T	[275.86	275.93	277.16]	278.34	279.39	280.00	280.32	281.14
μ	[0.06978	0.06936	0.06202]	0.05514	0.04901	0.04543	0.04357	0.03873
T	[259.24	259.26	259.46]	259.67	259.88	260.00	260.07	260.26
μ	[0.01096	0.01094	0.01064]	0.01027	0.00993	0.00973	0.00962	0.00931
T	[240.54	240.53]	240.40	240.29	240.10	240.00	239.94	239.79
μ	[−0.00704	−0.00705]	−0.00723	−0.00742	−0.00761	−0.00773	−0.00781	−0.00801
T	[222.19	222.17]	221.66	221.08	220.44	220.00	219.74	218.98
μ	[−0.02537	−0.02548]	−0.02778	−0.03040	−0.03329	−0.03528	−0.03464	−0.03989

H_2O Vapor, unit, °C/kg cm^{-2} (5)

°C	120	150	200	250	300	350	400
μ	5.33	3.63	2.20	1.50	1.15	0.90	0.75

At 165°C and 3.86 kg/cm², $\mu = 3.182$ (24).

CH_4, values of $\mu = \frac{t_1 - t_2}{p - 1}$ °C/atm. ±*ca.* 0.05 (21); *cf.* (15)

p	25	17	14.6	27	55
t_1, °C	−77	−78	−78	+10	10
μ	0.75	0.75	0.74	0.35	0.40

C_2H_5Cl, values of μ in °C/atm. for pressures less than 3 atm. (10)

°C	0	20	40	60	80	100
μ	5.22	4.51	3.86	3.31	2.84	2.43

Inversion Temperatures

$\mu = 0$ at t, °C and at p_{atm}.

t	p	Gas	t	p	Lit.
Air (20)		He	−173	(1)	(17)
300.4	90.1	H_2	80.5*	113	(15)
283.0	137.0	Liq. air	−133	150	(8, 12)
252.8	176.7		−140	125	(8, 12)
240.1	199.1	CO_2 (liq.)	− 24.0	18 to 100	(2)

* Temperature at which a drop from p to 1 atm. gives zero integrated cooling effect.

CHANGE IN TEMPERATURE ON ADIABATIC EXPANSION

H_2O, values of $10^5\left(\frac{\partial t}{\partial p}\right)$, unit, °C/kg cm^{-2}

p, kg/cm²	Lit.									
	(18)	(1)	(1)	(18)	(18)	(1)	(18)	(1)	(1)	(18)
	0°		20°	25°	37°	40°	54°	60°	80°	
1	−130	−16	+137	+ 66	260	287	390	417	548	492
500	− 20	+68	175	130	273	300	371	417	500	468
1 000	+ 64	132	220	167	279	309	357	413	462	445
1 500	116	183	248	188	279	316	344	406	427	423
2 000	150	215	263	203	279	322	335	397	403	406
3 000	189	251	280	223	284	325	325	381	367	382
4 000		260	283	240		323		366	344	
6 000		194	289			336		349	308	
8 000			355			333		337	279	
10 000						330		330	257	
12 000						320		320	238	

For calculated values 0 − 30°C and 1 to 1000 atm., *v.* (23).

Miscellaneous Substances

Substance	p	1	500	1000	1500	2000	2500	3000
	°C	$10^5 \frac{(dt)}{(dp)}$ (19)						
Benzene	90	2550	2000	1620	1390	1210	1090	990
Urethane	80	1300	1072	884	765	702	639	

Miscellaneous Substances.—(*Continued*)

Substance	p / °C	1	500	1000	1500	2000	2500	3000
		$10^5 \frac{(dt)}{(dp)}$ (19)						
Mix. A*........	90	2400	1890	1560	1300	1110	990	880
Phenol..........	80	1130	999	883	802	726	648	
p-Toluidine.....	80	1300	1158	1034				
Mix. B*........	80	1160	1016	905	782	691	644	
Ethyl alcohol....	30	1450	1180	965	805	715	658	
Water..........	0	−130	−20	+64	+116	+150	+173	+189
	80	492	468	445	423	406	392	382
Glycerol........	25	437	407	380	352	327	308	294
	98.2	625	570	520	475	441		
Castor oil......	0	785	700	628	564	507	468	448

* Mix. A is 75 mol % Benzene + 25 mol % Urethane. Mix. B is 75 mol % Phenol + 25 mol % *p*-Toluidine.

AQUEOUS SOLUTIONS (22)

Changes of temperature on adiabatic expansion

Wt. % KCl	0.747	7.11	19.43	Wt. % NaCl	5.63	10.68
ΔP	Δt	Δt	Δt	ΔP	Δt	Δt
101	−0.07	−0.05	−0.21	101	−0.10	−0.21
200	−0.05	−0.16	−0.39	200	−0.15	−0.34
300	−0.11	−0.26	−0.60	300	−0.24	−0.49
400	−0.12	−0.44	−0.72	400	−0.42	−0.67
498	−0.15	−0.55	−0.96	498	−0.55	−0.79

Wt. % H_2SO_4	3.94	7.69	Wt. % $ZnSO_4$	2.85	5.55	8.11
ΔP	Δt	Δt	ΔP	Δt	Δt	Δt
101	−0.11	−0.12	101	−0.02	−0.05	−0.09
200	−0.12	−0.32	200	−0.04	−0.10	−0.16
300	−0.25	−0.38	300	−0.10	−0.17	−0.24
400	−0.38	−0.58	400	−0.18	−0.24	−0.32
498	−0.54	−0.79	498	−0.27	−0.36	−0.45

Wt. % C_2H_5OH......	4.99	10.18
Wt. % NaCl..........	0.60	0.62
ΔP	Δt	Δt
101	−0.006	−0.04
200	−0.01	−0.09
300	−0.01	−0.13
400	−0.04	−0.19
498	−0.10	−0.24

Liquid NH_3, values of $l = \left(\frac{\partial Q}{\partial p}\right)_T$ (16)

Unit, joules per kg/atm.

°C.........	−44.1	−39.0	−24.2	−0.2	16.5	26.5	35.4	40.3
l..........	−57	−59	−70	−91	−111	−127	−145	−155

HEAT OF ISOTHERMAL COMPRESSION

$$Q = \int_0^p f(p)dQ$$

H_2O, values of 10^5Q, unit g-cal/g (1)

p, kg/cm²	0°	20°	40°	60°	80°C
0	0.0	0.0	0.0	0.0	0.0
500	0.2	0.7	1.5	2.1	2.6
1 000	0.6	1.6	2.9	4.1	5.0
2 000	1.9	3.8	5.8	7.9	9.2
3 000	4.0	6.4	8.7	11.4	13.1
4 000	6.4	8.9	11.6	14.6	16.5
6 000	10.6	14.0	17.3	20.9	23.2
8 000		19.6	23.1	27.0	29.3
10 000			28.7	32.9	35.3
12 000			34.5	38.8	40.8

Calculated values for CS_2, ether, alcohol and H_2O (3). Calculated values at 0°C for ethylene chloride, ethyl chloride, ethyl bromide, ethyl iodide, methyl acetate, ethyl acetate, benzene, toluene, xylene, cymene, bromine, mercury, acetone, carbon disulfide, carbon tetrachloride, chloroform and ether (13).

HEAT OF ELASTIC EXTENSION OF METALS

$\frac{\Delta t}{\Delta \tau} = -\frac{aT}{cd}$, where $\Delta\tau$ = tension increase and Δt the corresponding temperature increase, a = the coefficient of thermal expansion, d the density, c the specific heat per gram and T the temperature in °K; Q = heat absorbed.

$\Delta\tau$, kg/cm²	Δt, °C	Q, g-cal$_{15}$/cm³	
Steel at 23.9°C, d = 7.93 g/cm³ (4)			
1656	−0.1369	0.1279	±0.4%
3312	−0.2737	0.2556	
4968	−0.4106	0.3836	
German silver at 16.4°C, d = 8.40 g/cm³ (7)			
969	−0.1405	0.1135±3%	

TEMPERATURE CHANGE IN PLASTIC EXTENSION (6)

$100\ \Delta l/l_0$ = % elongation.

Δt_t = Temp. rise with tension maintained.

Δt_r = Temp. rise on relief of residual tension.

Δt_w = Temp. rise to be expected from work done by tension.

$\frac{\Delta t_t + \Delta t_r}{\Delta t_w}$ = R = Ratio of heat evolved to work done.

Metal	$100\ \Delta l/l_0$ max.*	Δt_t	Δt_r	R
Steel....................	13.10	9.00	0.37	0.86$_5$
Cu......................	17.45	6.29	0.31	0.92
Al.......................	23.06	5.68	0.28	0.93
Al, single crys...........	52.72	8.77	0.19	0.95

* R is independent of $\Delta\ l/l_0$ up to the maximum value studied.

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(For a key to the periodicals see end of volume)

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HEATS OF SOLUTION OF ORGANIC SUBSTANCES

ERNEST ANDERSON

CONTENTS

Tables 1 and 2 form a complete index to the whole.*

TABLE 1.—HEATS OF SOLUTION OF ORGANIC SUBSTANCES IN WATER

Q is expressed as kilojoules evolved per mole solute, at infinite dilution. These systems are arranged according to the ℭ- arrangement (*v.* Vol. III, p. viii). Inorganic salts of organic acids will be found immediately following the acid.

Formula	Name	*t*, °C	*Q*	Lit. and table numbers
$CHCl_3$	Chloroform	16	9.2	(20)
CH_2N_2	Cyanamide		−15.1	(105)
CH_2O_2	Formic acid (solid)	7	−9.83	(10)
	Formic acid (liquid)	7	0.33	(10); 5
CH_3NO_2	Nitromethane		−2.5	(39)
CH_4N_2O	Urea		−15.1	(43, 111)
CH_4N_2S	Thiourea	10	−22.3	(111)
CH_4O	Methyl alcohol		8.37	(14, 68, 69, 70, 75, 81); 6
CH_5N	Methylamine			(47)
$CH_5N_3O_4$	Urea nitrate		−45.2	(111)
$CH_6N_4O_3$	Guanidine nitrate		−42.7	(111)
$C_2HBr_3O_2$	Tribromoacetic acid		4.69	(115); 5
$C_2HCl_3O_2$	Trichloroacetic acid (solid)		12.1	(106, 115); 5
	Trichloroacetic acid (liquid)	15	22.08	(115)
	Na trichloroacetate		7.28	(106)
$C_2H_2Br_2O_2$	Dibromoacetic acid		11.7	(115); 5
$C_2H_2Cl_2O_2$	Dichloroacetic acid		4.69	(106, 115); 5
$C_2H_2O_2$	Glyoxal		−5.23	(66)
	Glyoxal bisulfite		−40.4	(66)
$C_2H_2O_4$	Oxalic acid		−9.58	(96, 108)
$C_2H_2O_4.2H_2O$	Oxalic acid		−35.5	(96)
$C_2H_3BrO_2$	Bromoacetic acid		−12.8	(115); 5
$C_2H_3ClO_2$	Chloroacetic acid (solid)	16	−14.0	(106, 115)
	Chloroacetic acid (liquid)	16	1.12	(106, 115)
$C_2H_3Cl_3O_2$	Chloral hydrate		−3.77	(20, 88, 122)
$C_2H_3NO_3$	Oxamic acid	12	−29	(111)
	K oxamate		−31.0	(110)
C_2H_4O	Acetaldehyde		15.1	(8)
$C_2H_4O_2$	Acetic acid (solid)	7	−8.91	(10)
		14	−9.42	(10)
	Acetic acid (liquid)	7	1.67	(37); 5
		23	1.00	(10)
$C_2H_4O_2$	Methyl formate	15	4.73	(41)
$C_2H_4O_3$	Glycolic acid		−11.55	(66)
	Ba glycolate		−21.26	(66)
	Ca glycolate		−6.78	(66)
	Ca glycolate ($3H_2O$)		−29.55	(66)
	Ca glycolate ($5H_2O$)		−32.6	(66)
	Cu glycolate		−6.78	(66)
	K glycolate		−6.86	(66)
	K glycolate ($0.5H_2O$)		−19.7	(66)
	Mg glycolate		−18.41	(66)
	Na glycolate		−10.30	(66)
	Na glycolate ($0.5H_2O$)		−14.6	(66)
	NH_4 glycolate		−13.52	(66)
	Pb glycolate		−24.02	(66)
	Sr glycolate		−5.02	(66)
	Zn glycolate		−2.76	(66)
$C_2H_4O_4$	Glyoxylic acid	11	−10.5	(67)
	Ca glyoxylate		−9.37	(67)
	Na glyoxylate		−20.1	(67)
C_2H_5NO	Acetamide	23	−8.33	(122)
$C_2H_5NO_2$	Glycocoll		−14.98	(106)
$C_2H_5NO_3$	Ethyl nitrate		4.14	(15)
C_2H_6O	Ethyl alcohol	13	10.63	(14, 48, 75, 81, 138); 3, 6
C_2H_6O	Dimethyl ether	17	34.7	(21)
$C_2H_6O_2$	Glycol		7.1	(23, 73); 3
$C_2H_6N_2O_3$	Urea formate		−30.1	(111)
$C_2H_6O_4S$	Ethyl sulfuric acid			
	Ba ethylsulfate		2.9	(14)
	Ba ethylsulfate ($2H_2O$)		−18.0	(14)
	Na ethylsulfate		−4.2	(14)
	Na ethylsulfate (H_2O)		−13.0	(14)
C_2H_7N	Ethylamine	19	26.49	(6, 22, 58)
C_2H_8ClN	Ethylamine hydrochloride		−9.33	(87)
$C_2H_8N_2$	Ethylenediamine		31.8	(60)
$C_2H_{10}Cl_2N_2$	Ethylenediamine dihydrochloride		−31.60	(60)
$C_2H_{12}N_6O_4S$	Guanidine sulfate		−28.25	(111)
$C_3H_2Br_2O_4$	Dibromomalonic acid		8.45	(108)
	KH dibromomalonate		−23.4	(108)
	K_2 dibromomalonate		−41.60	(108)
$C_3H_3N_3O_3$	Cyanuric acid		*v.* p. 182	
$C_3H_4Br_2O_2$	α-Dibromopropionic acid	13	6.86	(125)
	K α-dibromopropionate		2.18	(125)
	K α-dibromopropionate (H_2O)		−12.1	(125)
$C_3H_4N_2O_2$	Hydantoin		−25.1	(111)
$C_3H_4O_4$	Malonic acid		−18.8	(108)
	Ag_2 malonate		−41.0	(108)
	KH malonate		−21.3	(108)
	K_2 malonate		8.8	(108)
	K_2 malonate ($2H_2O$)		−23.4	(108)
	LiH malonate		−5.9	(108)
	Li_2 malonate		14.6	(108)
	NaH malonate		−25.5	(108)
	Na_2 malonate		13.0	(108)
	Na_2 malonate (H_2O)		6.3	(108)
	NH_4H malonate		−25.1	(108)
	$(NH_4)_2$ malonate		−10.5	(108)
$C_3H_4O_5$	Tartronic acid		−15.69	(108)
	KH tartronate	14	−31.4	(108)
	K_2 tartronate		−19.88	(108)
	Na_2 tartronate	10	−12.6	(108)
C_3H_5N	Propionitrile		−3.26	(120)
$C_3H_6N_2O_2$	Acetylurea		−28.5	(110)
$C_3H_6N_2O_3$	Hydantoic acid		−27.2	(111)
C_3H_6O	Allyl alcohol		8.37	(14)
C_3H_6O	Propionaldehyde		17	(14)
C_3H_6O	Acetone		10.5	(14); 4
$C_3H_6O_2$	Propionic acid		2.59	(108); 5
	Ba propionate		28.75	(11)
	K propionate		12.64	(108)
	Na propionate		12.76	(108)
$C_3H_6O_2$	Ethyl formate	10	8.8	(41)
C_3H_7N	Allylamine		19.59	(58, 87)
C_3H_7NO	Propionamide	15	−4	(35)
$C_3H_7NO_2$	Urethane	23	−15.9	(122)
$C_3H_8N_2O$	Ethylurea	14	−9.6	(111)
$C_3H_8N_2O_3$	Urea acetate		−36.8	(111)
C_3H_8O	*n*-Propyl alcohol		12.76	(49, 70); 6
C_3H_8O	Isopropyl alcohol		15.74	(75, 76)
$C_3H_8O_2$	Methylal		13.4	(40)
$C_3H_8O_3$	Glycerol		6.3	(8, 14, 71, 72, 89, 100); 4
C_3H_9N	Propylamine		25.74	(58)
C_3H_9N	Trimethylamine		36.62	(22, 58)
$C_3H_{10}ClN$	Trimethylamine hydrochloride	18	−2.1	(22)
$C_4H_2N_2O_4$	Alloxan		−17.6	(112)
$C_4H_4O_4$	Fumaric acid		−24.7	(83, 86)
$C_4H_4O_4$	Maleic acid		−18.58	(83, 86)
$C_4H_5NO_2$	Succinimide	22	−18.0	(122)
$C_4H_6N_4O_3$	Allantoin		−31.4	(110)
$C_4H_6O_4$	Succinic acid	11	−26.8	(54)
	KH succinate		−22.39	(108)
	KH succinate (H_2O)		−31.8	(54)

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* The numbers in the last column not in parentheses are numbers of other tables in this section which should be consulted for further data.

TABLE 1.—(*Continued*)

Formula	Name	t, °C	Q	Lit. and table numbers
$C_4H_6O_4$	K₂ succinate		0.8	(54)
	K₂ succinate (H₂O)		-14.2	(54)
	NaH succinate		-11.7	(108)
	Na₂ succinate		10.0	(108)
	Na₂ succinate (6H₂O)		-46.0	(54)
	NH₄H succinate		-20.5	(54)
	(NH₄)₂ succinate		-14.6	(108)
$C_4H_6O_4$	Isosuccinic acid	6	-14.31	(108)
	KH isosuccinate		-15.74	(108)
	KH isosuccinate (H₂O)		-19.08	(108)
	K₂ isosuccinate		13.06	(108)
	K₂ isosuccinate (H₂O)		8.16	(108)
	K₂ isosuccinate (2H₂O)		5.90	(108)
	Na₂ isosuccinate		20.5	(108)
$C_4H_6O_4$	Dimethyl oxalate		-9.37	(18)
$C_4H_6O_5$	Malic acid	15	-13.8	(107, 108)
		20	-13.18	(85)
	KH malate		-24.3	(107, 108)
	KH malate (H₂O)		-27.6	(108)
	K₂ malate		-6.49	(107, 108)
	NaH malate	21	-6.95	(107, 108)
	NaH malate (H₂O)	18	-11.17	(108)
	Na₂ malate	21	7.45	(107, 108)
$C_4H_6O_6$	*d*-Tartaric acid		-14.44	(36)
	KH tartrate	12	-48.5	(95)
	K₂ tartrate		-14.90	(10)
	K₂ tartrate (0.5H₂O)		-23.27	(10)
	KSbO tartrate	12	-21.3	(91)
	KSbO tartrate (0.5H₂O)		-22.2	(91)
	NaH tartrate		-23.69	(10)
	NaH tartrate (H₂O)		-35.74	(10)
	NaK tartrate		-7.83	(10)
	NaK tartrate (4H₂O)		-51.64	(10)
	Na₂ tartrate		-4.69	(10)
	Na₂ tartrate (2H₂O)		-24.61	(10)
	dl-Tartaric acid		-22.68	(36, 108)
	dl-Tartaric acid (H₂O)		-28.88	(36)
	meso-Tartaric acid		-21.93	(36, 108)
$C_4H_7Cl_3O_2$	Chloral alcoholate		0.0	(24)
$C_4H_7NO_4$	Aspartic acid	16	-30.34	(32)
$C_4H_8O_2$	*n*-Butyric acid			5
	Na *n*-butyrate		17.74	(11)
	Na *n*-butyrate (3H₂O)		14.40	(11)
$C_4H_8O_2$	Isobutyric acid		4.2	(84)
	Ca isobutyrate (5H₂O)		13.0	(53)
$C_4H_8O_2$	Ethyl acetate	15	12.81	(18)
$C_4H_{10}N_4O_6$	Urea oxalate	17	-74.5	(111)
$C_4H_{10}O$	Isobutyl alcohol		12.1	(14, 70)
$C_4H_{10}O$	Trimethyl carbinol	15	13.52	(77)
$C_4H_{10}O$	Ethyl ether	13	-24.7	(17)
$C_4H_{10}O_4$	Erythritol		-22.2	(38, 74)
$C_4H_{11}N$	Diethylamine		34.40	(58)
$C_4H_{11}N$	Isobutylamine		25	(58)
$C_4H_{12}ClN$	Diethylamine hydrochloride		-6.24	(7)
$C_5H_4N_4O_2S$	Thiouric acid (1.5H₂O)		-44.8	(112)
	K₂ thiourate		-69.5	(112)
	Na₂ thiourate		-26.8	(112)
$C_5H_4N_4O_3$	Uric acid			
	K urate		-35.2	(112)
C_5H_5N	Pyridine	22	8.87	(30, 58)
$C_5H_6N_2O_3$	Dimethylparabanic acid		-19.46	(110)
$C_5H_6N_4O_4$	Pseudouric acid			
	K pseudourate (H₂O)		-28.9	(112)
$C_5H_6O_4$	Citraconic acid		-11.7	(83)
$C_5H_6O_4$	Itaconic acid		-24.78	(83)
$C_5H_6O_4$	Mesaconic acid	19	-23.0	(83)
$C_5H_8O_2$	Acetylacetone		-2.68	(61, 120)
$C_5H_8O_3$	Levulinic acid (solid)		-15.02	(124)
	Levulinic acid (liquid)		-5.82	(124)
	K levulinate		6.03	(124)
	Na levulinate		5.65	(124)
$C_5H_8O_4$	Glutaric acid		-22.6	(108)
	KH glutarate		-18.58	(108)
	K₂ glutarate		19.13	(108)
$C_5H_8O_4$	Pyrotartaric acid		-21	(108)
	KH pyrotartrate		-13.0	(108)
	KH pyrotartrate (H₂O)		-17.6	(108)
	K₂ pyrotartrate		19.3	(108)

TABLE 1.—(*Continued*)

Formula	Name	t, °C	Q	Lit. and table numbers
$C_5H_8O_4$	Monoethyl malonate		2.5	(108)
	K ethyl malonate		-2.72	(108)
$C_5H_{10}O_2$	Isovaleric acid		2.9	(12)
$C_5H_{10}O_2$	Trimethylacetic acid			
	K trimethylacetate	16	30.76	(10)
$C_5H_{11}N$	Piperidine	21	27.04	(30, 58)
$C_5H_{12}ClN$	Piperidine hydrochloride		-4	(59)
$C_5H_{12}O$	Isoamyl alcohol		11.7	(14, 70)
$C_5H_{13}N$	Amylamine		21.13	(58, 87)
$C_5H_{14}ClN$	Amylamine hydrochloride		-5.73	(87)
$C_6H_3Br_3O_2$	1, 3-Dihydroxy-2, 4, 6-tribromobenzene		-9.2	(45)
$C_6H_3N_3O_7$	Picric acid		-29.7	(9)
	Ba picrate		-19.7	(129)
	Ba picrate (H₂O)		-39.3	(129)
	Ba picrate (6H₂O)		-61.73	(129)
	Ca picrate		9.2	(129)
	Ca picrate (6H₂O)		-62.4	(129)
	Cu picrate		13.8	(129)
	Cu picrate (8H₂O)		-73.7	(129)
	K picrate		-42	(9, 129)
	Mg picrate		61.5	(129)
	Mg picrate (8H₂O)		-66.5	(129)
	Na picrate		-26.95	(9, 129)
	NH₄ picrate		-36.4	(9, 129)
	Pb picrate		-29.7	(129)
	Pb picrate (2H₂O)		-55.2	(129)
	Sr picrate		3.3	(129)
	Sr picrate (6H₂O)		-60.3	(129)
	Zn picrate		48.1	(129)
	Zn picrate (8H₂O)		-66.5	(129)
$C_6H_4O_2$	Quinone		-16.7	(44)
C_6H_5BrO	*p*-Bromophenol		-15.5	(135)
$C_6H_5ClN_2$	Phenyldiazonium chloride		-7.70	(123)
$C_6H_5NO_3$	*o*-Nitrophenol		-26.4	(1)
	Na *o*-nitrophenate		-7.5	(1)
$C_6H_5NO_3$	*m*-Nitrophenol		-21.8	(1)
	Na *m*-nitrophenate		13.0	(106)
$C_6H_5NO_3$	*p*-Nitrophenol		-18.8	(1)
	Na *p*-nitrophenate		11.3	(1)
$C_6H_6O_2$	Catechol		-14.6	(44, 78)
$C_6H_6O_2$	Resorcinol	10	-16.57	(44, 78, 88, 122)
$C_6H_6O_2$	Hydroquinol		-18.4	(44, 78)
$C_6H_6O_3$	Phloroglucinol		-6.91	(44)
	Phloroglucinol (H₂O)		-28.0	(44)
$C_6H_6O_3$	Pyrogallol		-15.5	(44, 78, 88)
C_6H_6ClN	*o*-Chloroaniline		-2.34	(106)
C_6H_6ClN	*m*-Chloroaniline		-3.47	(106)
C_6H_6ClN	*p*-Chloroaniline		-21.39	(106)
$C_6H_6N_2O_2$	*p*-Nitroaniline		-15.65	(106)
C_6H_6O	Phenol (solid)		-10.9	(8, 78, 88, 100)
$C_6H_6O_3S$	Benzenesulfonic acid			
	Ba benzenesulfonate		10.9	(13)
	Ba benzenesulfonate (3H₂O)		-10.9	(13)
	Na benzenesulfonate	14	-3.3	(13)
	Na benzenesulfonate (2H₂O)		-14.2	(13)
$C_6H_6O_4S$	*o*-Phenolsulfonic acid			
	Ba *o*-phenolsulfonate (H₂O)		-56.5	(2)
	K *o*-phenolsulfonate (2H₂O)		-40.6	(2)
$C_6H_6O_6$	Aconitic acid		-17.6	(7)
$C_6H_6O_7S_2$	Phenol-2, 4-disulfonate			
	Ba phenol-2, 4-disulfonate (4H₂O)		-33.1	(3)
$C_6H_7Cl_2N$	*o*-Chloroaniline hydrochloride		-18.33	(106)
$C_6H_7Cl_2N$	*m*-Chloroaniline hydrochloride		-16.45	(106)
$C_6H_7Cl_2N$	*p*-Chloroaniline hydrochloride		-14.61	(106)
C_6H_7N	Aniline	16	-0.75	(29)
		24	-2.30	(29)
C_6H_8ClN	Aniline hydrochloride		-11.43	(29)
$C_6H_8N_2$	Phenylhydrazine (liquid)	21	1.21	(33)
	Phenylhydrazine (H₂O)		-31.0	(33)
$C_6H_8N_2$	*m*-Phenylenediamine		-13.4	(133)
$C_6H_8N_2$	*p*-Phenylenediamine		-15.9	(132)
$C_6H_8N_2O_3$	Aniline nitrate		-28.17	(29)

TABLE 1.—(*Continued*)

Formula	Name	*t*, °C	*Q*	Lit. and table numbers
$C_6H_8O_6$	Tricarballylic acid		−27.2	(108)
	KH_2 tricarballylate		−28.0	(108)
	K_2H tricarballylate		−16.7	(108)
	K_3 tricarballylate		13.0	(108)
	Na_3 tricarballylate		27.6	(108)
$C_6H_8O_7$	Citric acid		−22.6	(88, 108)
	KH_2 citrate		−33.5	(108)
	K_2H citrate		−28.0	(108)
	K_3 citrate		11.8	(108)
	NaH_2 citrate		−26.57	(108)
	Na_2H citrate		− 5.11	(108)
	Na_3 citrate		22.05	(108)
$C_6H_9ClN_2$	Phenylhydrazine hydrochloride		−24.94	(114)
$C_6H_{10}O_3$	Ethyl acetoacetate		5.27	(80)
	Na ethyl acetoacetate		18.4	(79)
$C_6H_{10}O_4$	Diethyl oxalate	15	12.89	(18)
$C_6H_{11}Cl_3N_2$	*o*-Phenylenediamine trihydrochloride ($5H_2O$)		−34.3	(133)
$C_6H_{12}N_4$	Hexamethylenetetramine		20.1	(62)
$C_6H_{12}O$	Cyclohexanol (solid)		8.12	(82)
	Cyclohexanol (liquid)		9.8	(82)
$C_6H_{12}O_6$	Inositol	18	−14.15	(31)
$C_6H_{13}ClN_4$	Hexamethylenetetramine hydrochloride	15	−16.49	(62)
$C_6H_{13}N_5O_3$	Hexamethylenetetramine nitrate		−23.02	(62)
$C_6H_{14}N_4O_4S$	Hexamethylenetetramine sulfate		− 6.70	(62)
$C_6H_{14}N_6O_6$	Hexamethylenetetramine dinitrate		−59.8	(62)
$C_6H_{14}O_6$	Dulcitol		−24.7	(14)
$C_6H_{14}O_6$	Mannitol	23	−22.01	(14, 122)
$C_6H_{15}IS$	Triethylsulfonium iodide		−24.06	(7)
$C_6H_{15}N$	Dipropylamine		31.60	(58)
$C_6H_{15}N$	Triethylamine		42	(58, 87)
$C_6H_{16}ClN$	Triethylamine hydrochloride		− 2.22	(87)
$C_7H_4O_7$	Meconic acid		−38.1	(27)
$C_7H_5ClO_2$	*o*-Chlorobenzoic acid		−26.9	(116)
	K *o*-chlorobenzoate ($0.5H_2O$)		1.51	(116)
$C_7H_5NO_4$	*o*-Nitrobenzoic acid		−22.2	(1, 90)
	Na *o*-nitrobenzoate		16.3	(1)
$C_7H_5NO_4$	*m*-Nitrobenzoic acid		−23.4	(1, 106)
	Na *m*-nitrobenzoate		− 4.6	(1, 106)
$C_7H_5NO_4$	*p*-Nitrobenzoic acid		−37.2	(1)
	Na *p*-nitrobenzoate		− 4.19	(1)
$C_7H_6O_2$	Salicylaldehyde		0.4	(25)
$C_7H_6O_2$	*p*-Hydroxybenzaldehyde		−20.5	(25)
$C_7H_6O_2$	Benzoic acid		−27.2	(9, 108)
	Ca benzoate		19.7	(9)
	K benzoate		− 6.3	(9)
	Na benzoate		3.3	(9)
	NH_4 benzoate		−11.3	(9)
$C_7H_6O_3$	*o*-Hydroxybenzoic acid		−26.57	(46)
	Na *o*-hydroxybenzoate		− 9.17	(108)
$C_7H_6O_3$	*m*-Hydroxybenzoic acid		−25.86	(46)
$C_7H_6O_3$	*p*-Hydroxybenzoic acid		−24.19	(46)
	p-Hydroxybenzoic acid (H_2O)		−32.31	(46)
$C_7H_6O_4$	3, 4-Dihydroxybenzoic acid (H_2O)	17	−29.7	(25)
$C_7H_6O_5$	Gallic acid (H_2O)		−29.7	(25)
$C_7H_7NO_2$	*o*-Hydroxybenzamide		−18.16	(1)
	Na *o*-hydroxybenzamide		1.46	(1)
$C_7H_7NO_2$	*m*-Hydroxybenzamide		−17.41	(106)
	Na *m*-hydroxybenzamide		5.9	(106)
$C_7H_7NO_2$	*p*-Hydroxybenzamide		−22.56	(1)
	Na *p*-hydroxybenzamide		8.0	(1)
$C_7H_8ClNO_2$	*m*-Hydroxybenzamide hydrochloride		−29.3	(106)
C_7H_8O	*o*-Cresol		− 8.8	(28)
C_7H_8O	*p*-Cresol		− 8.8	(28)
$C_7H_8O_2$	Orcinol		−10.9	(44)
	Orcinol (H_2O)		−22.6	(44)
$C_7H_8O_2$	*o*-Hydroxybenzyl alcohol		−13.4	(25)
$C_7H_8O_3S$	*p*-Toluenesulfonic acid			
	K *p*-toluenesulfonate		−20.9	(26)
C_7H_9N	Benzylamine		10.71	(58, 87)
C_7H_9N	*p*-Toluidine		−18.8	(7)
$C_7H_9NO_2$	Pyridine acetate		8.069	(109)
$C_7H_{10}ClN$	Benzylamine hydrochloride		−16.03	(87)
$C_7H_{10}ClN$	*p*-Toluidine hydrochloride		−13.60	(7)
$C_7H_{12}O_6$	Quinic acid	17	−12.76	(27)
$C_8H_6N_4O_8$	Alloxantin ($2H_2O$)		−44.4	(112)
$C_8H_6O_4$	Phthalic acid		−20.38	(57)
	Na_2 phthalate		1.00	(57)
	Na_2 isophthalate		− 3.3	(57)
	Na_2 terephthalate		− 2.5	(57)
$C_8H_6O_4$	Piperonylic acid		−38.1	(26)
$C_8H_8O_3$	Anisic acid		−33.1	(26)
$C_8H_8O_3$	Mandelic acid	18	−12.93	(26)
$C_8H_8O_3$	Vanillin		−21.8	(26)
$C_8H_8O_4$	Vanillic acid	14	−21.59	(26)
$C_8H_{10}N_4O_2$	Caffeine		−11.47	(112)
	Caffeine (H_2O)		−18.67	(112)
$C_8H_{11}NO_4$	Diethyl cyanomalonate			
	Ba ethyl cyanomalonate		10.0	(93)
	Ba ethyl cyanomalonate ($4H_2O$)		−20.5	(93)
	Na ethyl cyanomalonate		−10.9	(93)
$C_8H_{16}O_2$	Caprylic acid		0.67	(108)
$C_8H_{19}N$	Diisobutylamine		29.50	(58)
$C_9H_{10}O_4$	Veratric acid		−25.5	(26)
$C_{10}H_{11}NO_4$	Nitrocumic acid			
	Na nitrocumate		− 5.0	(1)
$C_{10}H_{12}O_2$	Cumic acid			
	Na cumate		15.9	(1)
$C_{10}H_{15}NO_3$	Nitrocamphor		− 7.5	(42)
	Hydrated nitrocamphor		−11.7	(42)
$C_{10}H_{16}Cl_2N_2$	Nicotine dihydrochloride		27.45	(58)
$C_{10}H_{16}O_2$	Campholenic acid		−13.4	(34)
$C_{10}H_{16}O_4$	Camphoric acid		− 2.1	(27)
$C_{10}H_{20}O$	Menthol		0	(88)
$C_{12}H_6O_{12}$	Mellitic acid		15.36	(27)
$C_{12}H_{10}O_4$	Piperic acid		−43.9	(26)
$C_{12}H_{13}ClN_2$	Benzidine hydrochloride		−31.4	(114)
$C_{12}H_{14}Cl_2N_2$	Benzidine dihydrochloride		−24.7	(114)
$C_{12}H_{16}N_2O_4S$	Aniline sulfate		−19.38	(29)
$C_{12}H_{20}O_{10}$	Dextrin		− 1.12	(136)
$C_{12}H_{22}O_{11}$	Lactose		10.5	(96)
	Lactose (H_2O)		−15.5	(96)
$C_{12}H_{22}O_{11}$	Sucrose	23	− 5.52	(14, 100, 122)
$C_{13}H_{18}O_7$	Salicin	18	−12.26	(26)
$C_{14}H_{10}N_2O_4$	*m, m'*-Azobenzoic acid			
	Na_2 *m, m'*-azobenzoate		18.4	(1)
	Na_2 *p, p'*-azobenzoate		− 7.5	(1)
$C_{14}H_{10}O_9$	Tannic acid			(100)
$C_{17}H_{22}N_2$	Tetramethyldiaminodiphenylmethane	18	0.25	(134)
$C_{18}H_{32}O_{16}$	Raffinose		35.2	(38)
	Raffinose ($5H_2O$)		−40.6	(38)
$C_{20}H_{22}N_2O_4$	Azocumic acid			
	Na_2 azocumate		28.9	(1)
$C_{20}H_{24}N_2O_4$	Hydrazocumic acid			
	Na_2 hydrazocumate		43.1	(1)
$C_{36}H_{62}O_{31}$	Inulin		− 0.4	(136)

TABLE 2.—HEATS OF SOLUTION OF BINARY ORGANIC SYSTEMS

ℭ-Table.—ℭ-Arrangement (*v.* Vol. III, p. viii)

The B-component where italicized is the solute, and otherwise is the solvent. *Q* is expressed in kilojoules evolved per mole solute, dissolved in more than one mole solvent; at room temperature where not given.

B-Component		*Q*	Lit. and Table No.*
Formula	Name (and temp., °C)		
	CCl_4		
CS_2	Carbon bisulfide	− 1.76	(127); 3
$\mathit{CHCl_3}$	*Chloroform*		3
CH_4O	Methyl alcohol	0.67	(127)

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* The numbers not in parentheses are numbers of other tables in this section which should be consulted for further data.

TABLE 2.—(*Continued*)

B-Component		Q	Lit. and Table No.*
Formula	Name (and temp., °C)		
CCl_4.—(*Continued*)			
CH_4O	*Methyl alcohol*	−6.7	(127)
$C_2H_4Br_2$	Ethylene bromide		3
$C_2H_4O_2$	Acetic acid	−0.8	(127)
$C_2H_4O_2$	*Acetic acid*	−1.88	(127)
C_2H_6O	Ethyl alcohol	0.88	(127)
C_3H_6O	*Acetone*	−1.7	(127)
C_3H_8O	Propyl alcohol	0.8	(127)
$C_4H_8O_2$	*Ethyl acetate*	−0.29	(127, 130); 3
$C_4H_{10}O$	Isobutyl alcohol	−1.3	(127)
$C_4H_{10}O$	*Ethyl ether*	2.1	(127)
C_5H_5N	Pyridine	1.3	(127)
C_5H_5N	*Pyridine*	−1.3	(127)
C_6H_6	Benzene	−0.67	(127); 3
C_6H_6	*Benzene*	−0.50	(127); 3, 4
C_6H_7N	Aniline	−4.52	(127); 3
C_6H_7N	*Aniline*	−8.8	(127)
$C_7H_6O_2$	*Benzoic acid*	−14.6	(127)
$C_7H_6O_3$	*Salicylic acid*	−11.3	(127)
C_7H_8	*Toluene*		3, 4
$C_7H_9NO_2$	*Pyridine acetate*	−0.448	(109)
C_7H_{16}	Heptane	−0.71	(127)
C_7H_{16}	*Heptane*	−1.00	(127)
$C_{12}H_{24}O_2$	*Lauric acid*	−35.6	(127)
$C_{22}H_{42}O_2$	*Erucic acid*	−50.6	(127)
CS_2			
$CHCl_3$	*Chloroform*	−2.43	(127); 3, 4
$C_2H_4Br_2$	Ethylene bromide		3
C_2H_6O	*Ethyl alcohol*	−6.7	(127); 4
C_3H_6O	*Acetone*	−7.5	(127); 4
$C_4H_8O_2$	*Ethyl acetate*	−6.53	(127); 3
$C_4H_{10}O$	*Ethyl ether*	−4.2	(127); 3
C_6H_6	*Benzene*	−2.80	(127); 3, 4
$C_6H_{12}O_3$	Paraldehyde		3
C_7H_8	*Toluene*		4
C_7H_{16}	*Heptane*	−2.85	(127)
$C_{10}H_7NO_2$	*Nitronaphthalene*	−22.68	(88)
$C_{10}H_8$	*Naphthalene*	−20.9	(88)
$C_{10}H_{16}$	Pinene		3
$C_{12}H_{10}N_2$	*Azobenzene*	−20.84	(88)
$C_{12}H_{11}N$	*Diphenylamine*	−15.0	(88)
$CHBr_3$, Bromoform			
C_7H_8	*Toluene*		3
$CHCl_3$, Chloroform			
CH_4O	Methyl alcohol	4.77	(127); 3
$C_2H_3Cl_3O_2$	*Chloral hydrate* (22°)	−25.07	(122)
$C_2H_4Br_2$	Ethylene bromide		3
C_2H_4O	Acetaldehyde		3
$C_2H_4O_2$	Acetic acid	2.43	(127)
$C_2H_4O_2$	*Acetic acid*	2.1	(127)
C_2H_6O	Ethyl alcohol	6.03	(127); 3
C_3H_6O	Acetone	4.85	(127); 3, 4
C_3H_6O	*Acetone*	8.0	(127, 128)
$C_3H_7NO_2$	*Urethane* (24°)	−19.3	(122)

TABLE 2.—(*Continued*)

B-Component		Q	Lit. and Table No.*
Formula	Name (and temp., °C)		
$CHCl_3$.—(*Continued*)			
C_3H_8O	*n*-Propyl alcohol	4.69	(127); 3
$C_4H_8O_2$	Ethyl acetate	5.61	(127); 3
$C_4H_8O_2$	*Ethyl acetate*	9.08	(127)
$C_4H_{10}O$	Ethyl ether	8.41	(127); 3
$C_4H_{10}O$	*Ethyl ether*	8.8	(127); 4
$C_4H_{10}O$	Isobutyl alcohol		3
C_5H_5N	Pyridine	6.19	(127)
C_5H_5N	*Pyridine*	7.70	(127)
$C_5H_{12}O$	Isoamyl alcohol		3
C_6H_5Cl	*Chlorobenzene*		3
$C_6H_5NO_3$	*o-Nitrophenol*	−17.03	(88)
C_6H_6	Benzene	1.00	(127); 3
C_6H_6	*Benzene*	1.80	(127, 130); 3, 4
C_6H_6O	*Phenol*	−16.7	(127)
C_6H_7N	Aniline	0	(127)
C_6H_7N	*Aniline*	−1.3	(127)
C_6H_{10}	*Cyclohexene*		3
C_6H_{12}	*Cyclohexane*		3
$C_6H_{12}O_3$	Paraldehyde		3
$C_7H_6O_2$	*Benzoic acid*	−13.4	(127)
C_7H_8	*Toluene*		3
C_7H_9N	*p-Toluidine* (23°)	−14.61	(122)
$C_7H_9NO_2$	*Pyridine acetate*	5.047	(109)
C_7H_{16}	*Heptane*	3.06	(127)
C_8H_9NO	*Acetanilide* (25°)	−18.4	(122)
C_8H_{10}	*p-Xylene*		3
C_8H_{18}	Octane	−2.34	(127)
$C_{10}H_7NO_2$	*Nitronaphthalene*	−17.45	(88)
$C_{10}H_8$	*Naphthalene* (23°)	−16.11	(122)
$C_{12}H_{10}$	*Acenaphthene* (21°)	−18.8	(122)
CH_4N_2O, Urea			
C_2H_6O	Ethyl alcohol (24°)	−15.11	(122)
CH_2O_2, Formic acid			
$C_2H_4O_2$	Acetic acid		3
CH_4O, Methyl alcohol			
$C_2H_2O_4$	*Oxalic acid*	−3.64	(126)
$C_2H_2O_4$	*Oxalic acid* ($2H_2O$)	−21.8	(126)
$C_2H_4O_2$	Acetic acid	0	(127)
$C_2H_4O_2$	*Acetic acid*	0.79	(127)
C_2H_6O	Ethyl alcohol		3, 4
C_3H_6O	*Acetone*	−2.09	(127); 3
$C_3H_7NO_2$	*Urethane* (24°)	−18.20	(122)
C_3H_8O	*n*-Propyl alcohol		3, 4
C_3H_8O	Isopropyl alcohol		3
$C_4H_8O_2$	Ethyl acetate	−5.44	(127)
$C_4H_8O_2$	*Ethyl acetate*	−3.10	(127)
$C_4H_{10}O$	Ethyl ether	−2.5	(127); 3
$C_4H_{10}O$	Isobutyl alcohol		3
C_5H_5N	Pyridine	2.30	(127)
C_5H_5N	*Pyridine*	4.19	(127)
$C_5H_{12}O$	*Isoamyl alcohol*		3
$C_6H_5NO_3$	*o-Nitrophenol*	−20.1	(127)
C_6H_6	Benzene	−11.7	(127)
C_6H_6	*Benzene*	−1.51	(127); 4
$C_6H_6O_2$	*Resorcinol*	0.84	(127)

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* The numbers not in parentheses are numbers of other tables in this section which should be consulted for further data.

TABLE 2.—(*Continued*)

B-Component		Q	Lit. and Table No.*
Formula	Name (and temp., °C)		
	CH_4O.—(*Continued*)		
C_6H_7N	Aniline	0.08	(127); 3
C_6H_7N	*Aniline*	2.85	(127)
$C_7H_5NO_4$	*o-Nitrobenzoic acid*	−17.2	(127)
$C_7H_5NO_4$	*m-Nitrobenzoic acid*	−15.1	(127)
$C_7H_6O_2$	*Benzoic acid* (13°)	−12.1	(126, 127)
$C_7H_6O_3$	*Salicylic acid*	−13.0	(126, 127)
$C_7H_6O_3$	*m-Hydroxybenzoic acid*	− 8.79	(127)
$C_7H_7NO_2$	*o-Aminobenzoic acid*	−12.6	(127)
$C_7H_7NO_2$	*m-Aminobenzoic acid*	−19.7	(127)
$C_7H_7NO_2$	*p-Aminobenzoic acid*	− 9.21	(127)
C_7H_8	Toluene	− 4.60	(127)
C_7H_{16}	Heptane	− 9.63	(127)
C_7H_{16}	*Heptane*	− 4.65	(127)
C_8H_9NO	*Acetanilide* (24°)	−18.8	(122)
$C_9H_8O_2$	*Cinnamic acid* (13°)	−15.9	(126)
$C_{10}H_8$	*Naphthalene* (24°)	−17.70	(122)
$C_{12}H_{10}$	*Acenaphthene* (24°)	−25.9	(122)
$C_{12}H_{24}O_2$	*Lauric acid*	−41.4	(127)
$C_{14}H_{28}O_2$	*Myristic acid*	−51.06	(127)
$C_{16}H_{32}O_2$	*Palmitic acid*	−61.52	(127)
$C_{19}H_{16}$	*Triphenylmethane*	−24.6	(127)
	$C_2H_2O_4$, Oxalic acid		
C_2H_6O	Ethyl alcohol	− 5.31	(126)
C_3H_8O	Propyl alcohol	− 7.87	(126)
	$C_2H_2O_4.2H_2O$, Oxalic acid		
C_2H_6O	Ethyl alcohol	−23.4	(126)
C_3H_8O	Propyl alcohol	−27.6	(126)
	$C_2H_3Cl_3O_2$, Chloral hydrate		
C_2H_6O	Ethyl alcohol (24°)	− 4.73	(88, 122)
C_3H_6O	Acetone	− 2.89	(88)
$C_4H_{10}O$	Ethyl ether	0	(88)
C_7H_8	Toluene (24°)	−31.4	(122)
	$C_2H_4Br_2$, Ethylene bromide		
$C_2H_4Cl_2$	*Ethylene chloride*		3
$C_2H_4O_2$	Acetic acid		5
$C_2H_4O_2$	*Acetic acid*		5
C_6H_5Cl	*Chlorobenzene*		3
C_6H_6	*Benzene*		3
C_6H_{10}	*Cyclohexene*		3
C_6H_{12}	*Cyclohexane*		3
C_6H_{14}	*n-Hexane*		3
C_7H_8	*Toluene*		3
C_8H_{10}	*p-Xylene*		3
C_9H_{12}	*Mesitylene*		3
$C_{10}H_{14}$	*p-Cymene*		3
	$C_2H_4Cl_2$, Ethylene chloride		
C_6H_6	*Benzene*		3
C_7H_8	*Toluene*		3
	C_2H_4O, Acetaldehyde		
C_2H_6O	Ethyl alcohol		3
$C_4H_{10}O$	*Ethyl ether*		3
	$C_2H_4O_2$, Acetic acid		
C_2H_6O	Ethyl alcohol	− 1.05	(7)
C_2H_6O	*Ethyl alcohol*	− 2.01	(127)
C_3H_6O	Acetone	1.38	(127)
C_3H_6O	*Acetone*	0.84	(127)
$C_3H_6O_3$	Lactic acid		3
C_3H_8O	Propyl alcohol	− 1.42	(127)
	$C_2H_4O_2$.—(*Continued*)		
C_3H_8O	*Propyl alcohol*	− 3.06	(127)
$C_4H_8O_2$	Isobutyric acid		3
$C_4H_8O_2$	*Ethyl acetate*	0.54	(127)
$C_4H_{10}O$	*Ethyl ether*	1.67	(127)
$C_4H_{10}O$	Isobutyl alcohol	− 2.76	(127)
C_5H_5N	*Pyridine*	27.2	(127)
C_6H_6	Benzene	− 1.88	(127); 5
C_6H_6	*Benzene*	− 2.26	(127); 3, 4, 5
C_6H_6O	*Phenol*	−10.00	(88)
C_6H_{12}	*Cyclohexane*		3
C_6H_7N	*Aniline*	28.9	(127)
C_7H_8	Toluene	− 1.3	(4, 127); 3
C_7H_{16}	*Heptane*	− 5.40	(127)
$C_{10}H_8$	*Naphthalene*	−17.45	(88)
	C_2H_5NO, Acetamide		
C_2H_6O	Ethyl alcohol (23°)	−15.11	(122)
	C_2H_6O, Ethyl alcohol		
C_3H_6O	Acetone	− 5.11	(127); 3
$C_3H_7NO_2$	*Urethane* (24°)	−19.80	(122)
C_3H_8O	*n*-Propyl alcohol		3, 4
$C_3H_8O_3$	*Glycerol* (24°)	− 3.18	(65)
$C_4H_5NO_2$	*Succinimide* (22°)	−22.85	(122)
$C_4H_8O_2$	Ethyl acetate	− 7.53	(127)
$C_4H_8O_2$	*Ethyl acetate*	− 4.81	(127); 3
$C_4H_{10}O$	Ethyl ether	− 3.8	(127); 3
$C_4H_{10}O$	Isobutyl alcohol		3
C_5H_5N	Pyridine	0.54	(127)
C_5H_5N	*Pyridine*	2.26	(127)
$C_5H_{12}O$	Isoamyl alcohol		3
$C_6H_4N_2O_4$	*m-Dinitrobenzene*	−17.66	(88)
C_6H_6	Benzene	−16.7	(127); 4
C_6H_6	*Benzene*	− 1.51	(127); 3, 5
C_6H_6O	*Phenol*	− 2.5	(88, 127)
$C_6H_6O_2$	*Resorcinol* (23°)	2.89	(88, 122, 127)
$C_6H_6O_3$	*Pyrogallol*	3.60	(88)
C_6H_7N	Aniline	− 2.26	(127)
C_6H_7N	*Aniline*	1.00	(127)
$C_6H_8O_7$	*Citric acid*	−17.87	(88)
$C_6H_{15}O_4P$	*Triethyl phosphate*	− 0.8	(52)
$C_7H_5NO_4$	*m-Nitrobenzoic acid*	−12.1	(127)
$C_7H_6O_2$	*Benzoic acid*	−12.6	(126, 127)
$C_7H_6O_3$	*Salicylic acid*	−11.3	(126, 127)
$C_7H_6O_3$	*m-Hydroxybenzoic acid*	− 6.70	(127)
C_7H_7NO	*Benzamide* (24°)	−17.74	(122)
$C_7H_7NO_2$	*o-Aminobenzoic acid*	−11.3	(127)
$C_7H_7NO_2$	*m-Aminobenzoic acid*	−18.4	(127)
$C_7H_7NO_2$	*p-Aminobenzoic acid*	− 7.53	(127)
C_7H_9N	*p-Toluidine* (24°)	−15.28	(122)
C_7H_{16}	Heptane	− 3.3	(127)
C_7H_{16}	*Heptane*	− 2.64	(127)
C_8H_9NO	*Acetanilide* (23°)	−17.6	(122)
$C_9H_8O_2$	*Cinnamic acid*	−15.5	(126)
$C_{10}H_8$	*Naphthalene* (24°)	−20.34	(88, 122, 127)
$C_{10}H_{14}O$	*Thymol*	− 8.79	(88)
$C_{10}H_{20}O$	*Menthol*	− 7.91	(88)
$C_{12}H_{10}$	*Acenaphthene* (24°)	−24.7	(122)

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* The numbers not in parentheses are numbers of other tables in this section which should be consulted for further data.

TABLE 2.—(*Continued*)

B-Component		Q	Lit. and Table No.*
Formula	Name (and temp., °C)		
$\mathrm{C_2H_6O}$.—(*Continued*)			
$C_{12}H_{10}$	*Diphenyl*	−17.79	(88)
$C_{12}H_{10}N_2$	*Azobenzene*	−21.97	(88)
$C_{12}H_{24}O_2$	*Lauric acid*	−40.6	(127)
$C_{14}H_{10}$	*Phenanthrene* (24°)	−18.04	(122)
$C_{22}H_{42}O_2$	*Erucic acid*	−56.08	(127)
$\mathrm{C_3H_6O}$, Acetone			
$C_3H_7NO_2$	*Urethane*	−15.86	(88)
$\mathrm{C_3H_8O}$	Isopropyl alcohol		(112.5)
$C_4H_8O_2$	*Ethyl acetate*	− 0.63	(127); 3
$C_4H_{10}O$	*Ethyl ether*		3
$\mathrm{C_6H_5ClO}$	*o*-Chlorophenol		4
$\mathrm{C_6H_6}$	Benzene	− 1.3	(127)
C_6H_6	*Benzene*	− 1.09	(127)
C_6H_6O	*Phenol*	− 0.59	(88)
$C_6H_6O_2$	*Resorcinol*	4.19	(127)
$C_6H_6O_3$	*Pyrogallol*	5.82	(88)
C_6H_7N	*Aniline*	5.44	(127)
$C_6H_8O_7$	*Citric acid*	−13.4	(88)
$C_7H_6O_2$	*Benzoic acid*	−12.1	(127)
$C_7H_6O_3$	*Salicylic acid*	−10.9	(127)
$C_7H_9NO_2$	*Pyridine acetate*	− 1.385	(109)
C_7H_{16}	*Heptane*	− 7.20	(127)
$C_{10}H_7NO_2$	*Nitronaphthalene*	−29.17	(88)
$C_{10}H_8$	*Naphthalene*	−18.29	(88)
$C_{10}H_9N$	*α-Naphthylamine*	−10.84	(88)
$C_{10}H_9N$	*β-Naphthylamine*	−15.61	(88)
$C_{12}H_{10}$	*Diphenyl*	−18.71	(88)
$C_{12}H_{10}N_2$	*Azobenzene*	−23.10	(88)
$C_{12}H_{11}N$	*Diphenylamine*	−13.52	(88)
$C_{22}H_{42}O_2$	*Erucic acid*	−63.6	(127)
$\mathrm{C_3H_6O_2}$, Methyl acetate			
$C_4H_8O_2$	*Ethyl acetate*		3, 4
C_6H_6	*Benzene*		4
$\mathrm{C_3H_7NO_2}$, Urethane			
$\mathrm{C_3H_8O}$	Propyl alcohol (25°)	−25.32	(122)
$\mathrm{C_7H_8}$	Toluene (23°)	−26.8	(122)
$\mathrm{C_3H_8O}$, *n*-Propyl alcohol			
$C_4H_8O_2$	*Ethyl acetate*	− 5.48	(127); 3
$C_4H_{10}O$	*Ethyl ether*		3
$\mathrm{C_4H_{10}O}$	Isobutyl alcohol		3
$\mathrm{C_5H_5N}$	Pyridine	0.17	(127)
$\mathrm{C_5H_{12}O}$	Isoamyl alcohol		3
$\mathrm{C_6H_6}$	Benzene	−14.6	(127)
C_6H_6	*Benzene*	− 2.26	(127); 4
$C_6H_6O_2$	*Resorcinol*	− 0.84	(127)
C_6H_7N	*Aniline*	− 1.51	(127); 3
$C_7H_5NO_4$	*o-Nitrobenzoic acid*	−20.9	(127)
$C_7H_6O_2$	*Benzoic acid*	−14.2	(126, 127)
$C_7H_6O_3$	*Salicylic acid*	−13.8	(126, 127)
$\mathrm{C_7H_{16}}$	Heptane	− 9.21	(127)
C_7H_{16}	*Heptane*	− 1.63	(127)
$C_9H_8O_2$	*Cinnamic acid* (13°)	−15.9	(126)
$C_{10}H_8$	*Naphthalene*	−20.5	(122, 127)
$C_{12}H_{10}$	*Acenaphthene* (13°)	−28.50	(122)
$C_{12}H_{24}O_2$	*Lauric acid*	−40.2	(127)

TABLE 2.—(*Continued*)

B-Component		Q	Lit. and Table No.*
Formula	Name (and temp., °C)		
$\mathrm{C_4H_5Cl_3O_2}$, Ethyl trichloroacetate			
$C_4H_8O_2$	*Ethyl acetate*		3
$\mathrm{C_4H_8O_2}$, Ethyl acetate			
$C_4H_{10}O$	*Ethyl ether*		3, 4
$\mathrm{C_4H_{10}O}$	Isobutyl alcohol	− 6.70	(127); 3
$\mathrm{C_5H_5N}$	Pyridine	− 0.25	(127)
$\mathrm{C_5H_{12}O}$	Isoamyl alcohol		3
$C_6H_4N_2O_4$	*m-Dinitrobenzene*	14.790	(56)
$\mathrm{C_6H_6}$	Benzene	− 0.67	(127); 3
C_6H_6	*Benzene*	− 0.59	(127); 4
$C_6H_6O_2$	*Resorcinol*	1.3	(127)
C_6H_7N	*Aniline*	3.01	(127)
$\mathrm{C_6H_{12}O_2}$	Amyl formate		3
$C_7H_5NO_4$	*o-Nitrobenzoic acid*	−13.4	(127)
$C_7H_6O_2$	*Benzoic acid*	−13.0	(127)
$C_7H_6O_3$	*Salicylic acid*	− 8.37	(127)
$C_7H_6O_3$	*m-Hydroxybenzoic acid*	− 7.95	(127)
$C_7H_9NO_2$	*Pyridine acetate*	− 0.988	(109)
$\mathrm{C_7H_{14}O_2}$	Amyl acetate		3, 4
$\mathrm{C_7H_{16}}$	Heptane	− 5.06	(127)
C_7H_{16}	*Heptane*	− 5.61	(127)
$\mathrm{C_9H_{10}O_2}$	Ethyl benzoate		3
$C_{10}H_8$	*Naphthalene*	−17.2	(127)
$C_{12}H_{24}O_2$	*Lauric acid*	−41.0	(127)
$C_{22}H_{42}O_2$	*Erucic acid*	−56.5	(127)
$\mathrm{C_4H_9Cl}$, Isobutyl chloride			
C_5H_5N	*Pyridine*	1.3	(127)
C_6H_6	*Benzene*	− 0.96	(127)
C_7H_{16}	*Heptane*	− 2.01	(127)
$\mathrm{C_4H_{10}O}$, Ethyl ether			
$C_4H_{10}O$	*Isobutyl alcohol*		3
$\mathrm{C_5H_5N}$	Pyridine	− 0.84	(127)
$\mathrm{C_5H_{12}O}$	Isoamyl alcohol		3
$C_6H_4N_2O_4$	*m-Dinitrobenzene*	−22.64	(88)
$C_6H_5NO_3$	*o-Nitrophenol*	−17.6	(88)
$\mathrm{C_6H_6}$	Benzene	− 0.42	(127); 4
C_6H_6O	*Phenol*	− 0.36	(88)
$C_6H_6O_3$	*Pyrogallol*	− 1.7	(88)
C_6H_7N	*Aniline*		3
$C_6H_{12}O_3$	*Paraldehyde*		3
$C_7H_6O_2$	*Benzoic acid*	−10.0	(127)
$C_{10}H_7NO_2$	*Nitronaphthalene*	−24.20	(88)
$C_{10}H_8$	*Naphthalene*	−20.30	(88)
$C_{10}H_{14}O$	*Thymol*	− 4.48	(88)
$C_{10}H_{20}O$	*Menthol*	−19.29	(88)
$C_{12}H_{10}N_2$	*Azobenzene*	−20.67	(88)
$C_{12}H_{11}N$	*Diphenylamine*	−14.6	(88)
$\mathrm{C_4H_{10}O}$, Isobutyl alcohol			
$C_5H_{12}O$	*Isoamyl alcohol*		3
C_6H_6	*Benzene*	− 3.18	(127)
C_7H_{16}	*Heptane*	− 1.7	(127)
$\mathrm{C_5H_5N}$, Pyridine			
$\mathrm{C_6H_5ClO}$	*o*-Chlorophenol		4
$C_6H_5NO_3$	*o-Nitrophenol*	−10.0	(127)
C_6H_6	*Benzene*	0	(127)
C_6H_6O	*Phenol*	7.11	(127)
$C_6H_6O_2$	*Resorcinol*	20.9	(127)
C_7H_8O	*o-Cresol*		4
C_7H_8O	*m-Cresol*		4

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* The numbers not in parentheses are numbers of other tables in this section which should be consulted for further data.

TABLE 2.—(*Continued*)

B-Component Formula	B-Component Name (and temp., °C)	Q	Lit. and Table No.*
$C_5H_{10}O_2$, Propyl acetate			
$C_6H_{12}O_2$	*Amyl formate*		3
$C_5H_{12}O$, Amyl alcohol			
C_8H_{10}	*p-Xylene*		4
$C_5H_{12}O$, Isoamyl alcohol			
C_6H_6	*Benzene*	− 2.9	(127)
C_7H_{16}	*Heptane*	− 1.3	(127)
$C_6H_4N_2O_4$, *m*-Dinitrobenzene			
C_6H_6	Benzene	−15.86	(88)
C_6H_5Br, Bromobenzene			
C_6H_5Cl	Chlorobenzene		3
C_6H_6	Benzene		3
C_6H_5Cl, Chlorobenzene			
C_6H_6	Benzene		(121)
C_8H_{10}	*p-Xylene*		3
C_6H_5ClO, *o*-Chlorophenol			
$C_8H_{11}N$	*Dimethylaniline*		4
C_9H_7N	Quinoline		4
$C_6H_5NO_2$, Nitrobenzene			
C_6H_7N	*Aniline*		3
C_7H_9N	*o*-Toluidine		3
$C_8H_{11}N$	Dimethylaniline		3
$C_8H_{11}N$	*Ethylaniline*		3
$C_{10}H_{15}N$	Diethylaniline		3
$C_6H_5NO_3$, *o*-Nitrophenol			
C_6H_6	Benzene	−20.9	(88, 127)
$C_7H_{14}O_2$	Isoamyl acetate	−14.73	(88)
C_6H_6, Benzene			
C_6H_6O	*Phenol*	−18.41	(88, 127)
$C_6H_6O_2$	*Resorcinol*	−15.78	(88)
C_6H_7N	Aniline	− 2.51	(127)
C_6H_7N	*Aniline*	− 4.85	(127)
C_6H_{12}	Cyclohexane		3
C_6H_{14}	*n-Hexane*		3
$C_7H_6O_2$	*Benzoic acid*	−14.2	(127)
$C_7H_6O_3$	*Salicylic acid*	−23.9	(127)
C_7H_8	Toluene		3, 4
C_7H_8O	*m-Cresol*		3
$C_7H_9NO_2$	*Pyridine acetate*	− 0.866	(109)
C_7H_{16}	Heptane	− 2.89	(127)
C_7H_{16}	*Heptane*	− 4.39	(127)
C_8H_{10}	*m*-Xylene		3
C_8H_{18}	Octane	− 2.9	(127)
$C_{10}H_7NO_2$	*Nitronaphthalene*	−22.52	(88)
$C_{10}H_8$	*Naphthalene*	−18.50	(88, 127)
$C_{10}H_{14}O$	*Thymol*	−23.8	(88, 127)
$C_{10}H_{16}$	*Pinene*		3
$C_{10}H_{20}O$	*Menthol*	−28.0	(88)
$C_{12}H_{10}$	*Diphenyl*	−18.0	(88)
$C_{12}H_{10}N_2$	*Azobenzene*	−21.18	(88)
$C_{12}H_{11}N$	*Diphenylamine*	−16.99	(88)
$C_{12}H_{24}O_2$	*Lauric acid*	−40.6	(127)
$C_{14}H_{28}O_2$	*Myristic acid*	−50.2	(127)
$C_{16}H_{32}O_2$	*Palmitic acid*	−59.0	(127)
$C_{19}H_{16}$	*Triphenylmethane*	−17.6	(127)
$C_{22}H_{42}O_2$	*Erucic acid*	−56.5	(127)

TABLE 2.—(*Continued*)

B-Component Formula	B-Component Name (and temp., °C)	Q	Lit. and Table No.*
C_6H_6O, Phenol			
C_6H_7N	Aniline		(103)
$C_6H_6O_3$, Pyrogallol			
C_6H_7N	Aniline	11.51	(88)
$C_7H_{14}O_2$	Amyl acetate	0	(88)
C_6H_7N, Aniline			
C_6H_{14}	*Hexane*		(99)
C_7H_{16}	*Heptane*	−10.17	(127)
C_8H_{10}	*p-Xylene*		4
$C_{10}H_7NO_2$	*Nitronaphthalene*	−17.54	(88)
$C_{10}H_8$	*Naphthalene*	−19.80	(88)
C_6H_{12}, Cyclohexane			
C_6H_{14}	*n-Hexane*		3
C_7H_8	Toluene		3
C_8H_{10}	*p*-Xylene		3
$C_7H_6O_2$, Benzoic acid			
C_7H_8	Toluene	−14.2	(127)
C_7H_8, Toluene			
C_7H_8O	*m*-Cresol		3
C_7H_{16}	*Heptane*	− 2.26	(127)
C_8H_{10}	*p*-Xylene		3
$C_{10}H_8$	*Naphthalene* (23°)	−17.87	(122)
$C_{12}H_{10}$	*Acenaphthene*(23°)	−20.05	(122)
$C_{12}H_{24}O_2$	*Lauric acid*	−38.1	(127)
$C_{19}H_{16}$	*Triphenylmethane*	−17.2	(127)
C_7H_8O, *m*-Cresol			
C_7H_9N	*o*-Toluidine		3
$C_8H_{11}N$	Dimethylaniline		3
$C_7H_{14}O_2$, Amyl acetate			
$C_{10}H_7NO_2$	*Nitronaphthalene*	−18.75	(88)
$C_{12}H_{10}N_2$	*Azobenzene*	−20.67	(88)
$C_{12}H_{11}N$	*Diphenylamine*	−14.86	(88)
C_8H_{10}, *o*-Xylene			
C_8H_{10}	*m*-Xylene		3
C_8H_{10}	*p-Xylene*		3
C_8H_{10}, *m*-Xylene			
C_8H_{10}	*p*-Xylene		3
$C_8H_{11}N$	Dimethylaniline		3

TABLE 3

The concentration is expressed by x_A, the mole fraction of the A-component in the mixture. Q is expressed in kilojoules evolved per mole mixture. The temperature is between 15 and 20° unless otherwise indicated.

H_2O

B = C_2H_6O (51)
Ethyl alcohol

x_A	t	Q
0.640	77°	−0.078
0.843	79.2°	+0.159

B = $C_2H_6O_2$ (119)
Glycol

x_A	Q
t = 17°	
0.1	0.175
0.2	0.349
0.3	0.423

B = $C_2H_6O_2$.— (*Continued*)

x_A	Q
0.4	0.6349
0.5	0.7286
0.6	0.7713
0.7	0.7433
0.8	0.7110
0.9	0.519
t = 32°	
0.1	0.147
0.2	0.295
0.3	0.357

B = $C_2H_6O_2$.— (*Continued*)

x_A	Q
0.4	0.5311
0.5	0.6148
0.6	0.6696
0.7	0.6725
0.8	0.6457
0.9	0.429
t = 55°	
0.1	0.136
0.2	0.271
0.3	0.328

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* The numbers not in parentheses are numbers of other tables in this section which should be consulted for further data.

B = $C_2H_6O_2$.—
(Continued)

x_A	Q
0.4	0.4838
0.5	0.5574
0.6	0.6056
0.7	0.6211
0.8	0.5867
0.9	0.397

t = 76°

0.1	0.136
0.2	0.271
0.3	0.329
0.4	0.4708
0.5	0.5311
0.6	0.5604
0.7	0.5796
0.8	0.5679
0.9	0.371

CCl_4

B = CS_2 (94.1)
t = 25°

0.0934	−0.127
0.1425	−0.180
0.2838	−0.276
0.4001	−0.307
0.5393	−0.311
0.6693	−0.264
0.8153	−0.179

B = $CHCl_3$ (94.1)
t = 25°

0.1150	−0.103
0.2428	−0.176
0.3623	−0.219
0.4331	−0.228
0.5411	−0.226
0.7295	−0.185
0.8178	−0.146

B = $C_2H_4Br_2$ (94.1)
Ethylene bromide
t = 25°

0.1146	−0.198
0.2817	−0.406
0.3733	−0.472
0.4835	−0.509
0.5404	−0.511
0.7565	−0.414
0.8455	−0.274

B = $C_4H_8O_2$ (51)
Ethyl acetate
t = 74.8°

0.308	−0.259

B = C_6H_6 (94.1)
t = 25°

0.2996	−0.091
0.3506	−0.106
0.5012	−0.107
0.6177	−0.104
0.7309	−0.089
0.8675	−0.054

(5)

0.033	−0.013
0.256	−0.086

B = C_6H_6.—*(Cont'd)*

x_A	Q
0.443	−0.110
0.507	−0.111
0.538	−0.106
0.636	−0.098
0.764	−0.072

B = C_6H_7N (94)
Aniline
t = 25°

0.0942	−0.408
0.1848	−0.707
0.3005	−0.991
0.4152	−1.181
0.4827	−1.218
0.5504	−1.245
0.6215	−1.209
0.7175	−1.129
0.7888	−1.030
0.8627	−0.787
0.9092	−0.623

B = C_7H_8 (5)
Toluene

0.216	0.0150
0.327	0.0193
0.475	0.2578

CS_2

B = $CHCl_3$ (94.1)
t = 25°

0.1897	−0.313
0.3492	−0.474
0.4046	−0.513
0.5906	−0.534
0.6720	−0.502
0.8193	−0.352
0.9351	−0.143

B = $C_2H_4Br_2$ (94.1)
Ethylene bromide
t = 25°

0.1607	−0.378
0.3728	−0.693
0.5184	−0.788
0.5683	−0.792
0.8300	−0.521
0.9206	−0.280

B = $C_4H_8O_2$ (94.1)
Ethyl acetate
t = 25°

0.2199	−0.729
0.4690	−1.123
0.5249	−1.145
0.6522	−1.112
0.7578	−0.946
0.8119	−0.821
0.9130	−0.468

B = $C_4H_{10}O$ (94.1)
Ethyl ether
t = 25°

0.1462	−0.200
0.3571	−0.396
0.4167	−0.436
0.6014	−0.456

B = $C_4H_{10}O$.—
(Continued)

x_A	Q
0.7305	−0.397
0.7703	−0.358
0.9246	−0.157

B = C_6H_6 (94.1, 118)
t = 25°

0.2020	−0.338
0.5224	−0.565
0.6229	−0.541
0.7259	−0.465
0.8384	−0.339
0.9025	−0.227

B = $C_6H_{12}O_3$ (94.1)
Paraldehyde
t = 25°

0.2974	−0.959
0.3908	−1.126
0.5498	−1.268
0.6365	−1.250
0.6972	−1.193
0.8243	−0.916
0.9082	−0.580

B = $C_{10}H_{16}$ (94.1)
Pinene
t = 25°

0.2845	−0.264
0.4719	−0.367
0.6532	−0.379
0.7353	−0.353
0.7976	−0.318
0.8998	−0.200
0.9585	−0.095

$CHBr_3$

B = C_7H_8 (5)
Toluene

0.067	0.082
0.238	0.248
0.444	0.326
0.780	0.223
0.940	0.075

$CHCl_3$

B = CH_4O (94.1)
Methyl alcohol
t = 25°

0.1154	0.434
0.2041	0.594
0.3001	0.607
0.4715	+0.349
0.6345	−0.014
0.6645	−0.080
0.8042	−0.314
0.9141	−0.393

B = $C_2H_4Br_2$ (94.1)
Ethylene bromide
t = 25°

0.2991	0.087
0.4246	0.103
0.5352	0.109
0.6293	0.108
0.8476	0.048
0.8902	0.030

B = C_2H_4O (94.1)
Acetaldehyde
t = 25°

0.2125	0.652
0.2562	0.782
0.3833	1.058
0.4144	1.109
0.4348	1.121
0.5787	1.208
0.6759	1.133
0.7226	1.076

B = C_2H_6O (94.1)
Ethyl alcohol
t = 25°

0.1216	0.508
0.1765	0.644
0.3175	0.624
0.3777	0.489
0.4770	0.246
0.5716	+0.009
0.7470	−0.365
0.8350	−0.457
0.9412	−0.387

B = C_3H_6O (51)
Acetone

x_A, t		Q
0.262	57°	1.214
0.359	59°	1.569
0.614	62°	1.544

x_A	Q

t = 25° (94.1)

0.2481	1.167
0.3967	1.715
0.4578	1.868
0.5004	1.921
0.5476	1.973
0.6486	1.900
0.6981	1.775
0.7558	1.573
0.9808	0.159

B = C_3H_8O (94.1)
n-Propyl alcohol
t = 25°

0.0486	0.212
0.1640	0.415
0.2794	0.342
0.3399	+0.244
0.5011	−0.131
0.5123	−0.151
0.6823	−0.516
0.7411	−0.587
0.8347	−0.637
0.9359	−0.449

B = $C_4H_8O_2$ (94.1)
Ethyl acetate
t = 25°

0.2145	1.109
0.3766	1.748
0.4581	1.967
0.5850	2.034
0.6255	1.985
0.6955	1.841
0.7158	1.778
0.9102	0.721

B = $C_4H_{10}O$ (94.1)
Ethyl ether

x_A	Q

t = 25°

0.1819	1.445
0.3627	2.405
0.4805	2.701
0.5031	2.708
0.5243	2.714
0.5841	2.599
0.6563	2.402
0.7516	1.915

B = $C_4H_{10}O$ (94.1)
Isobutyl alcohol
t = 25°

0.0586	0.080
0.0822	+0.089
0.1980	−0.015
0.2804	−0.214
0.5146	−0.743
0.6103	−0.873
0.8225	−0.882
0.9502	−0.455

B = $C_5H_{12}O$ (94.1)
Isoamyl alcohol
t = 25°

0.0129	0.102
0.0789	0.157
0.1972	+0.144
0.3742	−0.139
0.4590	−0.336
0.5793	−0.556
0.7986	−0.752
0.9402	−0.483

B = C_6H_5Cl (5)

0.204	0.102
0.339	0.149
0.4344	0.168
0.561	0.1753

B = C_6H_6 (5)

0.067	0.063
0.230	0.193
0.340	0.268
0.584	0.360
0.737	0.306
0.850	0.201

t = 25° (94.1)

0.1461	0.197
0.3115	0.324
0.4584	0.401
0.5601	0.424
0.7572	0.369
0.8681	0.239

B = C_6H_{10} (5)
Cyclohexene

0.100	0.0410
0.290	0.0891
0.525	0.1096

B = C_6H_{12} (5)
Cyclohexane

0.255	−0.5102
0.410	−0.6424
0.578	−0.6278
0.696	−0.5487
0.873	−0.2942

B = $C_6H_{12}O_3$ (94.1)
Paraldehyde

x_A	Q

t = 25°

0.2406	1.349
0.3982	1.988
0.4981	2.231
0.5916	2.311
0.6996	2.142
0.8519	1.373
0.9428	0.611

B = C_7H_8 (5)
Toluene

0.075	0.184
0.260	0.5374

B = C_8H_{10} (5)
p-Xylene

0.097	0.285
0.298	0.720
0.425	0.875
0.490	0.912
0.772	0.672
0.856	0.473

CH_2O_2

Formic acid

B = $C_2H_4O_2$ (101, 104)
Acetic acid

0.50	0.303

CH_4O

Methyl alcohol

B = C_2H_6O (94.1)
Ethyl alcohol
t = 25°

0.4421	−0.003
0.6110	−0.008
0.7082	−0.009

B = C_3H_6O (94.1)
Acetone
t = 25°

0.2426	−0.541
0.4244	−0.686
0.5163	−0.671
0.5966	−0.635
0.6014	−0.632
0.6870	−0.556
0.8067	−0.387
0.9315	−0.149

B = C_3H_8O (94.1)
n-Propyl alcohol
t = 25°

0.4451	−0.091
0.6666	−0.097
0.7962	−0.074

B = C_3H_8O (101, 104)
Isopropyl alcohol

x_A, t		Q
0.25	14.6°	0.082
0.25	34.2°	0.073
0.50	15.2°	0.080
0.50	30°	0.060
0.75	16.3°	0.051
0.75	34.1°	0.040

CH_4O.—(*Cont'd*)

B = $C_4H_{10}O$ (94.1)
Ethyl ether

x_A	Q
t = 25°	
0.2173	−0.414
0.3197	−0.502
0.5582	−0.410
0.6386	−0.336
0.7101	−0.257
0.8221	−0.153
0.9259	−0.049

B = $C_4H_{10}O$ (94.1)
Isobutyl alcohol
t = 25°

0.5140	−0.170
0.7135	−0.165
0.8508	−0.116

B = $C_5H_{12}O$ (94.1)
Isoamyl alcohol
t = 25°

0.5140	−0.191
0.7683	−0.187
0.8684	−0.132

B = C_6H_7N (94)
Aniline
t = 25°

0.0855	−0.018
0.1639	−0.016
0.2558	+0.015
0.3297	0.053
0.4359	0.116
0.5261	0.149
0.6205	0.187
0.7228	0.215
0.8172	0.208
0.8397	0.200
0.9362	0.121
0.9486	0.094

$C_2H_4Br_2$

Ethylene bromide
B = $C_2H_4Cl_2$ (5)
Ethylene chloride

0.215	−0.123

B = C_6H_5Cl (5)
Chlorobenzene

0.070	−0.086
0.332	−0.286

B = C_6H_6 (5)

0.054	−0.0590
0.186	−0.1762
0.364	−0.2624
0.535	−0.2888
0.648	−0.2616
0.821	−0.1728
0.946	−0.0590

B = C_6H_{10} (5)
Cyclohexene

0.107	−0.2440
0.296	−0.0544

B = C_6H_{12} (5)
Cyclohexane

0.098	−0.490
0.182	−0.841

B = C_6H_{12}.—(*Continued*)

x_A	Q
0.308	−1.184
0.375	−1.297
0.495	−1.381
0.529	−1.364
0.555	−1.360
0.687	−1.168
0.690	−1.168
0.765	−0.992
0.842	−0.741
0.949	−0.2745

B = C_6H_{14} (5)
n-Hexane

0.94	−0.4009

B = C_7H_8 (5)
Toluene

0.078	+0.0732
0.250	−0.0121
0.450	−0.0691
0.567	−0.0975
0.710	−0.114
0.830	−0.109

B = C_8H_{10} (5)
p-Xylene

0.082	0.087
0.272	0.175
0.486	0.106
0.602	0.036
0.642	+0.010
0.722	−0.036
0.868	−0.0632
0.966	−0.029

B = C_9H_{12} (5)
Mesitylene

0.110	0.0737
0.350	+0.0360
0.486	−0.0636
0.638	−0.1331
0.749	−0.1632
0.878	−0.1163

B = $C_{10}H_{14}$ (5)
p-Cymene

0.100	−0.00862
0.320	−0.0866
0.454	−0.1787
0.610	−0.2611
0.804	−0.297
0.900	−0.2335

$C_2H_4Cl_2$

Ethylene chloride
B = C_6H_6 (5)

0.74	−0.0732

B = C_7H_8 (5)
Toluene

0.079	0.0427
0.262	0.0783
0.385	0.661
0.537	0.025
0.618	+0.0025
0.803	−0.0314
0.944	−0.0184

C_2H_4O

Acetaldehyde
B = C_2H_6O (104.1)
Ethyl alcohol

x_A	Q
0.1621	−1.530
0.2475	−2.750
0.2709	−2.979
0.2910	−3.300
0.3059	−3.269
0.3422	−3.756
0.3906	−3.974
0.4211	−4.131
0.4244	−4.104
0.4422	−4.177
0.4973	−4.188
0.5114	−4.029
0.5285	−3.599
0.5470	−3.085
0.5812	−2.826
0.6478	−2.321
0.6717	−2.160
0.8110	−1.658

B = $C_4H_{10}O$ (94.1)
Ethyl ether
t = 25°

0.3477	−0.523
0.5434	−0.565
0.6588	−0.515
0.7473	−0.428
0.8740	−0.250

$C_2H_4O_2$

Acetic acid
B = $C_3H_6O_3$ (104)
Lactic acid

0.5	0.258

B = $C_4H_8O_2$ (104)
Isobutyric acid

0.49	0.206

B = C_6H_6 (4)
t = 5.3°

0.1528	−0.064
0.1765	−0.083
0.2120	−0.126
0.2500	−0.197
0.3289	−0.301

B = C_6H_{12} (5)
Cyclohexane

0.2424	−1.2743
0.417	−1.5945
0.540	−1.4145
0.643	−1.5246
0.701	−1.4380
0.772	−1.197
0.825	−0.983

B = C_7H_8 (5)
Toluene

0.189	−0.2256
0.258	−0.2754
0.324	−0.3281
0.437	−0.368
0.482	−0.3729
0.537	−0.3720

C_2H_6O

Ethyl alcohol
B = C_3H_6O (94.1)
Acetone

x_A	Q
t = 25°	
0.1710	−0.705
0.3404	−1.055
0.4417	−1.123
0.5400	−1.117
0.5558	−1.117
0.6325	−1.050
0.7392	−0.879
0.8947	−0.444

B = C_3H_8O
n-Propyl alcohol
t = 25° (94.1)

0.3541	−0.023
0.6031	−0.027
0.8030	−0.021

t = 25° (113)

0.158	−0.013
0.303	−0.018
0.439	−0.020
0.566	−0.020
0.684	−0.017
0.796	−0.012
0.902	−0.007

B = $C_4H_8O_2$ (94.1)
Ethyl acetate
t = 25°

0.1932	−0.934
0.5346	−1.320
0.5445	−1.166?
0.5812	−1.216?
0.7077	−1.045
0.7776	−0.846
0.9051	−0.421

B = $C_4H_{10}O$ (94.1)
Ethyl ether
t = 25°

0.0882	−0.382
0.2756	−0.668
0.4379	−0.677
0.5889	−0.569
0.6675	−0.478
0.7191	−0.434
0.8380	−0.254
0.9695	−0.040

B = $C_4H_{10}O$ (94.1)
Isobutyl alcohol
t = 25°

0.3519	−0.050
0.5914	−0.064
0.7748	−0.046

B = $C_5H_{12}O$ (94.1)
Isoamyl alcohol
t = 25°

0.3440	−0.057
0.6977	−0.067
0.8302	−0.058

B = C_6H_6 (51)

x_A, t		Q
0.420	68.2°	−0.963
0.649	68.5°	−1.507
0.807	68.9°	−0.812

C_3H_6O

Acetone
B = $C_4H_8O_2$ (94.1)
Ethyl acetate

x_A	Q
t = 25°	
0.2062	−0.093
0.3237	−0.120
0.5046	−0.133
0.5965	−0.131
0.6644	−0.123
0.7535	−0.098
0.9128	−0.045

B = $C_4H_{10}O$
Ethyl ether
t = 25° (94.1, 117)

0.1155	0.249
0.2068	0.385
0.2943	0.461
0.4998	0.505
0.7270	0.385
0.8295	0.258.
0.9077	0.159

x_A, t		Q (51)
0.334	37.1°	−0.473
0.456	40°	−0.404
0.594	40.5°	−0.557
0.789	46.3°	−0.312

$C_3H_6O_2$

Methyl acetate
B = $C_4H_8O_2$
Ethyl acetate
(101, 104)

x_A	Q
0.50	0.052

C_3H_8O

n-Propyl alcohol
B = $C_4H_8O_2$ (94.1)
Ethyl acetate
t = 25°

0.1382	−0.852
0.2784	−1.318
0.4406	−1.521
0.4779	−1.523
0.4875	−1.511
0.6248	−1.406
0.7880	−0.990
0.9101	−0.509

B = $C_4H_{10}O$ (94.1)
Ethyl ether
t = 25°

0.1056	−0.431
0.2110	−0.637
0.4258	−0.732
0.5322	−0.685
0.5548	−0.662
0.6949	−0.518
0.8135	−0.327
0.9311	−0.129

B = $C_4H_{10}O$ (94.1)
Isobutyl alcohol
t = 25°

0.3242	−0.005
0.5943	−0.008
0.7167	−0.009

B = $C_5H_{12}O$ (94.1)
Isoamyl alcohol

x_A	Q
t = 25°	
0.4247	−0.002
0.6166	−0.008
0.8204	−0.005

B = C_6H_7N (104)
Aniline

0.35	0.791
0.80	0.481

$C_4H_5Cl_3O_2$

Ethyl trichloroacetate
B = $C_4H_8O_2$
Ethyl acetate
(101, 104)

x_A, t		Q
0.25	16.7°	−0.144
0.25	34.1°	−0.100
0.50	15.9°	−0.176
0.50	34.2°	−0.130
0.75	16.5°	−0.156
0.75	33.5°	−0.089

$C_4H_8O_2$

Ethyl acetate
B = $C_4H_{10}O$ (94.1)
Ethyl ether

x_A	Q
t = 25°	
0.0875	−0.091
0.2269	−0.200
0.4372	−0.255
0.4560	−0.256
0.4803	−0.256
0.5815	−0.251
0.7256	−0.200
0.8419	−0.139

B = $C_4H_{10}O$ (94.1)
Isobutyl alcohol
t = 25°

0.0979	−0.655
0.2968	−1.518
0.3678	−1.687
0.5444	−1.810
0.5846	−1.772
0.7146	−1.572
0.8564	−0.958

B = $C_5H_{12}O$ (94.1)
Isoamyl alcohol
t = 25°

0.1824	−1.053
0.2358	−1.353?
0.4192	−1.748
0.5701	−1.739
0.5912	−1.718
0.6260	−1.684
0.7666	−1.355
0.8931	−0.776

B = C_6H_6 (94.1)
t = 25°

0.0943	−0.033
0.2479	−0.062
0.3694	−0.091
0.5065	−0.098

B = C_6H_6.—
(Continued)

x_A	Q
0.6324	−0.094
0.7976	−0.075
0.8760	−0.040

B = $C_6H_{12}O_2$ (101, 104)
Amyl formate

0.50	0.036

B = $C_7H_{14}O_2$ (101, 104)
Amyl acetate

0.49	0.216

B = $C_9H_{10}O_2$ (101, 104)
Ethyl benzoate

0.50	−0.227

$C_4H_{10}O$
Ethyl ether
B = $C_4H_{10}O$ (94.1)
Isobutyl alcohol
t = 25°

0.1097	−0.266
0.2467	−0.552
0.3654	−0.732
0.4813	−0.839
0.5449	−0.867
0.6828	−0.836
0.8614	−0.549
0.9478	−0.252

B = $C_5H_{12}O$ (94.1)
Isoamyl alcohol
t = 25°

0.1245	−0.271
0.3187	−0.592
0.4137	−0.699
0.5539	−0.770
0.5705	−0.776
0.7034	−0.739
0.8132	−0.603
0.8825	−0.465

B = C_6H_7N (94)
Aniline
t = 20°

0.1031	0.129
0.1933	0.206
0.3060	0.338
0.3833	0.406
0.4947	0.498
0.5961	0.542
0.6802	0.538
0.7927	0.461
0.8579	0.354
0.9294	0.225

B = $C_6H_{12}O_3$ (94.1)
Paraldehyde
t = 25°

0.2360	−0.210
0.4174	−0.299
0.5545	−0.314
0.5958	−0.315
0.6546	−0.300
0.7694	−0.244
0.9077	−0.132

$C_4H_{10}O$
Isobutyl alcohol
B = $C_5H_{12}O$ (94.1)
Isoamyl alcohol

x_A	Q
t = 25°	
0.3349	−0.005
0.5251	−0.006
0.7520	−0.015

$C_5H_{10}O_2$
Propyl acetate
B = $C_6H_{12}O_2$ (101, 104)
Amyl formate

0.299	−0.003
0.742	−0.013

C_6H_5Br
Bromobenzene
B = C_6H_5Cl (101, 104)
Chlorobenzene

0.212	0.0121
0.674	0.0154

B = C_6H_6 (5)

0.255	−0.038

C_6H_5Cl
Chlorobenzene
B = C_8H_{10} (5)
p-Xylene

0.198	0.080
0.330	0.106
0.425	0.116
0.790	0.076
0.939	0.028

$C_6H_5NO_2$
Nitrobenzene
B = C_6H_7N (101, 104)
Aniline

x_A, t		Q
0.25	87.6°	0.306
0.25	51.6°	0.322
0.25	16.5°	0.519
0.50	86.39°	0.343
0.50	52.16°	0.452
0.50	14°	0.552
0.75	86.3°	0.318
0.75	15°	0.398

B = C_7H_9N (101, 104)
o-Toluidine

0.50	17.6°	0.243
0.50	14.2°	0.239

B = $C_8H_{11}N$ (101, 104)
Dimethylaniline

x_A	Q
t = 15°	
0.46	−0.031

B = $C_8H_{11}N$ (101, 104)
Ethylaniline

0.51	0.112

B = $C_{10}H_{15}N$ (101, 104)
Diethylaniline

0.50	−0.062

C_6H_6
B = C_6H_{12} (5)
Cyclohexane

x_A	Q
0.097	−0.3013
0.670	−0.7140
0.752	−0.6068
0.859	−0.4028
0.924	−0.2323

B = C_6H_{14} (5)
n-Hexane

0.579	−0.912
0.687	−0.841
0.844	−0.5177
0.940	−0.2172

B = C_7H_8 (5)
Toluene

0.324	−0.0619
0.490	−0.0753
0.500	−0.0791*
0.600	−0.0703
0.750	−0.0561
0.857	−0.0360

* (101, 104).

B = C_7H_8O (101, 102, 104)
m-Cresol

0.54	0.866

B = C_8H_{10} (101, 104)
m-Xylene

0.5	0.239

B = $C_{10}H_{16}$ (94.1)
Pinene
t = 25°

0.2128	−0.424
0.4758	−0.739
0.5399	−0.730
0.6251	−0.725
0.7634	−0.624
0.8686	−0.470
0.9382	−0.234

C_6H_{12}
Cyclohexane
B = C_6H_{14} (5)
n-Hexane

0.75	−0.2000

B = C_7H_8 (5)
Toluene

0.053	−0.1247
0.165	−0.3465
0.324	−0.561
0.671	−0.586
0.743	−0.5114
0.832	−0.3926
0.946	−0.1448

B = C_8H_{10} (5)
p-Xylene

0.077	−0.1461
0.185	−0.3139
0.329	−0.4604
0.460	−0.5265
0.5114	−0.5432
0.5753	−0.5457
0.657	−0.5189

B = C_8H_{10}.—
(Continued)

x_A	Q
0.767	−0.4369
0.920	−0.1954

C_7H_8
Toluene
B = C_7H_8O
m-Cresol (101, 104)

0.47	0.686

B = C_8H_{10} (5)
p-Xylene

0.232	−0.00565
0.350	−0.0084
0.480	−0.0092

C_7H_8O
m-Cresol (101, 104)
B = C_7H_9N
o-Toluidine

B = C_7H_9N.—
(Continued)

x_A, t		Q
0.25	20.4°	−1.590
0.25	88°	−1.193
0.50	22.1°	−2.469
0.50	55.9°	−2.072
0.50	90.5°	−1.988
0.75	19.4°	−2.406
0.75	54.6°	−1.871
0.75	90°	−1.716

B = $C_8H_{11}N$
Dimethylaniline

0.50	16.3°	−0.144
0.50	15.3°	−0.128

C_8H_{10}
o-Xylene (101, 104)
B = C_8H_{10}
m-Xylene

B = C_8H_{10}.—
(Continued)

x_A	Q
0.269	0.0092
0.729	0.0067

B = C_8H_{10}
p-Xylene

0.319	0.011
0.815	0.004

C_8H_{10}
m-Xylene (101, 104)
B = C_8H_{10}
p-Xylene

0.292	−0.0109
0.754	−0.0013

B = $C_8H_{11}N$
Dimethylaniline

0.287	0.011
0.734	0.013

TABLE 4

The concentration is expressed as weight per cent of the A-component in the mixture. Q is expressed in joules evolved per gram of mixture.

H_2O
B = C_3H_6O (118.1)
Acetone

% A	Q
t = 15°	
19.04	6.9
29.91	13.5
40.29	22.9
50.00	28.5
55.60	30.4
60.00	31.1
65.00	32.2
66.67	32.0
70.00	31.6
75.00	29.8
81.19	26.5
84.80	21.3
90.00	16.5
95.00	8.4

B = $C_3H_8O_3$
Glycerol
(63)

10	7.5
20	10.9
30	15.5
40	17.6
50	18.8
60	18.8
70	16.3
80	13.4
90	8.0
(98)	
15.3	12
25.9	16
37.8	18
55.2	18
64.2	17
75.4	13

B = $C_3H_8O_3$.—
(Continued)

% A	Q
86.1	8.2
90.2	6.0
92.8	4.6
96.2	2.6

CCl_4
B = C_6H_6 (118.2)
t = 18°

10	−0.301
20	−0.598
30	−0.816
40	−0.963
50	−1.030
60	−1.030
70	−0.912
80	−0.699
90	−0.452

B = C_7H_8 (118.2)
Toluene
t = 17°

10	0.067
20	0.138
30	0.197
40	0.264
50	0.318
60	0.335
70	0.326
80	0.276
90	0.172

CS_2
B = $CHCl_3$ (118.2)
Chloroform
t = 13°

10	−2.55
20	−4.44
30	−5.65

$CHCl_3$.—*(Cont'd)*

% A	Q
40	−6.40
50	−6.65
60	−6.28
70	−5.27
80	−3.89
90	−2.22

B = C_2H_6O (137)
Ethyl alcohol
t = 0°

10	−2.948
20	−5.488
30	−7.483
40	−8.706
50	−9.203
60	−9.010
70	−8.513
80	−6.910
t = 3.2 to 5.5°	
10	−3.01
20	−5.603
30	−7.551
40	−8.844
50	−9.515
60	−9.607
70	−8.844
80	−7.369
t = 15.5°	
10	− 3.229
20	− 5.896
30	− 8.041
40	− 9.296
50	−10.47
60	−10.52
70	− 9.524
80	− 8.658

CS_2.—(*Continued*)

B = C_3H_6O (118.2)
Acetone

t = 16°

% A	Q
10	− 5.78
20	−11.80
30	−16.45
40	−19.92
50	−20.93
60	−20.80
70	−17.62
80	−16.15
90	−10.80

B = C_6H_6 (137)

t = 0°

% A	Q
10	−2.117
20	−3.85
30	−5.235
40	−6.305
50	−6.690
70	−6.101
80	−4.860
90	−3.001

t = 4°

% A	Q
10	−2.109
20	−3.827
30	−5.220
40	−6.257
50	−6.600
70	−6.040
80	−4.847
90	−2.997

t = 14.5°

% A	Q
10	−2.090
20	−3.807
30	−5.127
40	−6.109
50	−6.468
70	−5.920
80	−4.782
90	−2.976

t = 18° (118.2)

% A	Q
10	−2.59
20	−4.85
30	−6.78
40	−7.70
50	−7.95
60	−7.83
70	−6.82
80	−5.15
90	−2.93

B = C_7H_8 (118.2)
Toluene

t = 18°

% A	Q
10	−1.38
20	−2.64
30	−3.52
40	−4.44
50	−4.73
60	−4.60
70	−4.02
80	−3.01
90	−1.72

$CHCl_3$

Chloroform

B = C_3H_6O (118.2)
Acetone

t = 14°

% A	Q
10	4.77
20	9.83
30	14.31
40	19.38
50	23.27
60	25.53
70	25.07
80	21.55
90	13.56

B = $C_4H_{10}O$ (118.2)
Ethyl ether

t = 14°

% A	Q
10	7.49
20	13.89
30	18.71
40	23.48
50	26.53
60	25.99
70	23.77
80	18.83
90	10.21

B = C_6H_6 (118.2)

t = 18°

% A	Q
10	1.13
20	2.01
30	2.64
40	3.10
50	3.31
60	3.31
70	3.18
80	2.89
90	2.05

CH_4O

Methyl alcohol

B = C_2H_6O
Ethyl alcohol

t = 0.3° (48)

% A	Q
32.17	−0.322
67.83	−0.272
85.87	−0.146

t = 16° (118.2)

% A	Q
10	0.209
20	0.343
30	0.393
40	0.398
50	0.360
60	0.314
70	0.268
80	0.184
90	0.100

t = 20.8° (48)

% A	Q
32.3	−0.029
49.6	−0.029

B = C_3H_8O
n-Propyl alcohol

t = 0.3° (48)

% A	Q
32.84	−2.059
47.44	−2.239
70.84	−1.892

B = C_3H_8O.—(*Continued*)

t = 14° (118.2)

% A	Q
10	−0.75
20	−1.46
30	−2.05
40	−2.34
50	−2.30
60	−2.05
70	−1.72
80	−1.26
90	−0.71

t = 21.3° (48)

% A	Q
25.56	−1.507
50.03	−2.101
67.46	−1.908
82.41	−1.427

B = C_6H_6 (118.2)

t = 15°

% A	Q
10	− 9.33
20	− 9.54
30	−10.17
40	− 9.50
50	− 8.29
60	− 6.65
70	− 4.98
80	− 3.35
90	− 1.72

$C_2H_4O_2$

Acetic acid

B = C_6H_6 (118.2)

t = 16°

% A	Q
10	−2.39
20	−3.68
30	−4.81
40	−5.52
50	−5.98
60	−5.69
70	−5.06
80	−3.93
90	−2.39

C_2H_6O

Ethyl alcohol

B = C_3H_8O (48)
n-Propyl alcohol

t = 0.27°

% A	Q
45.2	−0.469
62.17	−0.594

t = 21°

% A	Q
32.86	−0.586
49.58	−0.523

B = C_6H_6 (137)

t = 0°

% A	Q
10	−4.045
20	−5.253
30	−6.055
40	−6.410
60	−6.120
70	−5.697
80	−4.414
90	−2.550

t = 3.1 to 5.9°

% A	Q
10	−4.320
20	−5.769

B = C_6H_6.—(*Continued*)

% A	Q
30	−6.550
40	−6.767
60	−6.411
70	−5.812
80	−4.469
90	−2.572

t = 15°

% A	Q
10	−5.416
20	−6.706
30	−7.338
40	−7.556
60	−6.867
70	−6.067
80	−4.578
90	−2.658

C_3H_6O

Acetone

B = C_6H_5ClO (50)
o-Chlorophenol

t = 0°

% A	Q
13.90	32.58
17.10	38.00
19.10	40.52
21.90	44.28
23.70	45.70
26.00	47.08
27.55	47.79
29.35	48.55
31.15	48.67
33.80	48.42
37.60	47.63
42.70	45.57
44.05	45.11
50.00	41.93
53.45	39.24
62.00	33.30

$C_3H_6O_2$

Methyl acetate

B = $C_4H_8O_2$ (118.2)
Ethyl acetate

t = 16°

% A	Q
10	−0.326
20	−0.594
30	−0.757
40	−0.850
50	−0.866
60	−0.787
70	−0.678
80	−0.511
90	−0.293

B = C_6H_6 (118.2)

t = 17°

% A	Q
10	−2.39
20	−4.52
30	−5.86
40	−6.36
50	−6.32
60	−5.69
70	−4.81
80	−3.64
90	−2.13

C_3H_8O

n-Propyl alcohol

B = C_6H_6 (118.2)

t = 15°

% A	Q
10	−10.30
20	−12.64
30	−13.56
40	−13.22
50	−12.26
60	−11.09
70	− 8.29
80	− 5.52
90	− 2.76

$C_4H_8O_2$

Ethyl acetate

B = $C_4H_{10}O$ (118.2)
Ethyl ether

t = 14°

% A	Q
10	−1.09
20	−1.76
30	−2.34
40	−2.76
50	−2.97
60	−2.76
70	−2.43
80	−1.88
90	−1.13

B = C_6H_6 (118.2)

t = 17°

% A	Q
10	−0.879
20	−1.310
30	−1.465
40	−1.528
50	−1.515
60	−1.444
70	−1.327
80	−1.109
90	−0.682

B = $C_7H_{14}O_2$
Amyl acetate (118.2)

t = 15°

% A	Q
10	−0.67
20	−1.00
30	−1.55
40	−1.84
50	−1.88
60	−1.76
70	−1.46
80	−1.13
90	−0.67

$C_4H_{10}O$

Ethyl ether

B = C_6H_6 (118.2)

t = 15°

% A	Q
10–90	0.00

C_5H_5N

Pyridine

B = C_6H_5ClO (50)
o-Chlorophenol

t = 0°

% A	Q
15.0	63.19
22.0	73.61

B = C_6H_5ClO.—(*Continued*)

% A	Q
25.1	78.01
30.0	85.08
34.0	89.18
38.1	91.15
41.1	90.19
46.9	84.70
55.1	72.74
61.0	63.44

B = C_7H_8O (50)
o-Cresol

t = 0°

% A	Q
17.5	52.94
25.05	68.63
30.7	76.25
36.4	80.64
39.9	81.11
40.2	81.31
44.85	79.39
48.7	75.79
49.9	74.79
50.85	73.53
57.25	64.74
57.65	64.66
63.0	53.15

B = C_7H_8O (50)
m-Cresol

t = 0°

% A	Q
9.85	26.03
19.5	45.87
27.5	57.54
33.1	61.60
36.8	63.70
42.2	63.24
49.05	58.97
54.25	54.66
61.00	47.54
68.25	38.54
82.9	21.42

$C_5H_{12}O$

Amyl alcohol

B = C_8H_{10} (55)
p-Xylene

t = 0°

% A	Q
20.6	4.48
39.2	6.57
46.5	6.78
53.1	6.40
64.8	5.23
72.7	3.81

C_6H_5ClO

o-Chlorophenol

B = $C_8H_{11}N$ (50)
Dimethylaniline

t = 0°

% A	Q
40.5	20.51
45.7	22.23
49.0	23.30
51.2	23.87
54.2	24.81
57.4	25.80
60.5	26.40
62.6	26.38

B = $C_8H_{11}N$.—(*Continued*)

% A	Q
64.85	25.88
67.25	25.08
69.85	23.87
73.65	22.24
80.0	18.84

B = C_9H_7N (50)
Quinoline
t = 0°

% A	Q
33.0	56.50
38.8	64.74
43.9	71.98
46.75	74.74
47.9	76.08
50.1	76.46
51.2	76.79

B = C_9H_7N.—(*Continued*)

% A	Q
51.7	76.79
52.6	76.63
53.6	76.33
54.7	75.79
57.5	72.74
61.4	65.83
66.75	57

C_6H_6

B = C_7H_8 (118.2)
Toluene
t = 16°

% A	Q
10	−0.335
20	−0.603
30	−0.829
40	−0.917

B = C_7H_8.—(*Continued*)

% A	Q
50	−0.933
60	−0.921
70	−0.778
80	−0.519
90	−0.264

C_6H_7N
Aniline
B = C_8H_{10} (55)
p-Xylene
t = 0°

% A	Q
27.6	9.96
31.7	10.80
49.1	11.22
58	10.42
66	9.54
78.6	6.65

TABLE 5

The concentration is expressed by the number of moles of solvent, M_s, added to one mole of solute. The B-component where italicized is the solute, and is otherwise the solvent. Q is expressed in kilojoules evolved per mole solute.

H_2O

B = CH_2O_2 (64)
Formic acid

M_s	Q
0.135	0.348
0.28	0.744
0.45	1.061
0.85	1.430
1.10	1.460
1.70	1.445
5.96	1.299
48.55	1.257

B = $C_2HBr_3O_2$
Tribromoacetic acid
(solid)
t = 15.2° (115)

M_s	Q
206	1.05
417	1.99
799	2.62
∞	3.52

B = $C_2HCl_3O_2$
Trichloroacetic acid (solid)
t = 15.31° (115)

M_s	Q
245	10.48
498	11.32
936	11.29

B = $C_2H_2Br_2O_2$
Dibromoacetic acid (solid)
t = 15.3° (115)

M_s	Q
364	−1.18
479	−3.76
712	−3.42

B = $C_2H_2Cl_2O_2$
Dichloroacetic acid
t = 15.9° (115)

M_s	Q
196	9.63
398	10.80
776	11.59

B = $C_2H_3BrO_2$
Bromoacetic acid
(solid)
t = 15.45° (115)

M_s	Q
199	−13.84
365	−13.45
712	−13.15

B = $C_2H_4O_2$
Acetic acid
(64)

M_s	Q
0.25	−0.293
0.58	−0.527
1.11	−0.624
1.42	−0.624
1.95	−0.544
5.00	−0.310
6.19	+0.056
30.00	0.386
63.33	0.449

t = 18.5° (115)

M_s	Q
139	1.12
197	1.53*
207	1.15
411	1.37
∞	1.90

* 13.6°.

B = $C_3H_6O_2$ (64)
Propionic acid
t = 8°

M_s	Q
0.216	−1.40
0.456	−2.00
0.720	−2.29
1.027	−2.46
1.718	−2.62
2.740	−2.52
4.110	−2.35
9.590	−1.79
14.570	−1.48
38.270	−1.26
78.110	−1.25

B = $C_4H_8O_2$ (64)
n-Butyric acid
t = 9°

M_s	Q
0.25	−1.00
0.54	−1.49
0.86	−1.77
1.22	−1.93
1.63	−2.04
2.09	−2.08
3.05	−2.08
3.67	−1.99
7.33	−1.68
19.55	−1.24
44.00	−0.91
93.00	−0.73

$C_2H_4Br_2$
Ethylene bromide
B = $C_2H_4O_2$ (4)
Acetic acid

M_s	Q
0.30	0.55
0.528	0.845
1.06	1.318

B = $C_2H_4O_2$.—(*Continued*)

M_s	Q
1.47	1.544
2.04	1.803
2.944	2.108
3.67	2.281
4.98	2.486

B = $C_2H_4O_2$ (4)
Acetic acid

M_s	Q
0.201	0.498
0.34	0.716
0.273	0.621
0.49	0.883
0.68	1.050
0.943	1.243
1.887	1.594
3.333	1.820

$C_2H_4O_2$
Acetic acid
B = C_6H_6 (4)

M_s	Q
0.2143	−0.370
0.2500	−0.414

B = C_6H_6.—(*Cont'd*)

M_s	Q
0.304	−0.481
0.333	−0.514
0.385	−0.552
0.515	−0.661
0.77	−0.820
0.775	−0.824
1.25	−1.004
2.137	−1.251
5.17	−1.515
7.75	−1.569
15.52	−1.689

B = C_6H_6 (4)

M_s	Q
0.0644	−0.109
0.129	−0.203
0.1934	−0.293
0.468	−0.586
0.80	−0.804
1.29	−1.063
1.30	−1.063
1.942	−1.282
2.60	−1.434

B = C_6H_6.—(*Continued*)

M_s	Q
3.00	−1.542
3.29	−1.578
4.00	−1.653
4.666	−1.724

C_2H_6O
Ethyl alcohol
B = C_6H_6 (131)

M_s	Q
0.2675	−0.289
1.642	−1.548
2.19	−2.093
2.633	−2.427
3.284	−2.930
3.940	−3.390
4.586	−3.850
6.569	−4.637
7.88	−5.608
8.53	−5.859
9.195	−6.236
10.5	−6.738

TABLE 6

The concentration is expressed as the mole per cent of the A-component in the mixture. Q is expressed in kilojoules evolved per mole B.

H_2O

B = CH_4O (49)
Methyl alcohol
t = 0°

M % A	Q
5	0.159
10	0.310
15	0.460
20	0.607
25	0.762
30	0.925
35	1.105
40	1.297
45	1.511
50	1.766
55	2.038
60	2.381
65	2.783
70	3.306
75	3.967
80	4.763
85	5.750
90	6.905
95	8.328

t = 19.69°

M % A	Q
5	0.134
10	0.272
15	0.419
20	0.569
25	0.716
30	0.862
35	1.017
40	1.197
45	1.398

B = CH_4O.—(*Continued*)

M % A	Q
50	1.632
55	1.896
60	2.218
65	2.591
70	3.055
75	3.666
80	4.357
85	5.114
90	5.989
95	6.838

t = 42.37°

M % A	Q
5	0.071
10	0.151
15	0.251
20	0.356
25	0.473
30	0.594
35	0.724
40	0.866
45	1.013
50	1.193
55	1.402
60	1.632
65	1.908
70	2.264
75	2.691
80	3.185
85	3.725
90	4.352
95	4.997

B = C_2H_6O (49)
Ethyl alcohol
t = 0°

M % A	Q
5	0.088
10	0.176
15	0.289
20	0.410
25	0.498
30	0.590
35	0.691
40	0.824
45	1.004
50	1.251
55	1.523
60	1.900
65	2.385
70	3.038
75	3.972
80	5.428
85	7.407
90	9.856
95	12.54

t = 17.33°

M % A	Q
5	0.042
10	0.092
15	0.167
20	0.251
25	0.335
30	0.423
35	0.519
40	0.636
45	0.757
50	0.946

H_2O.—(*Cont'd*)

$B = C_2H_6O$.—(*Continued*)

M % A	Q
55	1.201
60	1.507
65	1.925
70	2.478
75	3.218
80	4.269
85	5.821
90	7.801
95	9.818
$t = 42.05°$	
5	0.0029
10	0.0063
15	0.013
20	0.023
25	0.042
30	0.075
35	0.109
40	0.167
45	0.243
50	0.343
55	0.465
60	0.649
65	0.870
70	1.209
75	1.691
80	2.356
85	3.281
90	4.528
95	6.236

$B = C_3H_8O$ (49)
n-Propyl alcohol

M % A	Q
$t = 0°$	
5	−0.011
10	−0.021
15	−0.027
20	−0.019
25	−0.008
30	+0.010
35	0.042
40	0.092
45	0.167
50	0.264
55	0.419
60	0.590
65	0.883
70	1.264
75	1.354
80	2.758
85	4.323
90	7.382
95	12.68
$t = 21.03°$	
5	−0.042
10	−0.084
15	−0.121
20	−0.159
25	−0.197
30	−0.230
35	−0.243
40	−0.243
45	−0.209
50	−0.167

$B = C_3H_8O$.—(*Continued*)

M % A	Q
55	−0.084
60	+0.038
65	0.201
70	0.431
75	0.778
80	1.335
85	2.264
90	4.110
95	7.981
$t = 43.44°$	
5	−0.105
10	−0.205
15	−0.306
20	−0.402
25	−0.498
30	−0.590
35	−0.670
40	−0.737
45	−0.778
50	−0.795
55	−0.795
60	−0.770
65	−0.728
70	−0.644
75	−0.502
80	−0.259
85	+0.176
90	0.586
95	3.055

LITERATURE

(For a key to the periodicals see end of volume)

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(20) Berthelot, *6*, **12**: 536; 77. (21) Berthelot, *6*, **23**: 176; 81. (22) Berthelot, *6*, **23**: 243; 81. (23) Berthelot, *6*, **27**: 383; 82. (24) Berthelot, *6*, **27**: 389; 82. (25) Berthelot, *6*, **7**: 170; 86. (26) Berthelot, *6*, **7**: 179; 86. (27) Berthelot, *6*, **7**: 193; 86. (28) Berthelot, *6*, **7**: 200; 86. (29) Berthelot, *6*, **21**: 355; 90.

(30) Berthelot, *6*, **21**: 372; 90. (31) Berthelot, *6*, **21**: 416; 90. (32) Berthelot, *6*, **23**: 563; 91. (33) Berthelot, *6*, **4**: 117; 95. (34) Berthelot, *6*, **7**: 50; 96. (35) Berthelot and Fogh, *6*, **22**: 18; 91. (36) Berthelot and Jungfleisch, *6*, **4**: 147; 75. (37) Berthelot and Louguinine, *6*, **6**: 289; 75. (38) Berthelot and Matignon, *6*, **21**: 409; 90. (39) Berthelot and Matignon, *6*, **30**: 565; 93.

(40) Berthelot and Ogier, *6*, **23**: 199; 81. (41) Berthelot and Ogier, *6*, **23**: 200; 81. (42) Berthelot and Petit, *6*, **20**: 5; 90. (43) Berthelot and Petit, *6*, **20**: 13; 90. (44) Berthelot and Werner, *6*, **7**: 103; 86. (45) Berthelot and Werner, *6*, **7**: 117; 86. (46) Berthelot and Werner, *6*, **7**: 145; 86. (47) Bonnefoi, *34*, **127**: 516; 98. (48) Bose, *188*, **1906**: 309. (49) Bose, *7*, **58**: 585; 07.

(50) Bramley, *4*, **109**: 496; 16. (51) Carroll and Mathews, *1*, **46**: 30; 24. (52) Cavalier, *34*, **122**: 1486; 96. (53) Chancel and Parmentier, *34*, **104**: 474; 87. (54) Chroustchoff, *6*, **19**: 422; 80. (55) Clark, *63*, **6**: 154; 05. (56) Cohen and Moesveld, *7*, **93**: 385; 19. (57) Colson, *6*, **8**: 282; 86. (58) Colson, *6*, **19**: 407; 90. (59) Colson, *34*, **111**: 266; 90.

(60) Colson and Darzens, *34*, **118**: 250; 94. (61) Combes, *27*, **49**: 910; 88. (62) Delépine, *34*, **123**: 888; 96. (63) Drucker and Moles, *7*, **75**: 405; 11. (64) Faucon, *6*, **19**: 70; 10. (65) Favre, *34*, **51**: 316; 60. (66) de Forcrand, *6*, **3**: 187; 84. (67) de Forcrand, *34*, **101**: 1495; 85. (68) de Forcrand, *34*, **102**: 551; 86. (69) de Forcrand, *34*, **102**: 1398; 86.

(70) de Forcrand, *6*, **11**: 445; 87. (71) de Forcrand, *6*, **11**: 483; 87. (72) de Forcrand, *34*, **107**: 270; 88. (73) de Forcrand, *6*, **20**: 433; 90. (74) de Forcrand, *6*, **26**: 201; 92. (75) de Forcrand, *6*, **27**: 525; 92. (76) de Forcrand, *34*, **114**: 420; 92. (77) de Forcrand, *34*, **114**: 1062; 92. (78) de Forcrand, *6*, **30**: 56; 93. (79) de Forcrand, *34*, **118**: 922; 94.

(80) de Forcrand, *34*, **118**: 1101; 94. (81) de Forcrand, *34*, **120**: 737; 95. (82) de Forcrand, *34*, **154**: 1768; 12. (83) Gal and Werner, *34*, **103**: 1019; 86. (84) Gal and Werner, *27*, **46**: 801; 86. (85) Gal and Werner, *27*, **46**: 803; 86. (86) Gal and Werner, *27*, **47**: 158; 87. (87) Gautier, *Thesis*, Paris, 1888. (88) Gehlhoff, *7*, **98**: 252; 21. (89) Gerlach, *91*, **24**: 106; 84.

(90) Goldschmidt and Maarseveen, *7*, **25**: 91; 98. (91) Guntz, *6*, **13**: 388; 88. (93) Haller and Guntz, *34*, **106**: 1473; 88. (94) Hartung, *83*, **12**: 66; 17. (94.1) Hirobe, *44*, **1**: 155; 26. (95) Joannis, *6*, **26**: 530; 82. (96) Jorissen and van de Stadt, *52*, **51**: 102; 94. (97) Katayama and Tomiyama, *41*, **36**: 745; 15. (98) Katz, *64P*, **13**: 958; 11. (99) Keyes and Hildebrand, *1*, **39**: 2126; 17.

(100) de Kolossovsky, *28*, **1913**: 340. (101) Kremann, *57*, **37**: 11; 16. (102) Kremann and Borjanovics, *57*, **37**: 59; 16. (103) Kremann, Kerschbaum and Pilch, *57*, **31**: 203; 10. (104) Kremann, Meingast and Gugl, *57*, **35**: 1235; 14. (104.1) de Leew, *7*, **77**: 284; 11. (105) Lemoult, *34*, **123**: 559; 96. (106) Louguinine, *6*, **17**: 229; 79. (107) Massol, *34*, **113**: 800; 91. (108) Massol, *6*, **1**: 145; 94. (109) Mathews, *1*, **33**: 1291; 11.

(110) Matignon, *6*, **28**: 70; 93. (111) Matignon, *6*, **28**: 77; 93. (112) Matignon, *6*, **28**: 289; 93. (112.5) Parks and Chaffee, *50*, **31**: 427; 27. (113) Parks and Schwenck, *50*, **28**: 720; 24. (114) Petit, *6*, **18**: 145; 89. (115) Pickering, *4*, **67**: 664; 95. (116) Rivals, *34*, **122**: 480; 96. (117) Sameshima, *1*, **40**: 1482; 18. (118) Sameshima, *1*, **40**: 1503; 18. (118.1) Sandonnini, *22*, **1**: 448; 25. (118.2) Schmidt, *7*, **121**: 221; 26. (119) Schwers, *28*, **1908**: 833.

(120) Shükarev, *7*, **71**: 90; 10. (121) Sidgwick and Turner, *4*, **121**: 2256; 22. (122) Speyers, *1*, **18**: 146; 96. (123) Swietoslawski, *25*, **43**: 1479; 10. (124) Tanatar, *53*, **23**: 243; 91. *4*, **64 II**: 108; 93. (125) Tanatar, *53*, **24**: 365; 92. *4*, **64 II**: 358; 93. (126) Timofeev, *34*, **112**: 1137; 91. (127) Timofeev, *185*, **76 II**: 429; 05. (128) Tsakalotos and Guye, *42*, **8**: 340; 10. (129) Tscheltzow, *6*, **8**: 233; 86.

(130) Tyrer, *4*, **101**: 81; 12. (131) Viala, *27*, **15**: 5; 14. (132) Vignon, *34*, **106**: 1671; 88. (133) Vignon, *34*, **109**: 477; 89. (134) Vignon, *34*, **115**: 354; 92. (135) Werner, *6*, **3**: 567; 84. (136) Wiedemann and Lüdeking, *8*, **25**: 145; 85. (137) Winkelmann, *8*, **30**: 592; 73. (138) Winkelmann, *7*, **60**: 626; 07.

HEAT OF DILUTION

FRANK R. PRATT

INTRODUCTION

If to a solution having an initial concentration C_1 and at the temperature *t*, °C water at *t*° is added in sufficient amount to change the concentration to C_2, it is necessary to *abstract* from the system *H* joules of heat in order to keep its temperature constant, the *amount* of solution being that shown by the quantities in which C_1 is expressed. For example, in the table for KCl below; if to a solution composed of 1 gram-mole of KCl and 25 gram-moles of H_2O, C_1 ($=400$) at 18°C, 25 gram-moles of H_2O at 18°C be added, the final concentration will be C_2 ($=200$) and 794 joules of heat must be *supplied* (because of the negative sign) to the resulting mixture in order to maintain it at 18°C. It is the quantity *H* which (unless otherwise indicated) is recorded below. The values given have been interpolated from the original drawings of the graphs of Pratt, *143*, **185**: 663; 18.

TABLE

Ethyl alcohol (Squibb's), C_1 ≎ 400 = 1M C_2H_5OH and 25M H_2O

t, °C	C_2								
	300	240	200	160	100	80	60	40	20
0	309	447	531	602	702	744	782		
5	301	443	523	594	694	732	765		
10	293	435	514	585	686	719	753	*v. further* p. 162	
15	288	422	506	577	677	711	736		
20	280	414	493	569	665	694	719		
25	272	406	485	560	656	681	702		
30	263	397	477	552	648	677	690		
33.5	255	389	468	544	635	656	673		

Resorcinol, $C_1 \Bumpeq 400$ = 1M $C_6H_6O_2$ and 25M H_2O

t, °C	C_2								
	300	240	200	160	100	80	60	40	20
0	− 21	− 50	− 84	−125	−217	−251	−293	−343	−376
5	− 38	− 79	−113	−167	−272	−301	−360	−418	−468
10	− 54	−100	−142	−201	−309	−360	−418	−485	−560
15	− 67	−125	−171	−234	−364	−418	−481	−560	−635
20	− 84	−151	−205	−272	−410	−460	−544	−627	−744
25	−100	−176	−230	−314	−460	−527	−615	−744	−828
30	−117	−201	−268	−343	−502	−585	−669	−773	−920
33.5	−134	−226	−293	−376	−544	−619	−719	−836	−1003
Pyrocatechol, $C_1 \Bumpeq 400$ = 1M $C_6H_6O_2$ and 25M H_2O									
0	326	544	711	899	1187	1275	1359	1432	
5	293	489	635	811	1070	1162	1233	1296	
10	259	439	573	727	970	1045	1108	1171	
15	226	376	502	635	840	920	983	1045	
20	188	326	426	543	732	794	857	920	
25	151	272	351	452	619	673	736	794	
30	121	217	280	363.7	506	552	606	669	
33.5	100	167	226	301.0	418	460	502	552	
1/16 **Hydroquinol**, $C_1 \Bumpeq 400$ = 1M $C_6H_6O_2$ and 400M H_2O									
0	10.0	13.8	14.2	12.5	− 3.3	−13.4			
5	6.3	8.4	8.4	6.3	− 7.9	−15.1			
10	3.8	4.2	3.3	0.4	−11.7	−18.0			
15	1.3	0	− 1.7	− 5.4	−15.1	−19.2			
20	− 2.1	− 5.0	− 7.5	−11.3	−20.1	−23.0			
25	− 5.9	−10.0	−13.0	−16.7	−23.0	−25.5			
30	− 8.8	−14.2	−17.1	−20.5	−25.5	−27.2			
33.5	−12.1	−18.4	−21.7	−24.2	−26.7	−27.2			
½ **Mannitol**, $C_1 \Bumpeq 400$ = 1M $C_6H_{14}O_6$ and 50M H_2O									
0	4.2	3.8	2.1	− 3.3	−14.6				
5	6.7	8.4	6.7	5.0	− 0.8				
10	7.1	10.5	11.3	11.3	11.3				
15	7.5	12.5	15.1	19.2	25.1				
20	9.2	16.3	21.7	28.4	39.7				
25	9.2	16.7	23.8	33.0	50.2				
30	13.0	21.7	30.1	41.8	64.8				
33.5	13.4	23.8	33.4	46.8	76.9				
Dextrose, $C_1 \Bumpeq 400$ = 1M $C_6H_{12}O_6.H_2O$ and 25M H_2O									
0	167	268	343						
5	167	268	343						
10	167	268	343						
15	167	268	343						
20	167	268	343	431	560	606	652	690	
25	167	268	343	427	544	585	623	656	
30	167	268	343	418	527	560	594	623	
33.5	167	268	343	414	510	543	564	594	
Sucrose, $C_1 \Bumpeq 400$ = 1M $C_{12}H_{22}O_{11}$ and 25M H_2O									
0	247	393	481	564	673	707	736	769	
5	247	393	485	573	694	732	773	815	
10	247	397	493	585	719	761	807	857	
15	247	397	497	594	744	794	849	916	
20	247	401	502	606	769	824	891	962	
25	247	401	510	619	790	853	924	1008	
30	247	406	518	631	819	886	962	1054	
33.5	247	410	522	644	836	907	991	1095	

1.847 **NaOH**, $C_1 \Bumpeq 800$ = 2M NaOH and 25M H_2O

t, °C	C_2							
	720	300	200	140	80	60	40	20
0	−63	−1534	−2279	−2885	−3617	−3847		
5	−42	−1200	−1831	−2300	−2835	−2989	−3169	−3345
10	−21	− 911	−1401	−1756	−2132	−2237	−2354	−2467
15	4	− 619	−1016	−1254	−1480	−1559	−1647	−1714
20	8	− 334	− 606	− 778	− 928	− 978	−1020	−1066
25	12	− 63	− 242	− 355	− 447	− 477	− 489	− 493
30	17	171	84	21	− 42	− 50	− 63	− 67
33.5	21	343	326	284	251	247	247	247

1.645 **KOH**, $C_1 \Bumpeq 800$ = 2M KOH and 25M H_2O

t, °C	C_2						
	640	300	200	140	80	60	40
0	0	−355	−719	−1003	−1317	−1422	−1547
5	13	− 96	−385	− 544	− 753	− 828	− 899
10	25	138	4	− 100	− 209	− 251	− 293
15	38	355	326	284	251	251	263
20	50	560	606	652	690	719	773
25	63	744	870	953	1066	1129	1204
30	71	903	1087	1213	1392	1484	1589
33.5	79	983	1204	1346	1555	1651	1756

1.17 **NH₄Cl**, $C_1 \Bumpeq 400$ = 1.17M NH_4Cl and 25M H_2O

t, °C	C_2								
	300	240	200	160	100	80	60	40	20
0	−255	−431	−556	−698	−920	−983	−1037	−1087	
2	−238	−397	−514	−640	−836	−899	− 937	− 978	
4	−230	−364	−472	−585	−757	−811	− 840	− 861	
6	−201	−334	−431	−535	−669	−711	− 744	− 753	
8	−184	−305	−389	−468	−594	−619	− 644	− 644	
10	−167	−276	−351	−418	−518	−544	− 552	− 552	
12	−151	−247	−309	−368	−452	−468	− 460	− 477	−334
14	−138	−230	−272	−318	−385	−393	− 385	− 339	−226
16	−125	−201	−238	−272	−314	−314	− 309	− 255	−142
18	−109	−167	−201	−226	−247	−238	− 222	− 167	− 42
20	− 92	−134	−163	−176	−176	−167	− 151	− 84	+ 84
NH₄Cl, $C_1 \Bumpeq 400$ = 1M NH_4Cl and 25M H_2O									
22	−63	−88	−96	−96	−96	−96	−96	−84	−21
24	−46	−59	−67	−67	−42	−25	8	71	159
26	−33	−42	−33	−29	4	33	84	155	251
28	−17	−13	0	13	59	84	142	234	334
30	− 4	8	25	42	100	125	192	272	385
32	8	33	50	71	134	167	209	293	418
33.5	21	46	67	92	155	192	230	305	439
KCl, $C_1 \Bumpeq 400$ = 1M KCl and 25M H_2O									
0	−594	−974	−1246	−1547	−2095	−2308	−2530	−2718	−2843
2	−564	−924	−1179	−1484	−2007	−2195	−2404	−2575	−2663
4	−543	−907	−1129	−1409	−1902	−2091	−2279	−2438	−2509
6	−518	−845	−1087	−1346	−1819	−1999	−2174	−2329	−2366
8	−481	−807	−1037	−1288	−1735	−1902	−2070	−2195	−2245
10	−460	−761	− 983	−1217	−1631	−1781	−1944	−2086	−2111
12	−439	−727	− 937	−1162	−1547	−1697	−1835	−1957	−1982
14	−418	−702	− 891	−1100	−1463	−1589	−1735	−1840	−1848
16	−397	−661	− 845	−1037	−1388	−1505	−1639	−1748	−1748
18	−376	−619	− 794	− 983	−1325	−1421	−1547	−1631	−1631
20	−355	−585	− 753	− 928	−1233	−1338	−1455	−1534	−1505
22	−326	−552	− 707	− 878	−1162	−1258	−1363	−1432	−1421
24	−313	−518	− 665	− 828	−1091	−1179	−1267	−1325	−1296
26	−293	−489	− 627	− 773	−1020	−1104	−1183	−1237	−1191
28	−280	−460	− 585	− 723	− 953	−1033	−1104	−1145	−1087
30	−272	−439	− 556	− 681	− 891	− 962	−1003	−1041	− 974
32	−251	−410	− 523	− 635	− 815	− 907	− 932	− 962	− 853
33.5	−238	−389	− 493	− 594	− 773	− 828	− 874	− 899	− 786
½ **SrCl₂**, $C_1 \Bumpeq 400$ = 1M $SrCl_2$ and 50M H_2O									
14	−33	−54	−59	−46	−25	8	54	159	401
16	−17	−33	−13	13	54	88	146	251	493
18	0	33	33	63	134	171	230	334	585
20	21	50	84	121	209	251	309	427	669
22	42	92	134	184	276	330	389	506	753
24	59	117	163	217	334	389	460	585	828
26	75	142	197	268	414	460	535	669	911
28	92	171	230	314	456	514	594	744	978
30	117	201	272	351	506	577	661	799	1024
32	134	226	301	397	560	631	727	857	1095
33.5	146	251	330	426	602	677	773	920	1158
½ **SrCl₂**, $C_1 \Bumpeq 400$ = 1M $SrCl_2.6H_2O$ and 50M H_2O									
0	−70	−117	−146	−184	−234				
2	−59	−100	−125	−151	−171				
4	−52	− 84	−105	−113	−125				
6	−46	− 71	− 75	− 84	− 88				
8	−40	− 59	− 54	− 54	− 54				
10	−33	− 42	− 38	− 38	− 29				
12	−25	− 25	− 25	− 17	+ 4				
½ **BaCl₂**, $C_1 \Bumpeq 400$ = 1M $BaCl_2$ and 25M H_2O									
14	−125	−192	−226	−251	−272	−276	−251	−180	42
16	−105	−151	−167	−188	−192	−188	−146	− 63	167
18	− 84	−117	−125	−117	−105	− 8	− 42	50	251
20	− 63	− 75	− 75	− 63	− 17	4	59	163	376
22	− 42	− 42	− 38	0	63	92	159	255	447
24	− 21	4	38	59	134	167	247	343	573
26	0	33	63	109	201	251	314	426	635
28	21	63	109	167	280	326	401	510	732
30	42	105	151	226	347	397	489	552	794
32	63	134	201	272	418	468	564	594	857
33.5	84	163	226	309	460	523	615	619	920
½ **BaCl₂**, $C_1 \Bumpeq 400$ = 1M $BaCl_2.2H_2O$ and 50M H_2O									
0	−226	−364	−468	−577	−753	−824	−903	−1003	
2	−209	−330	−418	−514	−656	−702	−753	−811	
4	−184	−293	−372	−452	−564	−598	−619	− 652	
6	−155	−259	−322	−385	−472	−489	−502	− 502	

$\frac{1}{2}$**BaCl₂**, $C_1 \Leftrightarrow 400$ = 1M $BaCl_2.2H_2O$ and 50M H_2O.—(*Cont'd*)

t, °C	C_2								
	300	240	200	160	100	80	60	40	20
8	−146	−230	−280	−330	−385	−393	−393	− 376	
10	−125	−197	−230	−268	−293	−293	−276	− 234	
12	−109	−163	−188	−205	−201	−192	−159	− 84	
NH_4NO_3, $C_1 \Leftrightarrow 400$ = 1M NH_4NO_3 and 25M H_2O									
0	−1108	−1819	−2299	−2843	−3721	−4014	−4327	−4641	−5017
5	−1024	−1693	−2132	−2634	−3420	−3679	−3972	−4223	−4515
10	− 983	−1589	−1986	−2425	−3094	−3345	−3596	−3847	−4139
15	− 899	−1442	−1827	−2216	−2843	−3040	−3261	−3491	−3763
20	− 836	−1338	−1672	−2019	−2571	−2759	−2969	−3157	−3387
25	− 773	−1233	−1568	−1852	−2362	−2530	−2697	−2885	−3010
30	− 727	−1150	−1442	−1723	−2153	−2320	−2446	−2592	−2697
33.5	− 669	−1066	−1355	−1622	−2028	−2174	−2362	−2425	−2488
$NaNO_3$, $C_1 \Leftrightarrow 400$ = 1M $NaNO_3$ and 25M H_2O									
0	−1233	−2007	−2659	−3261	−4348	−4725	−5184	−5561	−5895
5	−1087	−1798	−2333	−2885	−3847	−4223	−4599	−4975	−5226
10	−1003	−1647	−2132	−2634	−3512	−3847	−4181	−4515	−4766
15	− 911	−1497	−1915	−2375	−3178	−3470	−3763	−4056	−4265
20	− 836	−1380	−1756	−2174	−2885	−3178	−3408	−3658	−3805
25	− 769	−1254	−1631	−2007	−2592	−2822	−3044	−3219	−3387
30	− 690	−1154	−1497	−1840	−2341	−2542	−2709	−2885	−3010
33.5	− 661	−1087	−1396	−1714	−2174	−2341	−2475	−2592	−2676
KNO_3, $C_1 \Leftrightarrow 400$ = 1M KNO_3 and 25M H_2O									
0	−1547	−2634	−3408	−4348	−6062	−6815	−7526	−8362	−9073
5	−1505	−2509	−3219	−4014	−5561	−6104	−6690	−7359	−8069
10	−1421	−2341	−2969	−3721	−5059	−5519	−6021	−6564	−7108
15	−1338	−2174	−2843	−3512	−4683	−5101	−5519	−5979	−6439
20	−1212	−2007	−2592	−3219	−4348	−4683	−5101	−5519	−5853
25	−1150	−1923	−2425	−3094	−4014	−4390	−4725	−5101	−5477
30	−1095	−1840	−2383	−2885	−3805	−4139	−4474	−4808	−5101
33.5	−1045	−1756	−2258	−2759	−3721	−3930	−4181	−4515	−4808
$\frac{1}{8}$**$Ba(NO_3)_2$**, $C_1 \Leftrightarrow 400$ = 1M $Ba(NO_3)_2$ and 25M H_2O									
0	−197	−334	−443	−564	−761	−836	−911	−1003	−1087
5	−171	−293	−376	−468	−640	−702	−761	− 836	−1003
10	−151	−255	−334	−418	−556	−606	−665	− 711	− 732
15	−138	−226	−293	−364	−472	−514	−552		
20	−125	−201	−255	−314	−401	−431	−460		
25	−113	−176	−222	−268	−351	−376	−389		
30	− 96	−159	−192	−251	−318	−330	−334		
33.5	− 84	−146	−176	−234	−284				

$\frac{1}{2}$**$Sr(NO_3)_2$**, $C_1 \Leftrightarrow 400$ = 1M $Sr(NO_3)_2$ and 50 MH_2O

t, °C	C_2								
	300	240	200	160	100	80	60	40	20
0	−978	−1568	−2049	−2571	−3512	−3847	−4181	−4641	−5184
5	−911	−1497	−1902	−2363	−3177	−3428	−3742	−4076	−4453
10	−832	−1359	−1735	−2132	−2835	−3073	−3324	−3617	−3888
15	−753	−1212	−1568	−1923	−2530	−2718	−2948	−3157	−3387
20	−686	−1108	−1401	−1714	−2216	−2404	−2592	−2739	−2843
25	−602	− 974	−1233	−1526	−1965	−2091	−2216	−2341	
30	−518	− 845	−1087	−1321	−1706	−1819	−1902	−2007	
33.5	−435	− 732	− 983	−1171	−1526	−1589	−1672	−1735	

HEAT OF DILUTION OF AQUEOUS SOLUTIONS OF ETHYL AND METHYL ALCOHOLS

If m grams of water are added to M grams of solution containing N gram-molecular-weights of the alcohol per 1000 g of H_2O the heat (Q) evolved per mole of water added is given by

$$Q = \mathrm{A} - 10^{-3} \times \mathrm{B}m, \text{ g-cal}_{20}/\text{Mole}$$
$$Q = \mathrm{a} - 10^{-3} \times \mathrm{b}m, \text{ joule/Mole}$$

up to m = 800 g. All weights *in vacuo*. t = 25°C. Braham, Atmospheric Nitrogen Corporation, Syracuse, N. Y., *O*. MacInnes and Braham, *1*, **39**: 2110; 17.

N	C_2H_5OH, M = 9611 g*				CH_3OH, M = 9600 g†			
	A	B	a	b	A	B	a	b
1	2.00	0.51	8.37	2.13	1.10	0.00	4.22	0.00
2	8.80	1.3_8	36.8	5.7_8	4.44	0.21	18.6	0.88
3	21.8_5	2.48_1	91.4	10.38	10.30	0.82_5	43.10	3.45
4	40.60	4.45_0	170.0	18.63	18.53	1.8	77.5	

* $\mathrm{A} = 0.56N + 0.80N^2 + 0.72N^3 - 0.08N^4$.
$\mathrm{a} = 2.34_5N + 3.35N^2 + 3.01_8N^3 - 0.335N^4$.
† $\mathrm{A} = -0.20N + 1.21N^2$.
$\mathrm{a} = -0.83_7N + 5.03N^2$.

HEATS OF COMBUSTION OF ORGANIC COMPOUNDS

Source of the Data

All of the values given in this section have been taken from the critical compilation by Kharasch (¹) to which the reader is referred for bibliography and critical discussion.

Units

The values recorded in the tables are expressed in 1922 International Combustion Calories[1] per gram-formula-weight (*in vacuo*) of substance in the **liquid state** (unless otherwise indicated by g = gas and s = solid) when the combustion takes place **at constant pressure** (1 atm.) and at 18 − 20°C, to form gaseous CO_2 and N_2, liquid H_2O, and such compounds of other elements present as are indicated under the individual entries.

Standard Substances for Combustion Calorimetry

Primary Standard.—The Third Conference of the International Union of Pure and Applied Chemistry (Lyons, 1922) adopted the benzoic acid standard with the following values: Q = 6 324 g-cal₁₅ (≡26 466 abs. j.) per gram in air; =6 319 g-cal₁₅ (≡26 445 abs. j.) per gram *in vacuo; cf.* (³, ⁵). These values define what may be called the "1922 International Combustion Calorie."

Proposed Secondary Standard.—Salicylic acid, Q = 5 242 g-cal₁₅ (≡22 699 abs. j.) per gram in air; =5 238 g-cal₁₅ (≡21 921 abs. j.) per gram *in vacuo* (⁴).

Other Standards.—The best values for cane sugar and naphthalene may be obtained from the following carefully determined ratios of Q per gram in air (²).

$$\frac{\text{Naphthalene}}{\text{Benzoic acid}} = 1.5201. \quad \frac{\text{Benzoic acid}}{\text{Sugar}} = 1.6028. \quad \frac{\text{Naph.}}{\text{Sugar}} = 2.4364$$

Calculation of Heat of Combustion from Structural Formula

The heat of combustion of any organic compound in the liquid state may be calculated from its structural formula with an accuracy, in most cases, of better than 1%. For most purposes for which heats of combustion are required this accuracy is sufficient. Indeed it is equal to or better than the accuracy of most of the experimental values now available. For a full description of the method of calculation and comparison between observed and calculated values, *see* (¹).

Heats of Formation

The heat of formation, H, of any compound ($C_aH_bBr_cCl_dF_eI_fN_gO_hS_i$) out of its elements in their standard states (*v.* p. 169) may be calculated from its heat of combustion, Q, as given below, by means of the equation $H = (-Q + 94.38a + 34.19b +$

---

[1] Calories instead of joules have been employed in this section in deference to the wishes of the Committee on Thermochemistry of the International Union of Pure and Applied Chemistry.

NH_3

$x_2 = NH_3$		x_2	0.5	0.4	0.3	0.2	0.1	0.05	0.02	0.01	0.00	$x_1 = H_2O$	
gas	liq.	N	1	1.5	2.333	4	9	19	49	99	∞	gas	liq.
		%	48.59	38.66	28.84	19.16	9.50	4.74	1.92	0.946	0.0		
45.495_1	67.33_7	$-H$	76.1_7	78.6_8	79.72_4	80.64_5	81.27_3	81.69_1	81.94_2	81.56_6	81.23_1	241.8_9	286.84_8
		$-\overline{H}_2$	69.8_9	75.3_8	77.21_8	79.30_6	80.60_3	81.35_6	82.90_5	84.9_6	81.23_1		
0°C		$-\overline{H}_1$	$293._0$	289.0_2	288.3_0	287.1_7	286.96_1	286.85_7	286.82_7	286.81_5	286.84_8		
45.867_6	66.03_9	$-H$	73.2_4	77.0_0	78.72_0	79.51_5	80.31_0	80.51_9	80.68_7	80.77_1	80.77_1	241.9_7	286.10_8
		$-\overline{H}_2$	66.1_2	72.8_2	76.1_7	78.09_2	79.68_2	80.31_0	80.64_5	80.77_1	80.77_1		
20°		$-\overline{H}_1$	$293._4$	289.1_8	287.1_3	286.459_1	286.170_3	286.114_6	286.106_7	286.103_8	286.103_3		
46.219_1	64.90_9	$-H$	70.7_3	$76._2$	78.17_6	79.09_7	79.80_8	80.05_9	80.14_3	80.18_5	80.18_5	242.1_0	285.45_0
		$-\overline{H}_2$	62.7_8	71.1_5	75.3_3	77.67_3	79.30_6	79.97_5	80.10_9	80.163_8	80.18_5		
40°		$-\overline{H}_1$	$293._4$	289.1_8	$286._7$	285.80_6	285.50_5	285.45_5	285.451_3	285.450_9	285.45_0		
46.566_5	63.31_9	$-H$		75.3_3	77.54_8	78.46_9	79.13_8	79.30_6	79.34_8	79.38_9	79.43_1	242.3_5	284.79_8
		$-\overline{H}_2$		69.4_7	74.0_7	76.5_9	78.6_8	79.26_4	79.34_8	79.38_9	79.43_1		
60°		$-\overline{H}_1$			286.2_5	285.4_2	284.83_1	284.799_7	284.79_7	284.79_7	284.79_7		
47.210_9	60.89_2	$-H$			(76.7_9)	(77.4_2)	(77.4_2)	(77.4_2)	(77.4_2)	(77.8_4)	(77.8_4)	(242.9_0)	(284.15_3)
		$-\overline{H}_2$			(72.4_0)	(75.3_3)	(77.0_1)	(77.4_2)	(77.4_2)	(77.8_4)	(77.8_4)		
100°		$-\overline{H}_1$			$(288._3)$	$(286._3)$	(284.2_0)	(288.3_5)	(284.15_3)	(284.15_3)	(284.15_3)		

THERMAL CONDUCTIVITY

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THERMAL CONDUCTIVITY: GASES AND VAPORS

T. H. Laby and E. A. Nelson

Thermal conductivity, k, is defined by the relation

$$\frac{dQ}{dt} = -k\, dx dy \frac{d\theta}{dz},$$

where dQ/dt is the time rate at which heat is conducted in the direction of the temperature gradient, $d\theta/dz$, across a parallel slab of area $dx \cdot dy$.

Theory.—*See* (**1.1, 1.2, 22.1, 22.2**).

Useful Formulae.—The relation, $k = f\eta c_v$ exists between the thermal conductivity, k, the viscosity, η, and the specific heat at constant volume, c_v, where f is "constant," *e.g.*, $k \propto \eta$ if the temperature varies. f depends on the number of atoms in the molecule: for diatomic gases f = *ca.* 1.75; for triatomic *ca.* 1.4; for monatomic 2.5, which is the theoretical value for spherically symmetrical molecules (**13**).

Accuracy of Values of k.—The experimental determination of the thermal conductivity of gases is subject to very large error. For example, the 19 determinations of k for air deviate on the average from the weighted mean (given below) by 7 per cent. The number of observers whose observations were used in deriving the weighted means which follow is equal to the number of literature citations, excluding (**8**).

Units.—In all of the tables of this section the thermal conductivity, k, is expressed in kilo-erg cm^{-2} sec^{-1} $(°C, cm^{-1})^{-1}$.

Conversion Factors.—1 [kilo-erg cm^{-2} sec^{-1} $(°C, cm^{-1})^{-1}$] = 10^{-4} [joule cm^{-2} sec^{-1} $(°C, cm^{-1})^{-1}$] = 0.239×10^{-4} [cal cm^{-2} sec^{-1} $(°C, cm^{-1})^{-1}$] = 0.192×10^{-4} [BTU $ft.^{-2}$ sec^{-1} $(°F, in.^{-1})^{-1}$]. *See further* Vol. I, p. 16.

𝔄-Table.—Elementary Substances and Atmospheric Air

Formula	t, °C	k	Lit.
A.........	0	1.58	(**6, 7, 18, 26, 36**)
Cl_2........	0	0.718	(**7**)
H_2........	0	15.9	(**4, 6, 7, 8, 10, 11, 17, 22, 23, 30, 36, 38, 44**); *cf.* (**10.5, 24.5, 49**)
He.........	0	13.9	(**6, 7, 8, 26, 36**)
Hg.........	203	0.772	(**24**)
N_2........	0	2.28	(**6, 7, 11, 33, 36, 38**)
Ne.........	0	0.444	(**1, 36, 37**)
O_2.........	0	2.33	(**6, 7, 11, 31, 33, 36, 38**)
S..........	Stafford's data (**29**) at various temperatures appear not to be comparable with the data in this and the following tables.		
Air........	0	2.23	(**2, 3, 4, 8, 9, 10, 13, 17, 18, 20, 23, 26, 29, 30, 33, 36, 38, 44, 45, 46**); *cf.* (**10.5, 24.5, 49**)

𝔅-Table.—Chemical Compounds

Formula	t, °C	k	Lit.
H_2O.......	100	2.17	(**19**)
SO_2........	0	0.768	(**7**)
H_2S.......	0	1.20	(**7**)
N_2O.......	0	1.44	(**7, 31, 36, 38**)
NO*.......	0	2.08	(**7, 33, 38**)

𝔅-TABLE.—CHEMICAL COMPOUNDS.—(*Continued*)

Formula	t, °C	k	Lit.
NO_2	55	4.01	(33)
NH_3	0	2.00	(7, 22, 40, 47); *cf.* (4.5)
CO	0	2.15	(7, 16, 19, 31, 38)
CO_2	0	1.37	(4, 6, 7, 10, 17, 23, 29, 31, 33, 36, 38, 44, 47)
CCl_4	100	0.807	(19)
CS_2	0	0.636	(7)

* Observed value reduced to 0° by Sutherland's formula, using C = 195 from viscosity data.

ℭ-TABLE

Formula	Name	t, °C	k	Lit.
$CHCl_3$	Chloroform	0	0.608	(19)
CH_2Cl_2	Methylene chloride	0	0.615	(19)
CH_3Br	Methyl bromide	0	0.574	(19)
CH_3Cl	Methyl chloride	0	0.841	(19)
CH_3I	Methyl iodide	0	0.433	(19)
CH_4	Methane	0	2.94	(7, 31, 36, 38, 48)
CH_4O	Methyl alcohol	0	1.32	(19)
CH_5N	Methylamine	6.5	1.51	(14)
C_2H_2	Acetylene	0	1.73	(7)
C_2H_4	Ethylene	0	1.64	(7, 16, 31, 38)
C_2H_5Br	Ethyl bromide	4.6	0.685	(19)
C_2H_5Cl	Ethyl chloride	0	0.873	(19)
C_2H_5I	Ethyl iodide	0	0.571	(19)
C_2H_6	Ethane	0	1.80	(7, 19, 48)
C_2H_6O	Ethyl alcohol	100	1.96	(19)
C_2H_7N	Dimethylamine	6.5	1.40	(14)
C_2H_7N	Ethylamine	6.5	1.34	(14, 22)
C_3H_6O	Acetone	0	0.906	(19)
$C_3H_6O_2$	Methyl acetate	0	0.938	(19)
C_3H_9N	Propylamine	6.5	1.19	(14)
C_3H_9N	Trimethylamine	6.5	1.30	(14)
$C_4H_8O_2$	Ethyl acetate	100	1.52	(19)
$C_4H_{10}O$	Ethyl ether	0	1.21	(19, 22)
$C_4H_{11}N$	Diethylamine	6.5	1.20	(14)
$C_4H_{11}N$	Isobutylamine	6.5	1.18	(14)
C_5H_{12}	*n*-Pentane	0	1.16	(19)
C_5H_{12}	Isopentane	0	1.15	(19)
$C_5H_{13}N$	*n*-Amylamine	6.5	1.11	(14)
C_6H_6	Benzene	0	0.825	(19)
C_6H_{12}	*n*-Hexylene	0	0.962	(19)
C_6H_{12}	Cyclohexane	101.8	1.64	(19)
C_6H_{14}	*n*-Hexane	0	1.03	(19)
$C_6H_{15}N$	Di-*n*-propylamine	6.5	1.02	(14)
$C_6H_{15}N$	Triethylamine	6.5	1.06	(14)

GAS MIXTURES

% = volume % of first named constituent. The values of k in italics are taken from the 𝔄-Table

A + He (34) 0°C

%	k
0	*13.9*
5.39	12.29
15.32	9.700
54.63	4.503
72.96	3.100
100	*1.58*

A + N_2 (36) 0°C

%	k
0	2.366
21.961	2.189
38.920	2.047
64.130	1.855
79.617	1.745
100	1.609

O_2 + H_2 (35) 22°C

%	k
0	*16.8*
5.26	15.65
14.29	13.45
25.0	11.49
33.33	9.922
50.0	7.639
75.0	4.649
80.0	4.14
84.64	3.84
93.94	2.99
96.64	2.72
100	*2.49*

N_2 + H_2 (36) 0°C

%	k
57.4	6.150

CO_2 + H_2 (36) 0°C

%	k	%	k	%	k
0	17.40	39.318	7.204	90.596	1.993
5.705	15.01	63.017	4.323	92.47	1.872
16.545	11.70	82.989	2.539	100	1.419

TEMPERATURE VARIATION OF THERMAL CONDUCTIVITY OF GASES

As k is not a linear function of the temperature, whenever possible a Sutherland equation,

$$k_T = k_{273}\frac{273 + C}{T + C}\left(\frac{T}{273}\right)^{3/2}$$

has been fitted to the observations, where T is the absolute temperature, and the value of the constant C so obtained is used to compute

$$\alpha_0 = \frac{1}{k_{273}}\left(\frac{dk}{dT}\right)_{273}$$

and k_T/k_{273}. When no value of C is given, no Sutherland equation would fit the observations, and the directly observed values of k_t/k_0 or of k_t are given. In parentheses is given the temperature interval over which Sutherland's equation may be applied with accuracy. If α is required for a gas not given below, it may be calculated by using a value of C obtained from viscosity observations on that gas.

𝔄-TABLE.—ELEMENTARY SUBSTANCES AND ATMOSPHERIC AIR

A (6)

t, °C	k_t/k_0
−182.4	0.366
− 78.4	0.750
0	1.0
+100	1.31

H_2 (4, 6, 7, 23)
C = 94
α_0 = 0.00277
(−252.2 to +100°)

t, °C	k_t/k_0
−252.2	0.067
−200	0.304
−150	0.511
−100	0.693
− 50	0.855
0	1.0
+ 50	1.13
100	1.26

He (6, 7)
C = 33
α_0 = 0.00223
(−252.2 to +100°)

t, °C	k_t/k_0
−252.2	0.154*
−252.2	0.120
−200	0.399
−150	0.593
−100	0.749
− 50	0.882
0	1.0
+ 50	1.11
100	1.20

* Obs. value; but k_t/k_0 = 0.120 according to Sutherland's equation which fits observations above −252°.

Hg (24)
$\alpha_{182.5\text{ to }215°}$ = 0.0074

N_2 (6)
C = 114
α_0 = 0.00291
(−191.4 to +100°)

t, °C	k_t/k_0
−191.4	0.323
−150	0.494
−100	0.680
− 50	0.848
0	1.0
+ 50	1.14
100	1.27

Ne (37)
C = 45
α_0 = 0.00235
(−181.4 to +105.8°)

t, °C	k_t/k_0
−181.4	0.452
−150	0.572
−100	0.736
− 50	0.876
0	1.0
+ 50	1.11
105.8	1.23

O_2 (6)
C = 144
α_0 = 0.00310
(−191.4 to +100°)

t, °C	k_t/k_0
−191.4	0.302
−150	0.472
−100	0.664
− 50	0.839
0	1.0
+ 50	1.15
100	1.29

Air (4, 6, 19, 23, 47)
C = 125
α_0 = 0.00298
(−191.1 to 212.5°)

t, °C	k_t/k_0
−191.1	0.316
−150	0.485
−100	0.674
− 50	0.844
0	1.0
+ 50	1.14
100	1.28
150	1.40
212.5	1.55
32.5	1.09*
253.2	1.78*
430.6	2.58*
539	3.67*
t°	k_t
32.5	1.99
253.2	3.24
430.6	4.69
539	6.67

* These values of k_t/k_0 calculated from the observations of Stafford(29) when plotted against t, give a curve of opposite curvature to that obtained from the results of other observers. Caution is necessary, therefore, in combining his observations with the others given. The values given in the table are calculated relative to the value of $k_{32.5}$ obtained from Sutherland's formula, using C = 125.

𝔅-Table.—Chemical Compounds

H_2O (19)

$t°$	k
46	1.80
100	2.17

N_2O (7, 47)

$t°$	k_t/k_0
− 71.8	0.771
0	1.0
+ 100	1.45

NO (7)

−71.4	0.750*
0	1.0*

* These values satisfy Sutherland's formula, with $C = 195$, obtained from viscosity measurements.

NH_3 (7, 47)

$t°$	k_t/k_0
− 57.6	0.744
− 36.1	0.859
0	1.0
+ 100	1.55

CO (7, 38)

$C = 156$

$\alpha_0 = 0.00316$

(−191.0 to +7.5°)

−191	0.296
−150	0.465
−100	0.658
− 50	0.836
0	1.0
+ 7.5	1.02

CO_2 (4, 6, 29, 47)

$t°$	k_t/k_0
−78.4	0.667
−50	0.782
0	1.0
+50	1.24
100	1.51
36.8	1.18*
282.1	2.66*
506.7	4.62*
555	5.56*
$t°$	k_t
36.8	1.25
282.1	2.84
506.7	4.93
555	5.94

* The above values are based upon $k_{36.8}/k_0$ obtained from the results of other observers.

ℭ-Table

CCl_4 (19)

$t°$	k_t
46	0.656
100	0.807
184	1.02

CS_2 (7, 22)

0	0.636
7.5	0.668

$CHCl_3$ (19)

$t°$	k_t/k_0
0	1.0
46	1.21
100	1.53
184	2.04

CH_2Cl_2 (19)

0	1.0
46	1.26
100	1.62
212.5	2.44

CH_3Br (19)

0	1.0
100	1.70

CH_3Cl (19)

0	1.0
46	1.36
100	1.76
184	2.45
212.5	2.79

CH_3I (19)

0	1.0
46	1.26
100	1.64

CH_4 (7)

−181.6	0.315
− 75.6	0.691
0	1.0

CH_3OH (19)

$t°$	k_t/k_0
0	1.0
100	1.54

C_2H_4 (7, 47)*

−71.1	0.636
−50	0.739
0	1.0
+50	1.29
100	1.60

* Sutherland's formula: $C = 10^5$ giving $\alpha_0 = 0.00548$.

C_2H_5Cl (19)

0	1.0
100	1.73
184	2.45
212.5	2.76

C_2H_6 (7, 19)

− 70.4	0.640
− 33.6	0.806
0	1.0
+100	1.78

C_2H_5OH (19, 22)

$t°$	k
7.5	1.24
20	1.41
100	1.96

$C_2H_5NH_2$ (22)

$\alpha_{0-100} = 0.006113$

$(CH_3)_2CO$ (19)

$t°$	k_t/k_0
0	1.0
46	1.29
100	1.72
184	2.56

$CH_3CO_2CH_3$ (19)

$t°$	k_t/k_0
0	1.0
20	1.14

$CH_3CO_2C_2H_5$ (19)

$t°$	k
46	1.13
100	1.52
184	2.24

$(C_2H_5)_2O$ (19)

$t°$	k_t/k_0
0	1.0
46	1.29
100	1.70
184	2.45
212.5	2.71

n-C_5H_{12} (19)

0	1.0
20	1.11

iso-C_5H_{12} (19)

0	1.0
46	1.32
100	1.75
184	2.58

C_6H_6 (19)

0	1.0
46	1.41
100	1.98
184	2.92
212.5	3.38

C_6H_{12} (19)

Hexylene

0	1.0
100	1.80

n-C_6H_{14} (19)

0	1.0
20	1.10

VARIATION OF CONDUCTIVITY WITH PRESSURE

According to the dynamical theory of gases, the thermal conductivity of a gas is independent of the pressure if the mean free path is small in comparison with the thickness of the conducting layer.

According to Knudsen (15), when the free path is large in comparison with the distance between two parallel plates, the quantity of heat, Q erg, passing in time t sec, from the plate at a temperature θ_1 to that at a temperature θ_2, is

$$Q = eA(\theta_1 - \theta_2)pt$$

where A cm² is the area of each plate, p dyne cm⁻² the pressure, and e, the "molecular coefficient of conductivity," is a function of θ and depends on the nature of the surfaces and on the nature of the gas. For a complete interchange of energy when the molecule hits the plates, e, (g^{-1} cm^{-1} sec) has the theoretical value,

$$e = \frac{1}{4}\sqrt{\frac{2}{273\pi\rho_0 T}}\,\frac{C_p + C_v}{C_p - C_v} = 1819\,(MT)^{-\frac{1}{2}}\,\frac{\gamma + 1}{\gamma - 1}$$

where T is the absolute temperature, ρ_0, (gram) is the mass of 1 cm³ of the gas at 273° and 1 dyne cm⁻² pressure, and C_p, C_v, its heat capacity at constant pressure and constant volume, respectively. M = molecular weight of the gas and $\gamma = C_p/C_v$. (In calculating the dimensions of e, temperature is assumed to have the dimensions of kinetic energy.) Experiment shows that the heat transferred is smaller than this theoretical value, but approaches it as a limit for rough plates, *i.e.*, for complete exchange of energy, *v.* (25).

MOLECULAR CONDUCTIVITY OF GASES

Calculated value, conduction between absolutely rough surfaces,

$$e = 1819\,\frac{1}{\sqrt{MT}} \times \frac{\gamma + 1}{\gamma - 1}.$$

At 0°C, H_2, $e = 460$ g^{-1} cm^{-1} sec (*i.e.*, unit of heat = 1 erg; O_2, $e = 117$; Cl_2, $e = 127$. If unit of heat is the calorie, e for H_2 at $0° = 10.97 \times 10^{-6}$.

Observed value, Knudsen (15). H_2 at 0°C, $e = 121$ g^{-1} cm^{-1} sec for conduction between glass and rough surface; $e = 70$ for glass and glass, surfaces being cylindrical.

Schreiner's values (25), using a fine drawn platinum wire along the axis of a glass tube: mean free path must be not less than 40 times diameter of wire for data to be valid, *cf.* (27, 28).

A		O_2		H_2*		CO		N_2	
$t°$	e	$t°$	e	$t°$	e	$t°$	e	$t°$	e
0	58	0	92	0	138	0	98	0	93
− 78	69	− 78	115	− 74	168	− 78	121	− 78	120
−183	104	−204	204	−190	325	−206	221	−204	213

* If unit of heat = 1 calorie: e for H_2 at $0° = 3.31 \times 10^{-6}$.

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(For a key to the periodicals see end of volume. The papers giving values of the temperature coefficient are marked by an asterisk)

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THERMAL CONDUCTIVITY OF NON-METALLIC SOLIDS

M. S. Van Dusen

For industrial materials, *see* Vol. II, p. 312, 316; single crystals, p. 230; SiO_2, p. 106. Data for other non-metallic solids, and for such of the preceding as are of special importance in the construction of scientific instruments are given in the following table. Data for crystalline materials and for compressed powders are too scanty to permit any general conclusion to be drawn; the values tabulated are subject to considerable uncertainty. For conductivity of powders under reduced gas pressure, *see* Vol. II, p. 315.

Thermal Conductivity of Non-Metallic Solids

Am. = amorphous, Art. = artificial, Crys. = crystalline, Nat. = natural; B 183 = boils at 183°C; d = density of the specimen at 20°C, not of the individual grains of a powder; D = thermal diffusivity near t_R; K_t = thermal conductivity at t,°C; M 114 = melts at 114°C; p = hydrostatic pressure; P [PP] = compressed [highly compressed] powder; t_R = room temperature. $K_t = C\{1 + \alpha t(10)^{-4}\}$ if t lies within the range indicated; unless 0°C lies within the range, C is not K_0. $K_{t,p} = K_{t,1}\{1 + bp(10)^{-6}\}$. In the portion for inorganic solids, the "remarks" in section A apply also to the corresponding entries in section B.

Unit of K_t and $C = 10^{-4}$ watt/(cm°C); of D = 1 cm² sec⁻¹; of d = 1 g cm⁻³; of p = 1 atm.; t_0, M, B and range are °C

Pure organic solids

Formula	Substance	t	K_t	C	α	Range	C	α	Range	Remarks	Lit.
$C_2H_2O_4$	Oxalic acid	0	90	90	−58	−190 to 0					(9)
$C_3H_8O_3$	Glycerol	0	30	30	−17	− 90 to +10	38	+ 10	−180 to −90	d = 1.263; solid*	(32)
$C_6H_5NO_3$	*p*-Nitrophenol	0	27	27	−19	− 50 to +50	25	− 47	−180 to −50	M 114	(32)
C_6H_7N	Aniline	−40	28.9	24	−51	−100 to −40	18	−103	−180 to −100	B 183; M −8	(32)
C_7H_9N	*p*-Toluidine	30	16							M 45	(30)
$C_{10}H_8$	Naphthalene	0	38	38	−33	−160 to +80				M 79	(9, 30, 32)
$C_{10}H_8O$	α-Naphthol	35	24		< 0						(30)
$C_{10}H_8O$	β-Naphthol	35	24.6	25	− 5	−170 to +100					(30, 32)
$C_{10}H_9N$	Naphthylamine	33	15		< 0					M 50	(30)
$C_{10}H_{14}O$	Thymol	12	15				D = 0.00108			M 13	(4)
$C_{12}H_{11}N$	Diphenylamine	0	22	22	− 6.5	−180 to +30				M 54	(32)
$C_{12}H_{22}O_{11}$	Sucrose	0	58	58	−45	− 80 to 0					(9)
$C_{17}H_{12}O_3$	β-Naphthyl salicylate	−80	22	20	−13	−190 to 0				Crystalline	(9)
$C_{17}H_{12}O_3$	β-Naphthyl salicylate	−80	12	14	+20	−190 to −80				Amorphous	(9)

* Probably a glass.

Pure Inorganic and Miscellaneous Solids

A. One temperature and effect of pressure

Substance		t, °C	K_t	Remarks	Lit.
AgCl	Art.	0	109	d = 3.06	(16)
AgCl	Nat.*	0	110	d = 7.2	(16)
AgCl	PP	t_R	75		(50)
AgBr		0	103	d = 5.9	(16)
Al_2O_3		15	1 050		(31)
Al_2O_3	P	t_R	68	d = 1.84	(28)
C (Dia)†	Crys.	0	15 000	D = 1.5	(10)
C (Gr)‡	Art.	0	15 000	D = 1.5	(7, 10, 18, 20, 23, 41, 45)
C	Am.	0	‡‡	D = 0.04 to 0.4	(3, 7, 18, 19, 20, 44, 49)
C $(Gr)_1$‡	P	40	119	d = 0.70; F§ 20 on 40	(45)
C $(Gr)_2$‡	P	40	38	d = 0.42; F§ 40	(45)
C $(Gr)_3$‡	P	40	18	d = 0.48; F§ 100	(45)
C (LB)‡	P	40	6.5	d = 0.165	(45)
C (CD)‡	P	40	11.2	d = 0.73	(45)
CaF_2		0	1 100		(9)
CaF_2		−190	3 900		(9)
$CaCl_2.6H_2O$		24	63		(30)
$CaSO_4.2H_2O$	Art.	t_R	38	d = 1.36; D = 0.0025	(49)
$CaSO_4.2H_2O$	Art.	t_R	74	d = 2.13	(19)
$CaSO_4.2H_2O$	Nat.‖	t_R	130	d = 2.88; D = 0.0042	(49)
$Ca_3(PO_4)_2$	PP	t_R	41		(50)
$CaCO_3$	Nat.¶	30	219	d = 2.602; b = 1.0	(6)
$CaCO_3$	Nat.¶	75	188	d = 2.602; b = 6.7	(6)
CdO	P	t_R	68	d = 3.39	(28)
Co_2O_3	P	t_R	42	d = 1.96	(28)
Cr_2O_3	P	t_R	45	d = 2.35	(28)
CuO		15	330		(31)
CuO	P	t_R	102	d = 2.19	(28)
$CuCl_2$		15	54		(31)
CuS		15	580		(31)
CuS	PP	t_R	82		(50)
$CuSO_4.5H_2O$		15	73		(31)
FeO	P	t_R	56	d = 2.24	(28)
Fe_2O_3		15	126		(31)
Fe_2O_3	P	100	49		(5)
FeS		15	710		(31)
$FeSO_4.7H_2O$		15	56		(31)
FeC_2O_4**	PP	t_R	52		(50)
H_2O (ice)	Crys.	0	209	d = 0.92; D=0.011††	(2, 13, 32, 35, 36, 42)
H_2O (snow)	Crys.		§§		(1, 22, 24, 26, 36, 38)
HgCl	PP	t_R	61		(50)
HgBr	PP	t_R	53		(50)
I		30	44		(40)
KCl		0	670		(9, 16)
KCl		−190	2 100		(9)
KI		0	500	d = 1.97	(16)

Substance		t, °C	K_t	Remarks	Lit.
$K_2Cr_2(SO_4)_4.24H_2O$		0	55		(9)
MgO		15	126		(31)
MgO	*P*	t_R	55	$d = 0.80$	(28, 50)
$MgSO_4.7H_2O$		15	48		(31)
$MgCO_3$	*P*	t_R	43	$d = 3.0$	(52)
$MgSiO_3$	*PP*	t_R	36		(50)
NaCl		0	670		(6, 9, 29, 31, 33, 49)
NaCl		−190	2 600		(9)
NaCl	Nat.‖‖	30	368	$b = 36$	(6)
NaCl	Nat.‖‖	75	316	$b = 36$	(6)
$NaClO_3$		0	112		(9)
$Na_2HPO_4.12H_2O$		25	54		(30)
NiO	*P*	t_R	94	$d = 1.45$	(28)
$NiSO_4.7H_2O$		15	48		(31)
$NiCO_3$	*PP*	t_R	58		(50)
PbO		15	210		(31)
PbO	*P*	t_R	72	$d = 5.84$	(28, 52)
Pb_3O_4		15	210		(31)
Pb_3O_4	*P*	t_R	55	$d = 4.7$	(52)
PbF_2	*PP*	t_R	40		(50)
$PbCl_2$		15	54		(31)
$PbCl_2$	*PP*	t_R	33		(50)
$PbBr_2$	*PP*	t_R	26		(50)
PbI_2	*PP*	t_R	24		(50)
PbS		15	65		(31)
S	Crys.	−190	64		(9)
S	Crys.	0	21		(9, 19, 29, 30, 33, 36, 37)
S	Am.	0	20		(9)
Si		30	8 400		(27)
SiO_2 (glass)		0	145	*v. also* p. 106	(3, 9, 11)
TlCl		0	98	$d = 6.6$	(16)
TlBr		0	82	$d = 7.1$	(16)
ZnO		15	380		(31)
ZnO	*P*	t_R	59	$d = 2.89$	(28, 52)
$ZnSO_4.7H_2O$		15	61		(31)
Basalt (diabasic)		30	169	$d = 2.924$; $b = 4.7$	(6)
Basalt (diabasic)		75	173	$d = 2.924$; $b = 2.2$	(6)
Canada balsam		t_R	11		(12, 29)
Catlinite¶¶		30	183	$d = 2.84$	(6)
Chalk		t_R	71	$d = 1.547$; $D = 0.0054$	(49)
Fibre (white)		0	29	$d = 1.22$	(30, 46)
Ivory (⊥ axis)		80	45 to 52		(17)
Ivory (‖ axis)		80	57		(17)
Mica		t_R	40 to 60		(17, 43)
Micanite		t_R	20 to 40		(17, 43, 45)
Paraffin		0	24	$D = 0.0024$; M 50–54	(9, 14, 25, 29, 30, 32, 33, 34, 37, 39, 47, 48, 51)
Pyrex glass		30 to 75	109	$d = 2.234$, $b = 4$	(6)
Rubber (hard)		0	16	$d = 1.2$, $D = 0.0016$	(3, 8, 9, 16, 17, 21, 29, 30, 33, 37, 46)
Rubber (soft)		t_R	13 to 16	>90 % pure	(17, 29, 33, 47)
Shellac		t_R	25		(29, 30, 33)
Talc		30	307	$d = 2.751$, $b = 15.7$	(6)
Vaseline		t_R	18		(30, 34)

B. Variation with temperature

Substance		C	α	Range, °C	Lit.
AgCl	Art.	109	−45	0 to 100	(16)
AgBr		103	−45	0 to 100	(16)
C (Dia)†	Crys.	15 000	0	−200 to +100	(10)
C (Gr)‡	Art.	15 000	−3.3	0 to 2 000	(7, 10, 18, 20, 23, 41, 45)
C	Am.	‡‡	>0?	0 to 600	(3, 17, 18, 19, 20, 44, 49)
C $(Gr)_1$‡	*P*	100	+48	40 to 100	(45)
C $(Gr)_2$‡	*P*	33	+40	40 to 100	(45)
C $(Gr)_3$‡	*P*	16	+34	40 to 100	(45)
C (LB)‡	*P*	6.4	+6	40 to 150	(45)
C (CD)‡	*P*	10.3	+23	30 to 150	(45)
CaF_2		1 100	−37	−80 to +100	(9)
Fe_2O_3	*P*	39	+25	100 to 700	(5)
H_2O (ice)	Crys.	209	−17	−170 to 0	(2, 13, 32, 35, 36, 42)
H_2O (snow)	Crys.	§§			(1, 22, 24, 26, 36, 38)
KCl		670	−44	−180 to +100	(9, 16)
NaCl		670	−44	−80 to +100	(6, 9, 29, 31, 33, 49)
$NaClO_3$		112	−52	−80 to 0	(9)
S	Crys.	21	−25	0 to 100	(9, 19, 29, 30, 33, 36, 37)
S	Am.	20	+10	−190 to 0	(9)
SiO_2 (glass)		145	+23	−250 to +100	(3, 9, 11)
TlCl		98	−43	0 to +100	(16)
Fibre (white)		29	+12	0 to 80	(30, 46)
Paraffin		24	−16	−180 to +30	(9, 14, 25, 29, 30, 32, 33, 34, 37, 39, 47, 48, 51)
Rubber (hard)		16	+6	−200 to +100	(3, 8, 9, 16, 17, 21, 29, 30, 33, 37, 46)

* Horn silver, cerargyrite.

† Diamond. If $t < -200$°C, K decreases with t.

‡ (Gr) = graphite, (LB) = lampblack, (CD) = coal dust.

§ F 20 on 40 means that the powder passed a sieve of 20 meshes to the inch, but was caught by one of 40; F 40 means that it passed a sieve of 40 meshes but that no indication of the limit of fineness of the powder is given.

‖ Gypsum.

¶ Limestone, nearly pure $CaCO_3$.

** Ferrous oxalate.

†† In the range 0 to −30°C.

‡‡ Values of K_0 and C vary from 400×10^{-4} to 4000×10^{-4} watt/(cm, °C).

§§ In the range 0 to −30°C, $K = (2.1 + 42d + 216d^3) \times 10^{-4}$ watt/(cm °C), $D = (d^{-1} + 20 + 103d^2) \times 10^{-4}$ cm² sec.⁻¹

‖‖ Rock salt, clear crystalline.

¶¶ Catlinite = pipestone.

p	1	2 000	4 000	6 000	8 000	10 000	12 000 atm.
K_{30}	183	212	228	235	240	245	249×10^{-4} watt/(cm, °C)

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RADIOMETRY (HEAT AND LIGHT)

RADIATION CONSTANTS

W. W. COBLENTZ

For a perfect (black-body) radiator, the total hemispherical radiation (over all wave-lengths) at the absolute temperature T is $J = \sigma T^4$; σ is known as the Stefan-Boltzmann constant of total radiation. The hemispherical radiation included in the spectral region $(\lambda - \frac{1}{2}d\lambda)$ to $(\lambda + \frac{1}{2}d\lambda)$ is $J_\lambda d\lambda = C_1\lambda^{-5}[e^{C_2/\lambda T} - 1]^{-1}d\lambda$; C_1 and C_2 are known, respectively, as the first and the second radiation constants, and J_λ as the monochromatic intensity of the hemispherical radiation. At each temperature T, there is a wave-length λ_m at which J_λ is a maximum; $w(= \lambda_m T)$ is independent of T, and is known as Wien's displacement constant; $C_2 = \alpha w$, where $\alpha = 4.9651$ is a pure numeric.

STEFAN-BOLTZMANN CONSTANT (σ) OF TOTAL RADIATION

$J = \sigma T^4$; σ_o = observed, or reported value; σ_p = probable value after correcting for reflection, etc. Unit of $\sigma = 10^{-5}$ erg cm^{-2} sec^{-1} (°K)$^{-4}$ = 6.451×10^{-12} watt in.$^{-2}$ (°K)$^{-4}$.

Observer	Year	σ_o	σ_p	Method
Kurlbaum (12)............	1898	5.45	(?)	Bolometer
Féry (6)...................	1909	6.3	(?)	Thermometer
Bauer and Moulin (2)......	1909	5.30	5.7	Thermopile
Bauer and Moulin (2)......	1910	5.7	5.7	Pyrheliometer
Todd (19)..................	1909	5.48	5.48	Gas-conduction
Valentiner (20)............	1910	5.58	5.68 to 5.75	Bolometer
Féry and Drecq (7)........	1911	6.51	(?)	Thermometer
Féry and Drecq (7)........	1912	6.2	5.68	Pyrometer*
Féry and Drecq (7)........	1912	5.57		
Shakespear (18)............	1912	5.67	5.67	Emissivity†
Gerlach (8).................	1916	5.85		Pyrheliometer‡
Gerlach (8).................	1920	5.80	5.80	
Puccianti (16)..............	1912	5.96	5.96	Bolometer
Puccianti (16)..............		6.15	(?)	Thermometer
Westphal (27)...............	1916	5.67	5.67	Emissivity†
Keene (11)..................	1913	5.89	5.89	Thermometer
Coblentz (3, 4).............	1915	5.72	5.73	Pyrheliometer‡
Kahanowicz (10)...........	1917	5.61	5.69 to 5.73	Pyrheliometer‡
Wachsmuth and Vierheller (21).....................	1921	5.73	5.73	Emissivity§
Hoffman (9)...............	1923	5.76	5.76	Westphal's‖
Kussmann (13).............	1924	5.79	5.79	Coblentz's
Mean value..................			5.72 to 5.74	

* Calibrated pyrometer.

† Ratio of radiance from metal to that from "black-body."

‡ Modified Ångström pyrheliometer.

§ From blackened sphere.

‖ Modification of Westphal's method.

WIEN'S DISPLACEMENT CONSTANT (w) AND THE CONSTANT (C_2) OF SPECTRAL RADIATION

$J_\lambda = C_1\lambda^{-5}[e^{C_2/\lambda T} - 1]^{-1}$; $w = \lambda_m T$; w_o = observed (recorded) value; w_c = value after correction for reflection, etc.; $C_2' = 4.9651w$ and values derived from isochromatics; C_2 = probable value after corrections have been applied. *Note:* $\left\{\begin{matrix}14\,200\\14\,600\end{matrix}\right\}$ denote 14 200 to 14 600. Unit of w and of $C_2 = 10^{-4}$ cm, °K = 1μ, °K.

Observer	Year	w_o	w_c	C_2'	C_2	Remarks
Paschen (15)....	1899	2 891	2 891		14 360	Fluorite prism
		2 907	2 907*			T is questioned
	1900	2 921	2 894			
Lummer and Pringsheim (14).	1900	2 879	2 879	14 290		Fluorite prism*†
		2 876	2 876			
		2 940	2 882	14 310	14 300	
Warburg, *et al.* (21–26)........	1911			{14 200		Fluorite prism
				14 600}		
	1912			{14 300		Fluorite prism
				14 400}		
	1912			14 360		Quartz prism

WIEN'S DISPLACEMENT CONSTANT (w) AND THE CONSTANT (C_2) OF SPECTRAL RADIATION.—(*Continued*)

Observer	Year	w_o	w_c	C_2'	C_2	Remarks
Warburg, *et al.*—	1913	2 894		14 370		Quartz prism
(*Cont'd*).......	1915			14 250‡		
	1915			14 300 14 400	14 300	Quartz prism †
Coblentz (4, 5)..	1913	2 911		14 456		Fluorite prism
	1916	2 894		14 369		Revised §
	1920			14 311 14 326	14 318	Zero correction ‖
Rubens and Michel (17)	1921			14 300	14 300¶	
Average value...			2 885		14 320	

* Temperature scale is questioned.

† Calibration of prism is questioned.

‡ Temperature deduced from Stefan-Boltzmann law.

§ Calibration of prism revised and preceding data recomputed.

‖ Correction for zero setting of bolometer.

¶ Adopted in testing Planck's equation.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bauer, *454*, **1913**: 45. (2) Bauer and Moulin, *34*, **149**: 988; 09. **150**: 167; 10. *250*, **1910**: 58. (3) Coblentz, *31A*, **12**: 553; 16. Coblentz and Emerson, *31A*, **12**: 503; 16. (4) Coblentz, *31A*, **15**: 529; 20. (5) Coblentz, *31A*, **10**: 1; 13. **13**: 459; 16. **17**: 39; 20. (6) Féry , *34*, **148**: 915; 09. (7) Féry and Drecq, *51*, **1**: 551; 11. *34*, **155**: 1239; 12. (8) Gerlach, *8*, **38**: 1; 12. **50**: 259; 16. *96*, **2**: 76; 20. (9) Hoffman, *96*, **14**: 301; 23.

(10) Kahanowicz, *59*, **13**: 142; 17. *22*, **28**: 73; 19. (11) Keene, *5*, **88**: 49; 13. *121*, **70**: 541; 12. (12) Kurlbaum, *8*, **65**: 746; 98. *88*, **14**: 576; 12. (13) Kussmann, *96*, **25**: 58; 24. (14) Lummer and Pringsheim, *88*, **1**: 23, 215; 99. *8*, **3**: 159; 00. (15) Paschen, *76*, **21**: 405, 959; 99. *8*, **4**: 277; 01. (16) Puccianti, *59*, **4**: 322; 12. (17) Rubens and Michel, *444*, **38**: 590; 21. (18) Shakespear, *5*, **86**: 180; 12. (19) Todd, *5*, **83**: 19; 09.

(20) Valentiner, *8*, **31**: 275; 10. **39**: 489; 12. Kurlbaum and Valentiner, *8*, **41**: 1059; 13. (21) Wachsmuth and Vierheller, *96*, **2**: 36; 21. (22) Warburg, *88*, **18**: 1; 16. (23) Warburg, Hupka and Müller, *243*, **32**: 134: 12. **34**: 125; 14. (24) Warburg, *76*, **1910**: 925. Warburg and Leithäuser, *243*, **30**: 118; 10. **31**: 124; 11. (25) Warburg, Leithäuser, Hupka and Müller, *76*, **1**: 35; 13. *8*, **40**: 609; 13. (26) Warburg and Müller, *243*, **35**: 98; 15. *8*, **48**: 410; 15. (27) Westphal, *88*, **14**: 987; 12. **15**: 897; 13.

RADIATION FROM A PERFECT (BLACK-BODY) RADIATOR

F. E. FOWLE

The following tables, giving the hemispherical radiation (J) and the monochromatic intensity (J_λ) of the hemispherical radiation of a perfect radiator, have been computed from the values of C_1 ($=3.703 \times 10^{-5}$ erg cm^{-2} sec^{-1}), C_2($=1.433$ cm, °K), and σ($=5.709 \times 10^{-5}$ erg cm^{-2} sec^{-1} (°K)$^{-4}$) which have been accepted for the purposes of International Critical Tables. A third table indicates how the values of J_λ are affected by changes in the value of C_2.

A line over a number indicates that it is negative. Thus (Table 1) at -270°C, $J = 5.272 \times 10^{-3} = 0.005272$.

The radiator receives radiation from surrounding bodies. If its temperature is T and if it is entirely surrounded by other perfect radiators, all at temperature T', its resultant loss of energy by radiation (net hemispherical radiation) will be $J_T - J_{T'}$, per unit of area. If $T = 1273.1$°K and $T' = 273.1$°K, the net hemispherical radiation will be $(1500 - 3.2) \times 10^5 = 1497 \times 10^5$ erg cm^{-2} sec^{-1}. (*See* Table 1.) Similarly for J_λ.

TABLE 1.—TOTAL HEMISPHERICAL RADIATION (J) OF A PERFECT (BLACK-BODY) RADIATOR

$J = \sigma T^4 = A \times 10^n$. $\sigma = 5.709 \times 10^{-5}$ erg cm^{-2} sec^{-1} (°K)$^{-4}$. T = absolute temperature, °K; t = centigrade temperature. Unit of $J = 1$ erg cm^{-2} sec^{-1} $= 2.389 \times 10^{-8}$ cal$_{15}$ cm^{-2} sec^{-1} $= 6.112 \times 10^{-10}$ BTU$_{60}$ in.$^{-2}$ sec^{-1}.

t	T	A	n	t	T	A	n
−273	0.1	5.71	$\bar{9}$	−180	93.1	4.289	3
−270	3.1	5.272	$\bar{3}$	−170	103.1	6.451	3
−260	13.1	1.681	0	−160	113.1	9.342	3
−250	23.1	1.626	1	−150	123.1	1.311	4
−240	33.1	6.852	1	−140	133.1	1.792	4
−230	43.1	1.970	2	−130	143.1	2.394	4
−220	53.1	4.539	2	−120	153.1	3.137	4
−210	63.1	9.050	2	−110	163.1	4.040	4
−200	73.1	1.630	3	−100	173.1	5.126	4
−190	83.1	2.722	3	− 90	183.1	6.417	4
− 80	193.1	7.937	4	46	319.1	5.918	5
− 70	203.1	9.714	4	48	321.1	6.070	5
− 60	213.1	1.177	5	50	323.1	6.221	5
− 50	223.1	1.414	5	52	325.1	6.377	5
− 40	233.1	1.686	5	54	327.1	6.535	5
− 30	243.1	1.994	5	56	329.1	6.697	5
− 20	253.1	2.343	5	58	331.1	6.862	5
− 10	263.1	2.735	5	60	333.1	7.029	5
− 8	265.1	2.820	5	70	343.1	7.912	5
− 6	267.1	2.906	5	80	353.1	8.875	5
− 4	269.1	2.993	5	90	363.1	9.923	5
− 2	271.1	3.084	5	100	373.1	1.106	6
0	273.1	3.176	5	200	473.1	2.860	6
+ 2	275.1	3.270	5	300	573.1	6.158	6
4	277.1	3.366	5	400	673.1	1.172	7
6	279.1	3.464	5	500	773.1	2.039	7
8	281.1	3.565	5	600	873.1	3.318	7
10	283.1	3.668	5	700	973.1	5.119	7
12	285.1	3.772	5	800	1073.1	7.570	7
14	287.1	3.879	5	900	1173.1	1.081	8
16	289.1	3.988	5	1 000	1273.1	1.500	8
18	291.1	4.100	5	1 500	1773.1	5.643	8
20	293.1	4.213	5	2 000	2273.1	1.524	9
22	295.1	4.330	5	3 000	3273.1	6.552	9
24	297.1	4.448	5	4 000	4273.1	1.903	10
26	299.1	4.569	5	5 000	5273.1	4.414	10
28	301.1	4.692	5	6 000	6273.1	8.841	10
30	303.1	4.818	5	7 000	7273.1	1.598	11
32	305.1	4.947	5	8 000	8273.1	2.674	11
34	307.1	5.078	5	9 000	9273.1	4.221	11
36	309.1	5.211	5	10 000	10273.1	6.358	11
38	311.1	5.348	5	15 000	15273.1	3.106	12
40	313.1	5.486	5	20 000	20273.1	9.644	12
42	315.1	5.628	5	25 000	25273.1	2.329	13
44	317.1	5.772	5				

TABLE 2.—MONOCHROMATIC INTENSITY (J_λ) OF HEMISPHERICAL RADIATION OF PERFECT (BLACK-BODY) RADIATOR

$J_\lambda = C_1\,\lambda^{-5}[e^{C_2/\lambda T} - 1]^{-1}$, T = absolute temperature, λ = wave-length of the radiation. Total hemispherical radiation in range λ_1 to λ_2 is $\int_{1}^{\lambda_2} J_\lambda d\lambda$. If $C_1 = 3.703 \times 10^{-5}$ erg cm² sec⁻¹, $C_2 = 1.433$ cm, °K and unit of dλ = 1 cm, then $J_\lambda = A \times 10^n$ erg cm⁻³ sec⁻¹, where A and n have the values tabulated below. 1 erg cm⁻³ sec⁻¹ = 2.389×10^{-8} cal$_{15}$ cm⁻³ sec⁻¹ = 6.118×10^{-10} BTU$_{60}$ in.⁻² sec⁻¹ × $(d\lambda)_{\text{cm}}^{-1}$, where $(d\lambda)_{\text{cm}}$ indicates that unit of dλ = 1 cm. For each T the maximum value of J_λ is printed in bold face. In column λ, unit of λ = 1μ = 10⁴Å = 10⁻⁴ cm; T = absolute temperature, °K.

T	25		50		75		100		125		150		175		200		225		250	
λ	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*
1.0	3.7	$\overline{234}$	1.3	$\overline{109}$	4.1	$\overline{68}$	2.2	$\overline{47}$	6.0	$\overline{35}$	1.2	$\overline{26}$	1.0	$\overline{20}$	2.8	$\overline{16}$	8.1	$\overline{13}$	4.7	$\overline{10}$
1.5	4.9	$\overline{152}$	4.9	$\overline{69}$	2.3	$\overline{41}$	1.6	$\overline{27}$	3.1	$\overline{19}$	1.1	$\overline{13}$	1.0	$\overline{9}$	8.8	$\overline{7}$	1.8	$\overline{4}$	1.23	$\overline{2}$
2.0	3.9	$\overline{111}$	6.8	$\overline{49}$	3.8	$\overline{28}$	8.8	$\overline{18}$	1.5	$\overline{11}$	2.1	$\overline{7}$	1.9	$\overline{4}$	3.2	$\overline{2}$	1.72	0	4.2	1
2.5	9.9	$\overline{87}$	6.4	$\overline{37}$	2.4	$\overline{20}$	4.8	$\overline{12}$	4.6	$\overline{7}$	9.6	$\overline{4}$	2.27	$\overline{1}$	1.36	1	3.26	2	4.2	3
3.0	1.6	$\overline{70}$	5.0	$\overline{29}$	3.3	$\overline{15}$	2.7	$\overline{8}$	3.8	$\overline{4}$	2.26	$\overline{1}$	2.12	1	6.5	2	9.2	3	7.7	4
3.5	5.1	$\overline{59}$	1.9	$\overline{23}$	1.4	$\overline{11}$	1.17	$\overline{5}$	4.2	$\overline{2}$	9.8	0	4.8	2	9.1	3	8.8	4	5.4	5
4	2.1	$\overline{50}$	2.8	$\overline{19}$	6.5	$\overline{9}$	1.00	$\overline{3}$	1.29	0	1.54	2	4.6	3	6.0	4	4.40	5	2.16	6
5	1.9	$\overline{38}$	1.5	$\overline{13}$	3.0	$\overline{5}$	4.2	$\overline{1}$	1.30	2	5.9	3	9.1	4	7.1	5	3.47	6	1.25	7
6	1.6	$\overline{30}$	8.6	$\overline{10}$	7.1	$\overline{3}$	2.03	1	2.40	3	5.8	4	5.62	5	3.11	6	1.18	7	3.38	7
7	6.1	$\overline{25}$	3.7	$\overline{7}$	3.1	$\overline{1}$	2.84	2	1.70	4	2.60	5	1.83	6	7.87	6	2.46	7	6.13	7
8	8.6	$\overline{21}$	3.1	$\overline{5}$	4.8	0	1.88	3	6.76	4	7.4	5	4.05	6	1.46	7	3.95	7	8.75	7
9	1.4	$\overline{17}$	9.3	$\overline{4}$	3.8	1	7.6	3	1.84	5	1.55	6	7.02	6	2.19	7	5.30	7	1.08	8
10	4.7	$\overline{15}$	1.32	$\overline{2}$	1.87	2	2.21	4	3.89	5	2.63	6	1.03	7	2.87	7	6.36	7	1.204	8
12	2.7	$\overline{11}$	6.3	$\overline{1}$	1.81	3	9.7	4	1.06	6	5.20	6	1.62	7	3.81	7	**7.42**	7	**1.264**	8
14	1.1	$\overline{8}$	8.9	0	8.1	3	2.46	5	1.92	6	7.50	6	1.99	7	**4.15**	7	7.36	7	1.167	8
16	9.8	$\overline{7}$	5.9	1	2.30	4	4.56	5	2.73	6	9.02	6	**2.13**	7	4.06	7	6.72	7	1.011	8
18	2.90	$\overline{5}$	2.39	2	4.84	4	6.84	5	3.36	6	9.76	6	2.10	7	3.73	7	5.87	7	8.47	7
20	4.14	$\overline{4}$	6.9	2	8.2	4	8.95	5	3.76	6	**9.83**	6	1.96	7	3.31	7	5.00	7	6.99	7
25	4.18	$\overline{2}$	4.00	3	1.82	5	1.233	6	**3.91**	6	8.49	6	1.490	7	2.289	7	3.22	7	4.26	7
30	7.68	$\overline{1}$	1.08	4	2.62	5	**1.295**	6	3.41	6	6.58	6	1.063	7	1.525	7	2.071	7	2.647	7
40	2.16	1	2.80	4	**3.07**	5	1.035	6	2.18	6	3.619	6	5.36	6	7.24	6	9.24	6	1.133	7
50	1.25	2	**3.85**	4	2.65	5	7.15	5	1.331	6	2.058	6	2.859	6	3.713	6	4.60	6	5.52	6
75	7.5	2	3.50	4	1.327	5	2.712	5	4.33	5	6.06	5	7.89	5	9.77	5	1.167	6	1.362	6
100	1.20	3	2.24	4	6.43	4	1.160	5	1.725	5	2.316	5	2.920	5	3.536	5	4.158	5	4.777	5

T	273		275		300		325		350		373		375		400		500		600	
λ	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*
1.0	5.9	$\overline{8}$	8.8	$\overline{8}$	6.7	$\overline{6}$	2.6	$\overline{4}$	6.1	$\overline{3}$	7.6	$\overline{2}$	9.4	$\overline{2}$	1.03	$\overline{1}$	1.32	3	1.58	5
1.5	3.1	$\overline{1}$	4.0	$\overline{1}$	7.2	0	8.4	1	6.8	2	3.7	3	4.2	3	2.08	4	2.46	6	5.94	7
2.0	4.6	2	5.6	2	4.9	3	3.10	4	1.51	5	5.3	5	5.8	5	1.93	6	6.92	7	7.55	8
2.5	2.88	4	3.37	4	1.91	5	8.3	5	2.92	6	8.0	6	8.8	6	2.27	7	4.00	8	2.69	9
3.0	3.84	5	4.36	5	1.86	6	6.3	6	1.80	7	4.16	7	4.56	7	9.94	7	1.08	9	5.32	9
3.5	2.16	6	2.41	6	8.3	6	2.38	7	5.85	7	1.20	8	1.27	8	2.52	8	1.96	9	7.68	9
4	7.2	6	7.9	6	2.36	7	5.90	7	1.30	8	2.44	8	2.57	8	4.66	8	2.80	9	9.25	9
5	3.26	7	3.54	7	8.4	7	1.75	8	3.30	8	5.45	8	5.68	8	9.17	8	3.85	9	**1.006**	10
6	7.56	7	8.05	7	1.66	8	3.07	8	5.19	8	7.90	8	8.18	8	1.218	9	**4.04**	9	9.07	9
7	1.22	8	1.29	8	2.40	8	4.06	8	6.37	8	9.15	8	9.42	8	**1.327**	9	3.73	9	7.51	9
8	1.60	8	1.68	8	2.89	8	4.59	8	**6.81**	8	**9.36**	8	**9.61**	8	1.298	9	3.23	9	6.01	9
9	1.84	8	1.92	8	3.12	8	**4.71**	8	6.70	8	8.90	8	9.11	8	1.194	9	2.710	9	4.75	9
10	**1.96**	8	**2.03**	8	**3.14**	8	4.56	8	6.28	8	8.12	8	8.30	8	1.060	9	2.236	9	3.71	9
12	1.90	8	1.96	8	2.83	8	3.87	8	5.07	8	6.32	8	6.43	8	7.92	8	1.489	9	2.36	9
14	1.660	8	1.706	8	2.35	8	3.08	8	3.90	8	4.73	8	4.81	8	5.78	8	1.020	9	1.530	9
16	1.381	8	1.414	8	1.880	8	2.40	8	2.96	8	3.52	8	3.53	8	4.22	8	7.07	8	1.024	9
18	1.122	8	1.147	8	1.484	8	1.851	8	2.246	8	2.632	8	2.664	8	3.103	8	5.01	8	7.076	8
20	9.04	7	9.24	7	1.158	8	1.434	8	1.716	8	1.986	8	2.011	8	2.317	8	3.627	8	5.032	8
25	5.29	7	5.39	7	6.59	7	7.85	7	9.15	7	1.039	8	1.051	8	1.188	8	1.767	8	2.371	8
30	3.206	7	3.255	7	3.892	7	4.550	7	5.23	7	5.865	7	5.920	7	6.626	7	9.53	7	1.252	8
40	1.332	7	1.349	7	1.572	7	1.799	7	2.028	7	2.242	7	2.262	7	2.496	7	3.453	7	4.426	7
50	6.379	6	6.458	6	7.409	6	8.37	6	9.35	6	1.025	7	1.033	7	1.132	7	1.535	7	1.935	7
75	1.544	6	1.557	6	1.754	6	1.952	6	2.151	6	2.335	6	2.351	6	2.551	6	3.357	6	4.166	6
100	5.366	5	5.416	5	6.050	5	6.683	5	7.32	5	7.906	5	7.958	5	8.60	5	1.116	6	1.374	6

TABLE 2.—(*Continued*)

T	800		1 000		1 200		1 400		1 600		1 800		2 000		2 200		2 400		2 600		2 800	
λ	A	n	A	n	A	n	A	n	A	n	A	n	A	n	A	n	A	n	A	n	A	n
0.10	6	$\overline{58}$	2.1	$\overline{42}$	5.1	$\overline{32}$	1.3	$\overline{24}$	4.7	$\overline{19}$	1.0	$\overline{14}$	2.8	$\overline{11}$	1.9	$\overline{8}$	4.3	$\overline{6}$	4.3	$\overline{4}$	2.2	$\overline{2}$
0.20	1.5	$\overline{20}$	9	$\overline{13}$	1.4	$\overline{7}$	6.9	$\overline{4}$	4.1	$\overline{1}$	6.0	1	3.2	3	8.3	4	1.25	6	1.24	7	8.9	7
0.30	1.8	$\overline{8}$	2.7	$\overline{3}$	7.9	0	2.3	3	1.65	5	4.5	6	6.5	7	5.7	8	3.46	9	1.60	10	5.9	10
0.40	1.28	$\overline{2}$	1.00	2	3.9	4	2.8	6	6.8	7	8.2	8	6.0	9	3.08	10	1.19	11	3.75	11	1.00	12
0.41	3.4	$\overline{2}$	2.1	2	7.2	4	4.6	6	1.04	8	1.18	9	8.2	9	4.01	10	1.52	11	4.65	11	1.22	12
0.42	8.5	$\overline{2}$	4.3	2	1.27	5	7.4	6	1.56	8	1.65	9	1.10	10	5.2	10	1.90	11	5.6	11	1.45	12
0.43	2.04	$\overline{1}$	8.5	2	2.19	5	1.16	7	2.26	8	2.30	9	1.46	10	6.6	10	2.35	11	6.8	11	1.71	12
0.44	4.7	$\overline{1}$	1.61	3	3.7	5	1.78	7	3.24	8	3.10	9	1.91	10	8.4	10	2.87	11	8.2	11	2.00	12
0.45	1.04	0	3.0	3	6.0	5	2.67	7	4.6	8	4.17	9	2.45	10	1.04	11	3.47	11	9.6	11	2.31	12
0.46	2.2	0	5.3	3	9.5	5	3.9	7	6.3	8	5.46	9	3.09	10	1.27	11	4.15	11	1.13	12	2.64	12
0.47	4.5	0	9.2	3	1.49	6	5.6	7	8.5	8	7.2	9	3.87	10	1.54	11	4.93	11	1.30	12	3.01	12
0.48	9.1	0	1.57	4	2.28	6	8.0	7	1.14	9	9.2	9	4.77	10	1.86	11	5.75	11	1.50	12	3.41	12
0.49	1.74	1	2.60	4	3.42	6	1.11	8	1.51	9	1.15	10	5.9	10	2.22	11	6.7	11	1.71	12	3.82	12
0.50	3.3	1	4.2	4	5.0	6	1.53	8	1.97	9	1.44	10	7.1	10	2.60	11	7.7	11	1.94	12	4.23	12
0.51	6.0	1	6.7	4	7.3	6	2.08	8	2.54	9	1.79	10	8.5	10	3.05	11	8.8	11	2.17	12	4.73	12
0.52	1.06	2	1.05	5	1.04	7	2.74	8	3.22	9	2.20	10	1.01	11	3.52	11	1.01	12	2.43	12	5.18	12
0.53	1.85	2	1.60	5	1.45	7	3.60	8	4.07	9	2.65	10	1.19	11	4.07	11	1.13	12	2.69	12	5.67	12
0.54	3.16	2	2.40	5	2.02	7	4.7	8	5.1	9	3.18	10	1.40	11	4.66	11	1.27	12	2.97	12	6.17	12
0.55	5.3	2	3.50	5	2.74	7	6.1	8	6.3	9	3.80	10	1.62	11	5.30	11	1.42	12	3.27	12	6.69	12
0.56	8.6	2	5.2	5	3.7	7	7.7	8	7.6	9	4.50	10	1.86	11	5.98	11	1.58	12	3.58	12	7.22	12
0.57	1.38	3	7.5	5	5.0	7	9.8	8	9.2	9	5.29	10	2.14	11	6.68	11	1.74	12	3.89	12	7.8	12
0.58	2.19	3	1.05	6	6.4	7	1.22	9	1.11	10	6.2	10	2.44	11	7.5	11	1.91	12	4.21	12	8.3	12
0.59	3.38	3	1.46	6	8.4	7	1.51	9	1.33	10	7.1	10	2.76	11	8.3	11	2.09	12	4.54	12	8.9	12
0.60	5.2	3	2.02	6	1.08	8	1.86	9	1.56	10	8.2	10	3.10	11	9.2	11	2.27	12	4.89	12	9.4	12
0.61	7.8	3	2.76	6	1.38	8	2.26	9	1.85	10	9.4	10	3.47	11	1.01	12	2.46	12	5.23	12	1.00	13
0.62	1.15	4	3.70	6	1.75	8	2.73	9	2.15	10	1.07	11	3.87	11	1.10	12	2.66	12	5.57	12	1.05	13
0.63	1.68	4	4.96	6	2.18	8	3.27	9	2.50	10	1.21	11	4.29	11	1.21	12	2.86	12	5.93	12	1.11	13
0.64	2.41	4	6.5	6	2.71	8	3.92	9	2.88	10	1.36	11	4.74	11	1.31	12	3.06	12	6.28	12	1.16	13
0.65	3.44	4	8.5	6	3.36	8	4.61	9	3.31	10	1.53	11	5.21	11	1.42	12	3.28	12	6.64	12	1.22	13
0.66	4.83	4	1.10	7	4.08	8	5.5	9	3.78	10	1.71	11	5.71	11	1.53	12	3.49	12	6.99	12	1.27	13
0.67	6.7	4	1.41	7	5.0	8	6.4	9	4.30	10	1.90	11	6.22	11	1.64	12	3.70	12	7.34	12	1.32	13
0.68	9.3	4	1.80	7	6.0	8	7.4	9	4.86	10	2.10	11	6.76	11	1.76	12	3.92	12	7.7	12	1.37	13
0.69	1.25	5	2.27	7	7.2	8	8.6	9	5.5	10	2.31	11	7.32	11	1.88	12	4.14	12	8.0	12	1.42	13
0.70	1.69	5	2.84	7	8.6	8	9.9	9	6.1	10	2.53	11	7.91	11	2.00	12	4.36	12	8.4	12	1.47	13
0.71	2.26	5	3.52	7	1.02	9	1.13	10	6.8	10	2.77	11	8.52	11	2.13	12	4.57	12	8.7	12	1.52	13
0.72	3.00	5	4.35	7	1.21	9	1.28	10	7.6	10	3.02	11	9.12	11	2.26	12	4.79	12	9.1	12	1.57	13
0.73	3.96	5	5.3	7	1.40	9	1.45	10	8.4	10	3.28	11	9.76	11	2.38	12	5.01	12	9.4	12	1.61	13
0.74	5.14	5	6.5	7	1.64	9	1.64	10	9.2	10	3.55	11	1.04	12	2.51	12	5.23	12	9.7	12	1.66	13
0.75	6.6	5	7.9	7	1.90	9	1.84	10	1.02	11	3.83	11	1.11	12	2.64	12	5.44	12	1.00	13	1.70	13
0.76	8.5	5	9.4	7	2.19	9	2.06	10	1.11	11	4.12	11	1.18	12	2.77	12	5.66	12	1.04	13	1.74	13
0.77	1.08	6	1.13	8	2.52	9	2.31	10	1.22	11	4.42	11	1.24	12	2.90	12	5.87	12	1.07	13	1.78	13
0.78	1.36	6	1.34	8	2.90	9	2.56	10	1.32	11	4.74	11	1.32	12	3.03	12	6.08	12	1.10	13	1.82	13
0.79	1.72	6	1.61	8	3.26	9	2.84	10	1.44	11	5.06	11	1.39	12	3.16	12	6.28	12	1.12	13	1.85	13
0.80	2.13	6	1.88	8	3.71	9	3.14	10	1.55	11	5.39	11	1.46	12	3.29	12	6.49	12	1.15	13	1.89	13
0.90	1.43	7	7.6	8	1.08	10	7.21	10	2.99	11	9.03	11	2.19	12	4.51	12	8.25	12	1.38	13	2.14	13
1.00	6.17	7	2.21	9	2.41	10	1.33	11	4.78	11	1.29	12	2.86	12	5.50	12	**9.47**	12	**1.50**	13	**2.23**	13
1.50	3.18	9	3.46	10	1.70	11	5.30	11	1.25	12	**2.43**	12	**4.15**	12	**6.44**	12	9.27	12	1.269	13	1.662	13
2.00	1.49	10	8.96	10	2.96	11	**6.98**	11	**1.33**	12	2.20	12	3.31	12	4.63	12	6.16	12	7.85	12	9.71	12
2.50	2.94	10	1.23	11	**3.22**	11	6.43	11	1.08	12	1.64	12	2.29	12	3.03	12	3.79	12	4.70	12	5.62	12
3.00	3.90	10	**1.29**	11	2.90	11	5.20	11	8.11	11	1.15	12	1.52	12	1.961	12	2.412	12	2.888	12	3.38	12
4.00	**4.16**	10	1.04	11	1.93	11	3.03	11	4.31	11	5.72	11	7.24	11	8.83	11	1.048	12	1.219	12	1.395	12
5.00	3.39	10	7.15	10	1.19	11	1.76	11	2.37	11	3.03	11	3.71	11	4.421	11	5.15	11	5.89	11	6.64	11
10.00	7.41	9	1.16	10	1.61	10	2.08	10	2.56	10	3.04	10	3.54	10	4.033	10	4.53	10	5.04	10	5.54	10

TABLE 2.—(*Continued*)

T	3 000		4 000		5 000		6 000		7 000		8 000		9 000		10 000		15 000		20 000		25 000	
λ	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*	*A*	*n*
0.10	6.7	$\bar{1}$	1.02	5	1.32	8	1.57	10	4.8	11	6.2	12	4.51	13	2.21	14	2.63	16	2.86	17	1.204	18
0.20	4.9	8	1.92	11	6.9	12	7.5	13	4.1	14	1.49	15	4.04	15	8.95	15	**9.84**	16	**3.31**	17	6.98	17
0.30	1.86	11	9.9	12	1.08	14	5.32	14	1.66	15	3.90	15	**7.59**	15	**1.296**	16	6.58	16	1.525	17	2.647	17
0.40	2.36	12	4.66	13	2.80	14	9.25	14	2.18	15	**4.16**	15	6.88	15	1.034	16	3.62	16	7.24	16	1.133	17
0.41	2.79	12	5.13	13	2.95	14	9.46	14	2.18	15	4.10	15	6.72	15	1.000	16	3.44	16	6.74	16	1.049	17
0.42	3.26	12	5.60	13	3.08	14	9.68	14	**2.18**	15	4.04	15	6.54	15	9.66	15	3.25	16	6.29	16	9.71	16
0.43	3.77	12	6.06	13	3.21	14	9.79	14	2.18	15	3.97	15	6.37	15	9.32	15	3.06	16	5.86	16	9.02	16
0.44	4.33	12	6.54	13	3.34	14	9.91	14	2.16	15	3.90	15	6.19	15	9.00	15	2.89	16	5.48	16	8.38	16
0.45	4.93	12	7.00	13	3.45	14	9.98	14	2.14	15	3.82	15	6.01	15	8.67	15	2.732	16	5.13	16	7.79	16
0.46	5.56	12	7.46	13	3.54	14	1.006	15	2.12	15	3.74	15	5.83	15	8.35	15	2.578	16	4.80	16	7.26	16
0.47	6.25	12	7.91	13	3.64	14	1.010	15	2.10	15	3.66	15	5.64	15	8.04	15	2.435	16	4.49	16	6.76	16
0.48	6.93	12	8.35	13	3.72	14	**1.011**	15	2.07	15	3.57	15	5.47	15	7.73	15	2.300	16	4.21	16	6.32	16
0.49	7.65	12	8.77	13	3.79	14	1.010	15	2.04	15	3.48	15	5.29	15	7.44	15	2.176	16	3.96	16	5.90	16
0.50	8.41	12	9.16	13	3.85	14	1.008	15	2.01	15	3.39	15	5.12	15	7.15	15	2.058	16	3.714	16	5.52	16
0.51	9.18	12	9.56	13	3.91	14	1.002	15	1.97	15	3.30	15	4.95	15	6.87	15	1.947	16	3.488	16	5.17	16
0.52	9.99	12	9.92	13	3.95	14	9.96	14	1.94	15	3.21	15	4.78	15	6.61	15	1.846	16	3.282	16	4.84	16
0.53	1.08	13	1.03	14	3.98	14	9.89	14	1.90	15	3.12	15	4.62	15	6.35	15	1.746	16	3.089	16	4.54	16
0.54	1.16	13	1.06	14	4.01	14	9.79	14	1.86	15	3.03	15	4.46	15	6.10	15	1.657	16	2.910	16	4.266	16
0.55	1.24	13	1.09	14	4.04	14	9.72	14	1.82	15	2.95	15	4.31	15	5.87	15	1.572	16	2.745	16	4.009	16
0.56	1.33	13	1.12	14	4.05	14	9.58	14	1.78	15	2.86	15	4.16	15	5.64	15	1.492	16	2.589	16	3.771	16
0.57	1.41	13	1.15	14	4.06	14	9.46	14	1.745	15	2.78	15	4.01	15	5.43	15	1.417	16	2.447	16	3.547	16
0.58	1.50	13	1.18	14	**4.06**	14	9.34	14	1.703	15	2.70	15	3.87	15	5.21	15	1.347	16	2.313	16	3.345	16
0.59	1.58	13	1.20	14	4.05	14	9.20	14	1.665	15	2.61	15	3.74	15	5.00	15	1.279	16	2.187	16	3.154	16
0.60	1.66	13	1.22	14	4.05	14	9.06	14	1.623	15	2.53	15	3.60	15	4.80	15	1.217	16	2.071	16	2.978	16
0.61	1.74	13	1.24	14	4.03	14	8.92	14	1.584	15	2.46	15	3.48	15	4.62	15	1.158	16	1.961	16	2.812	16
0.62	1.82	13	1.26	14	4.01	14	8.77	14	1.547	15	2.381	15	3.36	15	4.45	15	1.103	16	1.858	16	2.660	16
0.63	1.90	13	1.28	14	3.99	14	8.62	14	1.507	15	2.308	15	3.24	15	4.28	15	1.049	16	1.762	16	2.516	16
0.64	1.98	13	1.29	14	3.96	14	8.47	14	1.469	15	2.235	15	3.13	15	4.11	15	9.99	15	1.671	16	2.381	16
0.65	2.06	13	1.30	14	3.93	14	8.31	14	1.429	15	2.165	15	3.01	15	3.96	15	9.53	15	1.587	16	2.256	16
0.66	2.13	13	1.30	14	3.91	14	8.16	14	1.393	15	2.099	15	2.91	15	3.81	15	9.10	15	1.508	16	2.139	16
0.67	2.20	13	1.31	14	3.86	14	7.99	14	1.357	15	2.032	15	2.81	15	3.66	15	8.67	15	1.433	16	2.027	16
0.68	2.27	13	1.32	14	3.82	14	7.84	14	1.319	15	1.970	15	2.713	15	3.52	15	8.28	15	1.363	16	1.925	16
0.69	2.34	13	1.325	14	3.78	14	7.68	14	1.286	15	1.908	15	2.614	15	3.39	15	7.91	15	1.297	16	1.829	16
0.70	2.40	13	1.327	14	3.74	14	7.51	14	1.250	15	1.848	15	2.525	15	3.26	15	7.55	15	1.235	16	1.737	16
0.71	2.46	13	1.330	14	3.69	14	7.37	14	1.217	15	1.790	15	2.437	15	3.14	15	7.23	15	1.178	16	1.653	16
0.72	2.52	13	**1.332**	14	3.64	14	7.20	14	1.184	15	1.735	15	2.356	15	3.03	15	6.91	15	1.123	16	1.573	16
0.73	2.58	13	1.329	14	3.59	14	7.05	14	1.151	15	1.682	15	2.274	15	2.918	15	6.61	15	1.071	16	1.497	16
0.74	2.63	13	1.329	14	3.54	14	6.90	14	1.121	15	1.627	15	2.195	15	2.812	15	6.33	15	1.022	16	1.428	16
0.75	2.68	13	1.326	14	3.49	14	6.74	14	1.089	15	1.561	15	2.120	15	2.710	15	6.06	15	9.76	15	1.360	16
0.76	2.73	13	1.321	14	3.44	14	6.59	14	1.059	15	1.527	15	2.047	15	2.610	15	5.80	15	9.32	15	1.297	16
0.77	2.77	13	1.317	14	3.39	14	6.44	14	1.030	15	1.482	15	1.979	15	2.518	15	5.56	15	8.91	15	1.238	16
0.78	2.82	13	1.313	14	3.34	14	6.30	14	1.003	15	1.436	15	1.916	15	2.431	15	5.34	15	8.52	15	1.183	16
0.79	2.86	13	1.304	14	3.28	14	6.15	14	9.75	14	1.391	15	1.850	15	2.342	15	5.12	15	8.15	15	1.129	16
0.80	2.89	13	1.298	14	3.23	14	6.01	14	9.48	14	1.348	15	1.788	15	2.261	15	4.91	15	7.80	15	1.079	16
0.90	3.12	13	1.193	14	2.71	14	4.75	14	7.19	14	9.93	14	1.289	15	1.602	15	3.316	15	5.15	15	7.04	15
1.00	**3.15**	13	1.059	14	2.235	14	3.70	14	5.49	14	7.413	14	9.46	14	1.161	15	2.316	15	3.537	15	4.784	15
1.50	2.11	13	4.88	13	8.47	13	1.245	14	1.672	14	2.120	14	2.578	14	3.049	14	5.476	14	7.96	14	1.048	15
2.00	1.162	13	2.316	13	3.626	13	5.03	13	6.49	13	7.99	13	9.51	13	1.105	14	1.889	14	2.687	14	3.487	14
2.50	6.59	12	1.187	13	1.768	13	2.372	13	2.990	13	3.622	13	4.258	13	4.899	13	8.15	13	1.143	14	1.471	14
3.00	3.892	12	6.63	12	9.53	12	1.252	13	1.558	13	1.862	13	2.176	13	2.489	13	4.065	13	5.651	13	7.24	13
4.00	1.572	12	2.497	12	3.454	12	4.419	12	5.410	12	6.40	12	7.40	12	8.40	12	1.341	13	1.844	13	2.348	13
5.00	7.41	11	1.132	12	1.531	12	1.935	12	2.343	12	2.752	12	3.160	12	3.572	12	5.626	12	7.70	12	9.76	12
10.00	6.05	10	8.60	10	1.116	11	1.373	11	1.630	11	1.888	11	2.144	11	2.404	11	3.666	11	4.988	11	6.277	11

TABLE 3.—EFFECT OF A CHANGE IN C_2

If dJ_λ = increase produced in J_λ by an infinitesimal increase (dC_2) in C_2, then $(dJ_\lambda)/J_\lambda = -K(dC_2)/C_2$; for the units of Table 2 and C_2 = 1.433 cm, °K, K has the appropriate value tabulated below. *Example:* If C_2 = 1.433 cm, °K, then, at 300°K and $\lambda = 2\mu$, $J_\lambda = 4900$ (Table 2) and $K = 24$ (Table 3); hence, if $C_2 = 1.434$, $(dC_2)/C_2 = 0.0007$, $(dJ_\lambda)/J_\lambda = -24(0.0007) = -0.017$, $dJ_\lambda = -(0.017)(4900) = -83$ and $J_\lambda = 4900 - 83 = 4817$. Unit of $\lambda = 1\mu = 10^4$Å $= 10^{-4}$ cm; T = absolute temperature, °K.

λ	1	2	3	4	5	6	7	8	9	10	15	20	100	λ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	2	3	4	5
T	*K*													*T*	*K*													
25	573	287	191	143	115	96	82	72	64	57	34	29	6	800	179	90	60	45	36	30	26	22	20	18	9	6	4	4
50	287	143	96	72	57	48	41	36	32	29	17	14	3	1 000	143	72	48	36	29	24	20	18	16	14	7	5	3	3
75	191	96	64	48	38	32	27	24	21	19	11	10	2	1 500	96	48	32	24	20	16	14	12	10	10	5	3	3	3
100	143	72	48	36	29	24	20	18	16	14	8	7	2	2 000	72	36	24	18	14	12	10	9	8	7	5	2	2	2
200	72	36	24	18	14	12	10	9	8	7	4	3	1	3 000	48	24	15	12	10	8	7	6	6	5	3	2	1	1
250	57	29	19	14	11	10	8	7	6	6	3	3	1	4 000	36	18	12	9	7	6	5	4	4	3	2	1	1	1
300	47	24	16	12	10	8	7	6	6	5	3	3	1	5 000	29	14	8	7	6	5	4	3	3	3	2	1	1	1
350	40	20	13	11	8	7	6	5	4	4	3	2	1	7 500	20	9	6	5	4	3	3	3	2	2	1	1	1	1
400	36	18	12	9	7	6	5	4	4	3	3	2	1	10 000	14	7	5	3	3	3	2	2	2	2	1	1	1	1
500	29	14	10	7	6	5	4	3	3	3	2	2	1	20 000	7	3	3	2	2	1	1	1	1	1	1	1	1	1
600	24	12	8	6	5	4	3	3	3	3	2	1	1	25 000	6	3	2	2	1	1	1	1	1	1	1	1	1	1

THERMAL RADIATION FROM MATERIALS AND SELECTED SOURCES OF RADIATION

W. W. COBLENTZ

For radiation from a "black-body," *see* p. 238.

At wave-length λ, the monochromatic intensity of the normal radiation of a body is $J_{n\lambda}$, where $J_{n\lambda}d\lambda$ = amount of radiant energy, having wave-lengths lying between $(\lambda - 0.5d\lambda)$ and $(\lambda + 0.5d\lambda)$, which the body emits in a direction perpendicular to its radiating surface per unit of time, of surface, and of solid angle; $J_n = \int_0^\infty J_{n\lambda}d\lambda$ is the normal intensity of the total radiation of the body. If the emission satisfies Lambert's law, as is the case for the substances here considered, the hemispherical intensity of the total radiation is $J = \pi J_n$ = total emission per unit of time and of area, and the monochromatic intensity of the hemispherical radiation is $J_\lambda = \pi J_{n\lambda}$. If the corresponding quantities for a perfect radiator (black-body) at the same temperature be indicated by J_b and $J_{\lambda b}$, and if $e_\lambda \equiv J_\lambda/J_{\lambda b}$ and $e_t \equiv J/J_b$, then e_λ and e_t are, respectively, the monochromatic and the total emissivity of the body. If J_c = value of the hemispherical intensity of the total radiation of a black-body at such a temperature that it has the same color as that of the body considered, $e_c \equiv J/J_c$ is the color emissivity of the body; and if $e_v \equiv \left(\int_{\lambda_1}^{\lambda_2} J_\lambda d\lambda\right) \div \left(\int_{\lambda_1}^{\lambda_2} J_{\lambda b}d\lambda\right)$, where λ_1 and λ_2 mark the limits of visible spectrum (about 0.4μ and 0.75μ), e_v is the visible emissivity. The Crova wave-length is that at which $\frac{1}{J_\lambda}\frac{dJ_\lambda}{dT} = \frac{1}{J}\frac{dJ}{dT}$. Usually the quantities directly observed are $J_{n\lambda}$ and J_n, and J_λ and J are computed from them on the assumption that Lambert's law is valid.

TABLE 1.—MONOCHROMATIC EMISSIVITY (e_λ) OF ELEMENTARY SUBSTANCES AND OXIDES: TEMPERATURE OF FUSION(1)

Assumes C_2 = 14 450 micron °C. A micropyrometer was used. s = solid, l = liquid. Unit of $e_\lambda = 0.01 = 1\%$; of $\lambda = 1\mu$ = 0.001 mm = 10000 Å.

λ =	0.55		0.65		λ =	0.55		0.65	
Symbol	*s*	*l*	*s*	*l*	Symbol	*s*	*l*	*s*	*l*
Ag*.......	<35	<35	4	7	Cr........	53		39	39
Au*.......	<38	<38	14	22	Cu*.......	38	36	10	15
Be........	61	81	61	61	Er........		30	55	38
Cb........	61		49	40	Fe........			37	37
Co........			36	37	Ir........			30	
Mn.......			59	59	BeO......			37	
Mo*......			43	40	CbO_x.....			71	
Ni........	44	46	36	37	Co_3O_4.....			77	63
Pd........	38		33	37	Cr_2O_3.....			60	
Pt*.......	38		33	38	Fe_3O_4.....			63	53
Rh........			29	30	Mn_3O_4....				47
Th........	36		36	40	NiO.......			89	68
Ti........	75	75	63	65	ThO_2......			57	69
U.........	77		54	34	TiO_2......			52	51
V.........	29		35	32	U_3O_8......			30	31
W*.......			39		V_2O_3......			69	
Yt........			35	35	Yt_2O_3.....			61	
Zr........			32	30					

* *See also* Table 2.

TABLE 2.—EMISSIVITY AND HEMISPHERICAL RADIATION: AG, AL, AU, CU, MO, PT, AND W

e_λ, e_c, e_v and e_t = monochromatic, color, visible, and total emissivity, respectively. λ = wave-length; s, l = solid, liquid; M. P. = melting point; J_λ = monochromatic intensity of hemispherical radiation; J = hemispherical intensity of total radiation; t, T = temperature, °C, °K(absolute). Unit of e_λ, e_c, e_v, e_t = 0.01 = 1%; of J = 1 watt cm^{-2}; of λ = 1 mμ = 10^{-7} cm.

Ag, liquid* (16)			**Au** (17)			**Cu,** Solid (16)			Liquid*	
t =	1060°	1117°	t = {	949° 1061°	1067° 1177°	t =	991°	1035°	1090°	1174°
λ	e_λ	e_λ	λ	$e_\lambda s$	$e_\lambda l$	λ	e_λ	e_λ	e_λ	e_λ
			475.0		50.3					
500	8.17	9.48	496.1	53.1	47.3	500	38.9	42.1	37.4	40.2
525	8.49	9.03	518.6	49.5	43.4	525	35.5	36.7	33.0	34.9
550	8.06	8.27	541.8	37.1	39.0	550	30.8	31.9	29.8	28.6
575	7.75	7.74	564.9	30.1	34.7	575	23.7	25.7	25.1	24.4
600	7.17	7.58	589.5	22.9	30.4	600	17.3	20.1	21.0	19.7
625	6.97	7.37	614.9	17.4	26.3	625	13.0	15.0	17.1	16.7
650	7.22	7.30	640.9	14.4	23.2	650	10.4	12.4	14.8	14.6
675	6.90	7.41	671.2	11.5	20.3	675	9.5	11.1	12.3	13.0
700	6.66	7.21	701.4	10.3	18.4	700	7.7	9.4	10.6	12.4
(1)	M. P. *s*	M. P. *l*	(1)	M. P. *s*	M. P. *l*	(1)	M. P. *s*		M. P. *l*	
550	<35	<35	550	<38	<38	550	38		36	
650	4	7	650	14	22	650	10		15	

Al, liquid	t	700	800	850	900	950	1000	(12.1)
λ = 650	e_λ	12	12	13	14	15	17	

Mo (18), assumes C_2 = 14 330 micron deg.; M. P. of Au = 1336°K

λ = 475		665	Visible	Color	Total	J	$\frac{T}{J}, \frac{dJ}{dT}$
T	e_λ	e_λ	e_v	e_c	e_t		
273	42.5	42.0					
300	42.4	41.9					
400	42.1	41.5					
600	41.5	40.6					
800	40.9	39.8					
1000	40.3	39.0	39.3	36.1	9.6	0.55	5.32
1200	39.8	38.2	38.6	34.7	12.1	1.43	5.23
1400	39.3	37.5	37.9	33.3	14.5	3.18	5.16
1600	38.8	36.7	37.3	32.1	16.8	6.30	5.10
1800	38.3	36.0	36.7	30.9	18.9	11.3	5.04
2000	37.9	35.3	36.2	29.7	21.0	19.2	4.99
2200	37.5	34.7	35.7	28.7	23.0	30.7	4.94
2400	37.1	34.1	35.2	27.7	24.8	47.0	4.90
2600	36.8	33.6	34.8	26.8	26.5	69.5	4.86
2800	36.5	33.1	34.4	26.0	28.1	98	4.83
2895	36.3	32.8	34.2	25.5	29.0	116	4.81

Mo, at M. P. and λ = 650; solid, e_λ = 43; liquid e_λ = 40 (1)

Pt, intensity (J_λ) of monochromatic radiance; unit of J_λ = (arbitrary) (3)

Pt, (J_λ) (3).—(*Continued*)

λ	t = 1056°	1174°	1216°	1271°	1353°	1442°	t = 1481°	1625°	1691°
589						43.30	37.38	126.0	162.4
646						118.4	94.80	257.1	295.0
698			31.51	36.42	34.92	187.9	154.6	348.9	461.9
757		16.49	55.73	55.02	65.60	293.6	237.3	549.5	724.7
836	11.52	31.19	101.3	105.0	107.8	501.1	382.4	830.3	1064
934	26.79	56.85	200.1	212.6	201.6	772.1	581.9	1176	1436
1054	52.46	101.7	319.5	339.9	314.0	1141	859.2	1639	1815
1197	85.60	167.2	459.1	494.1	425.0	1395	1073	1840	2096
1357	126.7	234.8	603.1	615.6	514.2	1544	1217	1929	2225
1526	166.4	275.2	680.4	692.1	569.8	1560	1225	1901	2140
1698	176.9	289.2	676.1	682.0	567.6	1409	1143	1728	1885
1868	188.5	287.0	646.0	658.3	528.1	1302	1047	1528	1675
2033	187.8	276.9	617.7	614.1	492.3	1135	932.4	1238	1442
2190	176.2	253.9	548.3	559.9	441.5	1014	830.3	1156	1279
2410	158.5	225.4	462.0	469.1	380.2	835.8	699.8	869.0	1015
2546	141.1	197.4	399.7	408.1	350.0	712.2	624.0	811.4	841.7
2801	115.1	152.5	321.7	313.0	251.2	538.6	444.8	599.5	640.5
2921	103.4	139.4	284.2	279.3	224.2	464.3	394.0	530.5	563.0
3037	94.76	123.1	252.0	255.4	206.9	426.6	364.0	460.0	497.3
3150	84.61	115.9	232.1	235.9	191.0	384.5	318.8	432.5	445.6
3367	77.10	99.78	211.6	202.3	158.3	328.1	270.8	358.0	362.8
3569	70.93	89.82	178.0	174.7	137.7	283.5	238.5	292.9	315.0
3760	64.54	75.19	149.6	155.6	120.0	252.2	206.0	265.0	273.2
4031	50.80	67.03	121.2	125.7	103.6	198.5	168.8	225.1	217.2
4446	40.09	47.78	96.99	96.80	74.86	147.2	123.8	152.0	158.7
4638	35.78	42.84	84.12	85.05	65.90	129.3	105.0	140.0	140.8
4827	29.50	38.06	74.64	72.13	55.93	111.4	92.60	125.3	114.2
5001	28.30	34.00	62.53	64.46	50.40	101.1	80.22	105.0	107.4
5168	25.20	30.63	56.00	57.26	46.92	88.60	75.79	90.61	98.79
5486		26.52	40.39	48.46	36.32	75.35	61.34	69.20	78.81
6240			27.61	30.59	25.12	41.72	35.81	38.66	44.92
6852							22.50	25.64	29.28

For platinum black, *see* Table 4.

Pt, total emissivity† (7)

T	$e_{\text{calc.}}$	$e_{\text{obs.}}$
300	4.11	3.59
350	4.77	4.10
400	5.43	4.66
450	6.06	5.30
500	6.68	5.98
550	7.29	6.71
600	7.90	7.50
650	8.48	8.25
700	9.07	9.05
750	9.61	9.79
800	10.14	10.52
850	10.7	11.3
900	11.2	12.0
950	11.7	12.7
1000	12.2	13.4
1050	12.7	14.1
1100	13.2	14.7
1150	13.7	15.3
1200	14.1	15.9
1250	14.6	16.5
1300	15.0	17.1
1350	15.5	17.6
1400	15.9	18.2
1450	16.3	18.7
1500	16.7	19.2

Pt, monochromatic emissivity

λ	536	647
e_λ‡ (10)	36.3	34.8
λ	550	650
e_λ (1) t = M. P.	38	33 *s* 38 *l*

W (18), data apply to aged tungsten filaments

λ =	467	665	Visible	Color	Total	Crova	J	$\frac{T}{J}, \frac{dJ}{dT}$
T	e_λ	e_λ	e_v	e_c	e_t	λ_c		
300	50.5	47.0			3.2		0.0015	
400	50.1	46.8			4.2		0.006	
500	49.8	46.6			5.3		0.019	
600	49.5	46.4			6.4		0.048	
700	49.2	46.2			7.6		0.105	
800	49.0	46.0			8.8		0.206	
900	48.8	45.8			10.1		0.379	
1000	48.6	45.6	46.4	39.6	11.4	607.7	0.654	5.35
1100	48.4	45.4	46.3	39.3	12.8	603.8	1.072	5.35
1200	48.2	45.2	46.2	39.1	14.4	600.4	1.691	5.35
1300	48.0	45.0	46.0	38.8	15.8	597.1	2.576	5.35
1400	47.8	44.8	45.9	38.6	17.4	593.4	3.82	5.29
1500	47.6	44.5	45.7	38.3	19.2	590.2	5.55	5.23
1600	47.5	44.3	45.6	38.1	20.7	587.4	7.77	5.15
1700	47.3	44.1	45.5	37.8	22.2	585.0	10.59	5.07
1800	47.2	43.9	45.4	37.6	23.6	582.6	14.22	4.99
1900	47.0	43.7	45.3	37.3	24.9	580.6	18.25	4.91
2000	46.9	43.5	45.2	37.0	26.0	578.5	23.72	4.85
2100	46.7	43.3	45.0	36.7	27.0	576.9	29.86	4.79
2200	46.6	43.1	44.9	36.4	27.9	575.3	37.18	4.74
2300	46.4	42.9	44.8	36.2	28.8	573.7	45.9	4.69
2400	46.3	42.7	44.7	35.9	29.6	572.4	55.8	4.64

W (18).—(*Continued*)

λ =	467	665	Visible	Color	Total	Crova	J	$\frac{T}{J'}\frac{dJ}{dT}$
T	e_λ	e_λ	e_v	e_c	e_t	λ_c		
2500	46.2	42.5	44.6	35.6	30.2	571.1	67.6	4.59
2600	46.0	42.3	44.4	35.3	31.1	570.1	80.8	4.55
2700	45.9	42.1	44.3	35.0	31.8	569.1	96.2	4.51
2800	45.8	41.9	44.2	34.7	32.3	568.2	112.9	4.47
2900	45.6	41.7	44.1	34.5	32.9	567.4	132.1	4.43
3000	45.5	41.5	44.0	34.3	33.4	566.6	153.9	4.40
3100	45.4	41.3	43.8	34.1	33.7	565.9	177.5	4.37
3200	45.2	41.1	43.7	33.8§	34.1§	565.2	203	4.34
3300	45.1	40.9	43.6	33.5§	34.4§	564.5	232	4.31
3400	45.0§	40.7§	43.5§	33.2§	34.8§	563.8	264§	4.29
3500	44.9§	40.5§	43.4§	32.9§	35.1§	563.1	300§	4.27
3655	44.7§	40.2§	43.3§	32.4§	35.4§	562.1	360§	

W, t = 2000 to 3200°C, $e_\lambda = 49$, same for $\lambda = 536$ as for $\lambda = 647$; independent of t (10); others (8, 12) have found e_λ varies with t. For solid W at M. P., $\lambda = 650$, $e_\lambda = 39$ (1).

* Fused in H.

† Radiator was a Pt wire in a highly evacuated enclosure; $e_{\text{calc.}} = 0.751 \times \sqrt{T\rho} - 0.632T\rho + 0.670\,(T\rho)^{3/2} - 0.607\,(T\rho)^2$, where ρ = resistivity (ohm-cm), and T = absolute temperature (°K); $e_{\text{obs.}}$ = observed emissivity.

‡ Between 20°C and 1710°C, e^λ is independent of t.

§ Extrapolated values.

TABLE 3.—TOTAL EMISSIVITY (e_t) OF OXIDIZED METALS (15)

Surfaces were oxidized at $t \geqq 600$°C; Unit of $e_t = 0.01 = 1\%$

Metal	200°C	400°C	600°C
Ag, Silver	2.0	3.0	3.8
Al, Aluminum*	11.3	15.3	19.2
Cu, Copper†	18.0	18.5	19.0
Cu, Copper*	56.8	56.8	56.8
Cu-Zn, Brass*	61.0	60.0	58.9
Fe, Cast iron	21.0		
Fe, Cast iron*	64.3	71.0	77.7
Steel†	52.1	54.7	57.0
Steel*	79.0	78.8	78.7
Ni, Nickel*	36.9	42.4	47.8
Ni-Cu, Monel*	41.1	43.9	46.3
Pb, Lead*	63.1		
Pt, Platinum	6.0	8.6	11.0
Zn, Zinc*		11.0	

* Oxidized. † Calorized surface.

TABLE 4.—TOTAL EMISSIVITY (e_t) OF PLATINUM BLACK AND OF LAMPBLACK: VARIATION WITH THICKNESS (11)

Deposited upon Pt. The lampblack was covered with lacquer. D_s = surface density of the black. Unit of $D_s = 10^{-6}$ g cm^{-2} = 0.001 mg cm^{-2}; of $e_t = 0.01 = 1\%$. Temperature = 100°C.

Pt Black		Lampblack	
D_s	e_t	D_s	e_t
37	7.8	22	33.0
150	12.9	25	40.7
224	23.4	79	58.0
257	31.1	79	64.0
286	46.5	90	72.9
327	58.5	97	77.6
412	72.9	126	82.5
599	89.3	173	89.8
827	93.5	242	93.1
942	94.2	267	94.9
1072	94.9	300	94.2
1140	95.3	332	94.5
1897	96.8	339	94.0
3185	96.7	527	93.1
		1182	88.2

TABLE 5.—EFFICIENCY OF COATED SHEETS AS SUN-SHIELDS, AND RELATIVE EMISSIVITIES OF PAINTS AND COATINGS (6)

While one side (upper) of a sheet was continuously exposed normally to the sun, the radiation (r) proceeding normally from the other side (lower) was measured. If r_1 and r_2 are simultaneous values for two sheets similarly exposed, r_2/r_1 measures the relative efficiency of the second with reference to the first; if the sheets are unperforated and are good thermal conductors, r_2/r_1 is the ratio of the emissivities of the two lower surfaces. All sheets were approximately at 50°C. Unit of $r_2/r_1 = 0.01 = 1\%$.

	Sheet 1		Sheet 2		r_2/r_1
	Upper	Lower	Upper	Lower	
Sheet iron*	Asbestos	Asbestos	Asbestos	Al paint	55
			Al paint	Al paint	72
Iron, 6 mm†	Black‡	Oxidized	Al paint	Oxidized	50
			White lead	Oxidized	30
Iron, 0.5 mm†	Black	Al paint d.§	Black	Al paint p.§	100
	Black	White lead	Black	Lampblack	95, 100
			Black	Al paint	28, 29
			Black	Enamel‖	98, 100
	Black	Lampblack	Black	Enamel‖	95, 98
	Black	Enamel‖	Black	Al paint	27, 30
Cypress, 12.7 mm†	Unpainted	Unpainted	Unpainted	Al paint	43
Rubberized cloth¶	Rubber	Cloth	Al paint	Cloth	45
Leatheroid** (1)	Unpainted	Unpainted	Unpainted	Al paint	44
			Al paint	Unpainted	30
(2)	Unpainted	Unpainted	Unpainted	Al paint	39
			Al paint	Unpainted	25
(3)	Unpainted	Unpainted	Unpainted	Al paint	47
			Al paint	Unpainted	27
Duck, 11 H††	Unpainted	Unpainted	Unpainted	Al paint	14, 15
			Al paint	Unpainted	22, 23
Duck, 4 H††	Unpainted	Unpainted	Unpainted	Al paint	22, 25
Duck†† (12 H; 4 H)‡‡	Unpainted	Al paint	Unpainted	Al paint	80, 81
Duck†† (12 H; 4 H)‡‡	Unpainted	Unpainted	Unpainted	Unpainted	58

* Corrugated asbestos roofing. Temperature in shade = 29°C; temperature of sheet with asbestos on both sides = 44°C; asbestos upper, Al lower = 45°C; Al both sides = 52°C; Zn sprayed on both sides = 55°C.

† Thickness of sheet. ‡ Asphalt paint. § d., p. = dull, polished. ‖ White, vitreous enamel. ¶ Balloon fabric.

** Artificial leather: (1) Single fabric. (2) Double fabric enclosing thin layer of rubber-friction stock. (3) Similar to (2), but of double-texture fabric. All three were coated on upper side with a black, rubber composition.

†† Cotton duck; 11 H is 13.08 oz./yd.^{2}; 4 H is 24.54 oz./yd.^{2}; 12 H is 11.45 oz./yd.^{2}

‡‡ Sheet 1 is 12 H; sheet 2 is 4 H.

TABLE 6.—LOSS OF HEAT FROM VERTICAL BRICK WALL (2)

In still air at 21°C, the wall, at the surface temperature t, lost heat, from one side, at the rate E. E is the same for the natural color (red), for brick coated with Ca(OH)$_2$, and for brick coated with lampblack. Uncertainty in t is about 2%. Unit of E = 0.001 watt/cm^2 = 2.39×10^{-4} cal cm^{-2} sec^{-1} = 6.12×10^{-6} BTU in.$^{-2}$ sec^{-1}.

t	47°C	66°C	86°C	131°C	199°C	218°C
E	30.8	61.7	92.5	185	370	431

TABLE 7.—NORMAL IRRADIATION (R) BY HEFNER STANDARD LAMP AND BY SPERM CANDLE: DISTANCE = 1 METER

R = radiant power, per unit area of receiving surface, which is received by a surface which is normal to the direction of propagation of the radiation and 1 meter from the source. Unit of $R = 10^{-5}$ watt/cm^{-2} = 2.389×10^{-6} cal cm^{-2} sec^{-1} = 6.118×10^{-8} BTU in.$^{-2}$ sec^{-1}.

Source	R	Remarks	Lit.
1 Sperm candle	12.1		(4)
1 Hefner lamp	10.9*		(4)
	9.6†		(4)
	9.47†	Amyl acetate, ordinary	(9)
	9.40†	Amyl acetate, pure	(9)
	9.43†	Isoamyl acetate	(9)

* No diaphragm. † Diaphragm, opening 14 mm by 50 mm.

TABLE 8.—MONOCHROMATIC EMISSIVITY (e_λ) AND MONOCHROMATIC INTENSITY (J_λ) OF RADIATION OF WELSBACH GAS MANTLE (14)

The mantle contained 0.993 ThO_2 per 0.007 Ce_2O_3; J_λ depends upon relative amount of Ce_2O_3. e_λ is computed on assumption that true absolute temperature of mantle = 1800°K. Unit of $\lambda = 1\mu = 0.001$ mm $= 10^4$Å; of J_λ = (arbitrary); of $e_\lambda = 0.01 = 1\%$.

λ	J_λ	e_λ	λ	J_λ	e_λ	λ	J_λ	e_λ
0.45	3.8	86	1.5	34.0	0.9	8.0	23.9	21
0.50	11.5	72	2.0	25.5	0.7	9.0	29.9	39
0.55	22.0	49	3.0	17.0	0.9	10.0	27.4	52
0.60	24.0	24	4.0	7.6	0.8	12.0	19.1	70
0.70	25.8	6.2	5.0	7.0	1.4	15.0	8.9	79
1.0	34.3	1.9	6.0	7.9	2.7	18.0	5.0	81
1.2	34.3	1.2	7.0	15.0	8.4			

TABLE 9.—MONOCHROMATIC INTENSITY (J_λ) OF RADIATION FROM A CYLINDRICAL ACETYLENE FLAME (5)

The value of J_λ for a flat flame, whether viewed flatwise or edgewise, is different from that for a cylindrical flame. J'_λ is the intensity of the radiation from a black-body at 2360°K, assuming $C_2 = 14350$ micron °K. Unit of $\lambda = 10^{-3}\mu = 10^{-7}$ cm = 10 Å; of J_λ = of J'_λ = (arbitrary); of $J_\lambda/J'_\lambda = 0.01 = 1\%$.

λ	J_λ	J'_λ	J'_λ/J_λ	λ	J_λ	J'_λ	J'_λ/J_λ
400	5	3.3	66	460	11.8	11.2	94.9
425	7	5.5	79	475	15.0	14.6	97.4
440	8.5	7.6	89.4	500	20.9	21.0	100.5
450	10.0	9.25	92.5	520	27.5	27.3	99.3
525	29.2	29.2	100.0	650	91.2	92.1	101.0
540	34.6	34.6	100.0	660	97.6	98.5	100.7
550	38.9	38.8	99.8	675	107.5	108.0	100.4
560	42.9	43.1	100.4	680	110.9	111.3	100.7
575	49.8	49.9	100.2	700	124.1	124.1	100.0
580	52.2	52.4	100.3	720	137.5	137.2	99.8
600	62.5	62.9	100.6	725	141.0	140.5	99.6
620	73.3	74.0	101.1	740	151.0	150.2	99.5
625	76.1	76.8	100.8	750	157.9	157.2	99.5
640	85.0	86.0	101.1	750	163.0	157.2	96.5

TABLE 10.—MONOCHROMATIC INTENSITY (J_λ) OF RADIATION OF A GAS-FILLED TUNGSTEN LAMP (13)

Color temperature = 2848°K; efficiency = 15.6 lumen per watt. Unit of $\lambda = 10^{-2}\mu = 10^{-6}$ cm = 100Å; of J_λ = (arbitrary).

λ =	40	42	44	46	48	50	52	54	56
J_λ =	35	45	57.5	73.5	94.0	116.5	141	167.5	196
λ =	58	60	62	64	66	68	70	72	74
J_λ =	224	252	280	307.5	336.5	365	.393	421	450

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(For a key to the periodicals see end of volume)

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TEMPERATURE, BRIGHTNESS AND EFFICIENCY OF SELECTED SOURCES OF LIGHT

W. E. FORSYTHE

(All data and computations not credited to another have been supplied by the Nela Research Laboratory, Cleveland, Ohio, U. S. A.)

Definitions

The *brightness temperature* of a body (*B*) for a stated wavelength (frequently, $\lambda = 0.665\mu$) is the temperature at which an ideal black-body has, at this wave-length, the same brightness as *B*.

The *color temperature* of a body (*B*) is the temperature at which an ideal black-body has the same integral (or apparent) color as *B*.

The *radiation temperature* of a body (*B*) is the temperature at which the rate of total energy radiation from an ideal black-body is equal to that from *B*.

By the *brightness* of a source is meant the brightness in the direction perpendicular to the emitting surface.

TABLE 1.—BRIGHTNESS TEMPERATURE ($\lambda = 0.665\mu$) CORRESPONDING TO TRUE TEMPERATURE T

T = true absolute temperature, °K

T	C* (8)	Mo (14)	Ni (14)	Pt (14)	Ta (14)	W (12)	Nernst glower (11)
1000	995	958	956	950	966	966	
1100	1092	1049	1047	1037	1058	1058	959
1200	1189	1139	1137	1124	1149	1149	1065
1300	1286	1228	1226	1211	1239	1240	1271
1400	1382	1316	1315	1296	1329	1330	1277
1500	1478	1403	1403	1381	1418	1420	1384
1600	1574	1489		1466	1506	1509	1491
1700	1670	1574		1551	1592	1597	1598
1800	1766	1658		1634	1680	1684	1705
1900	1862	1741		1717	1766	1771	1814
2000	1958	1824		1800	1851	1857	1922
2100	2054	1905			1935	1943	2030
2200	2150	1986			2018	2026	2140
2300	2245	2065			2099	2109	2250
2400	2340	2143			2180	2192	2361
2500		2220			2260	2274	2472
2600		2297			2339	2356	
2700		2373			2417	2437	
2800		2448			2495	2516	
2900		2523			2571	2595	
3000					2647	2673	

T	Au (14)	Cu† (3)	Fe† (3)	FeO‡ (3)	Ni_2O_3‡ (3)	Ni-Cr§ (3)	Slag† (3)
1000	908			1000	999	997	
1100	990			1099	1098	1095	
1200	1071			1197	1196	1193	
1300	1151			1295	1292	1289	
1400		1255		1392	1389	1383	
1500		1335	1412	1489	1484	1475	

TABLE 1.—(*Continued*)

T	Au (14)	Cu† (3)	Fe† (3)	FeO‡ (3)	Ni_2O_3‡ (3)	Ni-Cr§ (3)	Slag† (3)
1600		1413	1499		1580		
1700		1490	1586				1646
1800		1566	1673				1738
1900			1759				1831
2000			1844				1924
2100			1929				
2200			2016				

* Untreated carbon filament.
† Molten.
‡ Solid.
§ Nichrome, chromel.

TABLE 2.—COLOR TEMPERATURE CORRESPONDING TO TRUE TEMPERATURE (T) (9) AND TABLE 1

T = true absolute temperature, °K

T	C*	Mo	Ni	Pt	Ta	W	Nernst glower
1000		1004	1020	1011		1006	
1100		1105	1125	1116		1108	
1200		1207	1231	1222		1210	
1300	1300	1309	1336	1328		1312	
1400	1396	1411	1442	1435		1414	
1500	1492	1513	1546	1542	1532	1517	1517
1600	1590	1616		1649	1642	1619	1631
1700	1687	1720		1757	1751	1722	1744
1800	1785	1823		1865	1859	1825	1857
1900	1884	1927		1974	1967	1929	1968
2000	1984	2032		2083	2075	2033	2074
2100	2086	2138			2182	2137	2173
2200	2187	2244			2288	2242	2265
2300	2288	2350			2393	2347	2345
2400		2456			2497	2452	2426
2500		2563			2601	2557	2502
2600		2672			2705	2663	
2800		2891			2911	2878	
3000						3094	

* Untreated carbon filament.

TABLE 3.—COLOR TEMPERATURE CORRESPONDING TO BRIGHTNESS TEMPERATURE (T_B) (9) AND TABLE 1

T_B = brightness temperature, absolute, °K

T_B	C*	C†	Os
1400	1414		1444
1500	1515		1562
1600	1616	1620	1680
1700	1718	1735	1799
1800	1820	1852	1919
1900	1923	1962	2045
2000	2028	2064	2168
2100	2134	2161	2295
2200	2240	2255	2427
2300			2556
2400			2688

* Untreated carbon filament.
† Treated carbon filament, "Gem."

TABLE 4.—RADIATION TEMPERATURE CORRESPONDING TO TRUE TEMPERATURE (T)

T = true absolute temperature, °K

T	Cu* (3)	CuO (3)	Fe* (3)	FeO (3)	Mo (14)	Ni_2O_3 (3)	Pt (13)	W (5)
1000		880		963	557	892	562	581
1100		961		1060	633	1003	632	659
1200		1156		1156	708	1112	704	738
1300	815	1245		1251	786	1220	775	819
1400	873	1334		1346	864	1332	849	905
1500	934	1424	1092	1442	945	1442	922	991
1600	1000	1514	1163		1024		995	1080
1700			1235		1106		1070	1167
1800			1307		1187		1146	1254
1900			1382		1272		1222	1342
2000			1456		1354		1297	1428
2200					1523			1601
2400					1693			1775
2600					1866			1945
2800					2039			2116
3000								2286

* Molten.

TABLE 5.—BRIGHTNESS* (B) CORRESPONDING TO TRUE TEMPERATURE

T = true absolute temperature, °K; $B = A \times 10^n$. *Examples:* W has a brightness of 0.00012 candle/cm² at 1000°K, of 2.26 at 1700°K, and of 347 candle/cm² at 2600°K. Unit of B = 1 candle/cm² = 6.452 candle/in.² = 3.142 lambert.

T	n	B. B.†	W	Mo	Ta	C‡	Nernst§	Pt	Ni	n
		A								
1000	−4	2.5	1.2	1.0		2.0		0.7	0.9	−4
1100	−4	21	10	8.1		17.4		6.2	8.0	−4
1200	−2	1.30	0.6	0.50		1.1		0.43	0.52	−2
1300	−2	6.4	2.9	2.4		5.4		2.04	2.5	−2
1400	−1	2.35	1.1	0.89		1.9	0.5	0.74	0.90	−1
1500	−1	7.22	3.3	2.7	3.2	6.0	2.2	2.4	2.8	−1
1600	−1	20.5	9.2	7.65	9.1	16.2	7.8	6.43		−1
1700	0	5.06	2.26	1.87	2.21	4.05	2.27	1.61		0
1800	0	11.25	5.05	4.13	5.04	8.89	6.0	3.56		0
1900	0	22.9	10.40	8.34	10.35	18.5	14.0	7.5		0
2000	1	4.39	2.00	1.59	2.02	3.44	2.93	1.43		1
2100	1	7.94	3.56	2.86	3.63	6.30	5.70			1
2200	1	13.62	6.13	4.85	6.23	10.69	10.6			1
2300	1	22.47	10.05	7.95	9.45	24.45	20.6			1
2400	2	3.50	1.570	1.23	1.46		3.72			2
2500	2	5.31	2.375	1.86	2.22					
2600	2	7.75	3.470	2.70	3.24					
2700	2	11.30	4.980	3.91	4.57					
2800	2	15.80	6.94	5.40	6.16					
2900	2	21.60	9.49							
3000	2	28.90	12.57							
3100	2	37.60	16.47							
3200	2	48.50	21.10							
3300	2	61.10	26.85							
3400	3	7.42	3.37							
3500	3	8.82	4.22							
3600	3	10.30	5.74							

* Computed from brightness of black-body (6) and data in Table 2.
† Black-body (6); data for T = 1000 to 1600° and 2700 to 3600° are calculated.
‡ Untreated carbon filament.
§ Nernst glower.

TABLE 6.—BRIGHTNESS* (B) CORRESPONDING TO COLOR TEMPERATURE (T_c)

T_c = absolute color temperature, °K. Unit of B = 1 candle/cm² = 6.452 candle/in.² = 3.142 lambert.

T_c	C†	C‡	Os
		B	
1400	0.20		0.15
1500	0.62		0.43
1600	1.8	1.8	1.15
1700	4.4	4.1	2.60
1800	9.9	8.9	5.7
1900	20.0	17.4	11.0
2000	39.0	32.5	20.5
2100	68	57.5	35.0
2200	117	102	59.0
2300	187	171	93.0
2400			144.0
2500			209
2600			306
2700			427
2800			590

* Computed from brightness of black-body (6) and data of Table 2.

† Untreated carbon filament.

‡ Treated carbon filament, "Gem."

TABLE 7.—TEMPERATURE, BRIGHTNESS AND EFFICIENCY OF SELECTED SOURCES OF ILLUMINATION

T, T_B, T_c = true, brightness, and color temperature, absolute scale, expressed in °K; E = efficiency; B = intrinsic brightness; C = carbon, Os = Osmium, Ta = Tantalum, W = Tungsten; 50-w. = 50 watt; w.p.c. = watt per candle; cp. std. = candle power standard. Unit of B = 1 candle/cm² = 6.452 candle/in.² = 3.142 lambert; of E = 1 lumen/watt.

Source	T	T_B	T_c	E	B	Remarks
Candle: sperm			1 930		1.0	Bright spot
Paraffin			1 925			
Kerosene: flat		1 500	2 055		1.2	Bright spot
Round		1 530	1 920		1.5	Bright spot
Hefner lamp			1 880		0.7	Bright spot
Pentane lamp*			1 920			10 cp. std.
Gas: flame†			2 160			Batswing
			1 875			Candle
Mantle					6.2	Bright spot
Acetylene‡			2 380			Whole flame
		1 660	2 465		6.7	One spot
		1 730	2 360		10.8	Mees burner
Vacuum lamps:						
C, 4 w.p.c		2 030	2 080	2.5	55	Filament
3.1 w.p.c		2 065	2 165	3.2	71	Treated
2.5 w.p.c		2 130	2 195	4.0	78	Gem
50-w	2 095		2 080	2.5	55	Untreated (5)
50-w	2 130		2 195	4.0	78	Gem (5)
Vacuum lamps:						
Os, 2 w.p.c		2 035	2 185	6.3	61	
Ta, 2 w.p.c		2 000	2 260	6.3	53	
50-w	2 180		2 260	6.3	53	(5)
W, 10-w	2 355		2 390	7.7	128	Straight§§ (5)
25-w	2 450		2 493	9.8	193	Straight§§ (5)
40-w	2 460		2 504	10.0	206§	Straight§§ (5)
60-w	2 465		2 509	10.1	211	Straight§§ (5)
W, Bulb frosted on inside (9):						
15-w	2 470			8.4	2.3	Coiled
25-w	2 505			9.5	4.1	Coiled
40-w	2 535			10.0	5.2	Coiled
Gas-filled lamps (5):						
W, 50-w					408	White mazda‖
50-w	2 685		2 670	10.0	469	
75-w	2 735		2 705	11.8	563	White mazda¶
100-w	2 760		2 740	12.9	605	
200-w	2 840		2 810	15.2	781	
200-w	2 860			10.0		"Daylight"
500-w	2 960			11.2		"Daylight"
750-w	3 065					Photographic
900-w	3 290		3 220	27.3	2 660	Special**
1000-w	2 990		2 980	20.0	1 225	
1000-w	3 185		3 175	24.2	2 065	Stereopticon
1500-w	3 105					Photographic
2000-w	3 020		3 000	21.2	1 350	Mazda††
10 kw	3 350		3 300	31.0	3 050	Special**
30 kw	3 350		3 300	31.0	3 050	Special**
Bulb frosted on inside (9):						
50-w	2 650			10.0	7.8	Coiled
60-w	2 655			11.1	9.2	Coiled
100-w	2 765			13.4	12.3	Coiled
Electric arc:						
Solid C		3 385	3 780		9 200	(10)
Cored C		3 075	3 420		4 130	(10)
Graphite (C)		3 735	3 775		17 300	(10)
Hg, 385-w	(2)	Direct current			2.2	110 volt
430-w	(2)	Alternating current			2.4	110 volt
500-w	(2)	Quartz tube			350	100 volt
Clear sky (7)					0.8	Average
Moon (4)					0.25	Bright spot
Sun‡‡ (as observed from surface of earth)					165 000	
(As observed from top of earth's atmosphere)					224 000	

* Color-matched by Bureau of Standards.

† Mixture of coal gas and water gas, heating value *ca.* 600 BTU/ft.³; "batswing" and "candle" refer to the shape of the flame; the candle-shaped flame was about 10 cm high.

‡ For first two lines, the burner was from a "prest-o-lite" automobile headlight, reflector removed; for third line, a Mees burner was used.

§ For frosted bulb, B = 2.5; for "golden mazda" bulb, B = 2.0 (9).

‖ For bulb, B = 1.3.

¶ Filament, sprayed; for bulb, B = 2.1.

** For special illumination.

†† For inside surface of coil, B = 3 000; for frosted bulb, B = 130.

‡‡ Calculated from data of (1).

§§ Straight filament.

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SPECTROSCOPY

SPECTROSCOPIC STANDARDS OF WAVE-LENGTH

CH. FABRY

All wave-lengths (λ) given below are expressed in international ångstroms and are the wave-lengths in dry atmospheric air at 15°C and a pressure of one normal atmosphere. Some of them differ slightly from the corresponding values internationally accepted for use as secondary or tertiary standards. These differences are made necessary by the high precision of modern measurements and the very recent elimination of irregularities produced by the pole-effect (*see* p. 432). All arc lines refer to arcs in air at atmospheric pressure (not to arcs in a vacuum); those produced by arcs which are not satisfactorily defined are marked (*).

PRIMARY STANDARD

It is internationally agreed that in dry atmospheric air at 15°C and a pressure of one normal atmosphere the red line of cadmium, produced under the conditions described by Michelson (1, 9) and specified below, has the wave-length (3)

$$\lambda_{Cd} = 6438.4696\ \text{Å} = 0.64384696\mu$$

This defines the length of the international ångstrom and of the micron (μ) as used in the measurement of wave-lengths. As so defined, $1\ \text{Å} = 10^{-10}$ m and $1\mu = 0.001$ mm within the limits of experimental error.

The primary (cadmium) standard of wave-length shall be produced by high-voltage electric current in a vacuum-tube having internal electrodes and the form described by Michelson (11). The tube shall be maintained at a temperature not higher than 320°C, and shall have a volume not less than 25 cm³. The effective value of the exciting current shall not exceed 0.05 ampere. At room temperature the tube shall be non-luminous when connected to the usual high-voltage circuit.

Table 1.—Secondary Standards (2, 4, 5, 6, 7, 8, 10)

In arriving at the values here given, the papers mentioned have been critically compared. The table is divided into 3 sections: Fe-lines, Cu-, Ni-, and Si-lines that fill gaps occurring in the Fe-spectrum, and Ne-lines. Unit of λ = 1 Int. Å = $10^{-4}\mu$ = 10^{-8} cm.

FE-LINES

As far as possible the values here tabulated refer to the Pfund arc (11) in air at atmospheric pressure. That arc satisfies the following conditions:

Anode is below and consists of a bead of iron oxide supported on a massive rod of iron or other good conductor of heat; cathode is above and consists of a rod of iron 6 or 7 mm in diameter, having close to its lower end a massive cooling cylinder of copper or brass. Current not over 5 amperes, 110 to 250 volts, arc 12 to 15 mm long; zone used is midway between the electrodes and not over 1.5 mm wide.

These values are the most accurate and are unmarked. Others, obtained with the arc between two rods of iron 6 to 7 mm in diameter, current about 6 amperes and no statement of either length of arc or of portion used, are marked (*).

λ_{Fe}	λ_{Fe}	λ_{Fe}	λ_{Fe}
*2373.737	3977.744	4966.097	6393.606
*2413.310	4021.870	4994.132	6430.852
*2562.541	4074.789	5001.872	6494.985
*2588.016	4076.638	5012.072	6546.245
*2628.296	4095.973	5041.759	6592.920
*2679.065	4107.492	5049.825	6677.994
*2714.419	4118.549	5083.343	6703.573
*2739.550	4134.680	5110.414	6733.164
*2778.225	4147.673	5123.723	6750.157
*2813.290	4156.803	5150.843	6752.724
*2851.800	4175.639	5167.491	6806.851
*2874.176	4184.894	5192.353	6828.612
*2912.157	4191.436	5202.339	6841.355
*2941.347	4203.987	5216.277	6843.676
*2987.293	4219.364	5232.948	6855.179
*3030.152	4233.609	5250.650	6885.772
*3075.725	4245.260	5266.564	6916.709
*3125.661	4282.406	5270.361	6933.628
*3175.447	4315.087	5302.309	6945.211
*3225.790	4352.738	5324.187	6951.271
*3271.003	4375.933	5328.534	6978.857
*3323.739	4427.313	5341.026	6988.531
*3370.789	4466.556	5371.493	6999.912
*3399.337	4494.568	5405.779	7022.976
3445.153	4531.152	5434.527	7038.255
3485.343	4547.851	5455.613	7068.418
3513.821	4592.655	5497.520	7090.410
3556.882	4602.945	5506.783	7107.464
3558.518	4647.437	5569.626	7112.178
3606.682	4691.414	5586.763	7130.946
3640.392	4707.282	5615.652	7132.996
3676.314	4710.287	5658.825	7164.472
3677.630	4733.596	*5763.013	7181.222
3724.381	4736.782	6024.065	7187.341
3753.615	4741.533	6027.058	7207.422
3805.346	4772.818	6065.489	7219.690
3843.261	4789.654	6136.620	7223.670
3850.820	4859.749	6137.697	7239.896
3865.527	4878.219	6191.563	7284.843
3906.482	4903.318	6230.729	7288.764
3907.937	4919.001	6265.141	7293.073
3935.816	4924.776	6318.023	7307.938
3940.882	4939.691	6335.338	7311.103

FE-LINES.—(*Continued*)

λ_{Fe}	λ_{Fe}	λ_{Fe}	λ_{Fe}
7320.694	7511.047	7710.397	8198.960
7386.394	7531.178	7748.282	8220.413
7389.423	7546.177	7780.594	8327.069
7401.691	7568.931	7832.233	8331.956
7411.184	7583.801	7937.172	8387.787
7418.676	7586.050	7945.882	8468.422
7443.031	7620.538	7998.980	8514.088
7445.778	7653.783	8028.356	8661.915
7491.678	7661.230	8046.084	8688.641
7495.092	7664.306	8085.207	8824.238
7507.300			

CU-, NI- AND SI-LINES

(*a*) Copper: Arc between rods of Cu 4 mm in diameter, current = 4 to 5 amperes. (*b*) Silicon: Arc between ordinary rods of carbon; light from electrodes is eliminated. (*c*) Nickel: Arc between rods of Ni 5 mm in diameter, current = 6 amperes.

λ_{Cu}	λ_{Cu}	λ_{Cu}	λ_{Si}
*2112.105	*2242.622	*2369.891	*2528.516
*2126.047	*2276.261	λ_{Si}	λ_{Ni}
*2189.631	*2303.134	*2435.159	*5857.759
*2218.107	*2334.816†	*2506.904	*5892.882

* No statement of length of arc or of portion used. † A Sn-line.

NE-LINES

The lines are emitted by a tube containing Ne at a pressure of a few mm of mercury.

λ_{Ne}	λ_{Ne}	λ_{Ne}	λ_{Ne}
5400.562	6096.163	6334.428	6717.043
5852.488	6143.062	6382.991	6929.466
5881.895	6163.594	6506.528	7032.412
5944.834	6217.280	6532.883	7173.938
5975.534	6266.495	6598.953	7245.165
6029.997	6304.789	6678.276	7535.785
6074.338			

Table 2.—Tertiary Standards (11)

All the following tertiary standards are Fe-lines emitted by a Pfund arc under the conditions stated in Table 1. Their wave-lengths have been determined by interpolation from those of the secondary standards, and the published values have been corrected so as to make them accord with the values adopted for the secondary standards. Unit of λ = 1 Int. Å = $10^{-4}\mu$ = 10^{-8} cm.

λ_{Fe}	λ_{Fe}	λ_{Fe}	λ_{Fe}
3370.786	3485.343	3586.116	3659.521
3379.023	3489.674	3589.109	3669.524
3380.115	3495.290	3594.635	3676.314
3392.657	3497.111	3603.207	3677.630
3396.982	3497.844	3606.683	3679.917
3399.337	3506.501	3608.863	3684.113
3401.523	3513.821	3617.792	3687.460
3402.261	3521.265	3618.771	3690.732
3407.465	3529.820	3621.465	3695.055
3413.136	3541.087	3623.189	3702.035
3417.845	3542.080	3625.149	3704.464
3418.511	3545.642	3630.353	3705.569
3424.288	3556.882	3631.467	3707.051
3427.124	3558.518	3632.043	3711.227
3445.153	3565.382	3638.301	3715.916
3447.282	3576.761	3640.393	3719.936
3450.334	3581.196	3645.826	3722.566
3458.307	3582.202	3647.845	3724.381
3465.864	3584.664	3649.510	3727.623
3476.706	3585.322	3651.472	3732.400

Table 2.—(*Continued*)

λ_{Fe}	λ_{Fe}	λ_{Fe}	λ_{Fe}
3733.320	3841.052	3966.066	4154.501
3734.869	3843.261	3967.423	4156.803
3737.135	3846.805	3969.260	4170.904
3738.310	3849.971	3971.325	4175.639
3742.624	3850.821	3977.744	4177.596
3745.564	3852.577	3981.774	4181.758
3745.904	3856.373	3983.960	4184.894
3748.265	3859.914	3986.176	4191.436
3749.489	3865.527	3990.378	4202.030
3753.615	3867.220	3997.395	4203.987
3756.943	3871.752	4005.246	4213.649
3758.237	3872.505	4009.716	4216.185
3760.054	3873.764	4014.534	4219.364
3763.792	3878.022	4021.870	4226.423
3765.544	3878.575	4031.964	4233.609
3767.196	3883.286	4044.614	4245.260
3774.827	3884.362	4045.816	4250.789
3776.459	3886.286	4062.486	4266.968
3781.191	3887.051	4066.979	4267.830
3785.951	3888.518	4067.275	4271.764
3786.681	3895.658	4067.983	4282.406
3787.883	3899.709	4074.789	4285.447
3790.096	3902.950	4076.638	4294.128
3794.342	3903.902	4085.008	4298.041
3795.005	3906.483	4095.973	4305.455
3797.518	3907.937	4098.183	4307.907
3798.514	3910.847	4100.740	4315.087
3799.550	3917.185	4107.492	4325.764
3805.346	3920.260	4109.806	4327.099
3806.702	3922.914	4114.449	4337.050
3807.540	3925.945	4118.549	4346.559
3808.732	3927.921	4120.210	4351.550
3814.527	3930.299	4121.805	4352.738
3815.843	3932.631	4122.519	4358.505
3821.161	3935.816	4127.611	4367.583
3824.445	3937.331	4132.060	4369.776
3825.885	3940.883	4132.902	4375.933
3827.826	3942.443	4134.680	4383.549
3833.313	3948.778	4137.000	4387.898
3834.225	3952.605	4143.418	4390.955
3839.260	3956.459	4143.870	4404.753
3840.440	3956.680	4147.673	4407.715

Table 2.—(*Continued*)

λ_{Fe}	λ_{Fe}	λ_{Fe}	λ_{Fe}
4408.419	4678.453	5166.286	6127.913
4415.126	4691.414	5167.491	6136.622
4422.572	4707.282	5168.901	6137.697
4427.313	4710.287	5171.599	6157.730
4430.620	4733.596	5192.353	6165.364
4435.153	4736.782	5198.712	6173.340
4442.345	4741.533	5202.339	6191.564
4443.197	4745.805	5216.277	6200.319
4447.723	4772.818	5227.189	6219.287
4454.384	4786.809	5232.948	6230.730
4459.122	4788.759	5242.492	6252.563
4461.655	4789.655	5250.650	6254.263
4466.556	4802.881	5266.564	6265.141
4476.022	4859.749	5269.537	6297.799
4489.742	4878.220	5270.361	6318.024
4490.085	4903.318	5302.309	6322.692
4494.568	4919.002	5307.361	6335.338
4514.190	4924.776	5324.187	6344.157
4517.528	4939.691	5328.534	6380.749
4528.619	4966.099	5332.901	6393.607
4531.152	4994.132	5341.026	6421.357
4547.851	5001.872	5371.493	6430.853
4587.134	5012.072	5397.132	6462.733
4592.655	5041.074	5405.779	6475.633
4602.006	5041.759	5429.700	6494.987
4602.945	5049.825	5434.527	6518.376
4619.296	5051.637	5446.920	6546.247
4630.126	5083.343	5455.613	6575.023
4632.915	5098.704	5497.520	6592.920
4638.017	5110.414	5501.469	6609.118
4647.437	5123.723	5506.783	6663.447
4654.502	5127.364	6027.058	6677.994
4667.458	5150.843	6065.489	6750.160
4673.168	5151.914		

LITERATURE

(For a key to the periodicals see end of volume)

(1) Babcock, *538*, **2**: 40; 25. (2) Babcock, *21*, **66**: 256; 27. (3) Benoît, Fabry and Perot, *238*, **15**: 1913. (4) Buisson and Fabry, *51*, **7**: 169; 08. (5) Burns, *48*, **11**: 301; 25. (6) Kayser, *Trans. International Union for Co-operation in Solar Research*, **3**: 30, 139; 11. (7) Meggers and Kiess, *31A*, **19**: 273; 24. (8) Meggers, Kiess and Burns, *31A*, **19**: 263; 24. (9) Michelson, *238*, **11**: 1895. (10) Mitra, *16*, **19**: 315; 23. (11) St. John, *538*, **1**: 35; 22.

EMISSION SPECTRA OF ELEMENTARY SUBSTANCES

H. Kayser

In the following table are given the wave-lengths (λ) of selected lines from the spectra of air, of all known elements except Ac, Ma, Pa, Po, Re, UX_2, and certain doubtful, or unidentified elements. The number of lines given in each case is determined by the spectroscopic importance of the element and by the number of lines which its spectrum contains; the strongest and the most easily reversed lines throughout the spectrum have been given, and the distribution of the lines has been chosen so that the list will satisfy the practical requirements of such a table and will exhibit all the characteristics of the spectrum. In the spark-spectrum of air all the observed lines are given, although many of them are false, being metallic lines. For each element, are given the more important literature references from which the data were taken; for a more complete list of references, *see* Kayser, *Handbuch der Spektroscopie*, Vols. 5 to 7, or Watts, *Index of Spectra*. It is assumed that the wave-length of a line is the same in the arc as in the spark, that changes in λ arise only from pressure, magnetic and electric fields, pole-effect, and apparent shifts from unsymmetrical broadening. The data given refer to atmospheric pressure, except in those cases in which the observation must be made under reduced pressure. The precision of measurements in the infra-red is so low that the correction from the Rowland to the international scale is unimportant; in all other cases λ is expressed in international ångstroms.

The values given for λ are weighted means of the best determinations available, and consequently are to some extent arbitrary. The relative intensities of the lines depend upon so many conditions, frequently undefined or even undefinable, that an average is meaningless. But the intensity of a line is an important characteristic of it, and in very many cases the relative intensities vary from one type of spectrum—arc, spark, Geissler tube—to another much more than they vary with the conditions in any one type; for this reason a kind of average, or typical value of the relative intensity is given.

Spectra obtained by means of the arc, spark, or Geissler tube are generally mixtures of different spectra. Some of the lines belong to the neutral atom (denoted by A or AI), some to the simply ionized atom (A^+ or AII), some to the doubly ionized atom—the atom which has lost two electrons—(A^{++} or AIII), etc. It is now possible to determine in many cases the particular type of atom to which a given line belongs. In such cases, the type is indicated in the following table by placing before the wave-length the proper symbol (I, II, III . . .).

WAVE-LENGTHS (λ) OF SELECTED LINES IN EMISSION SPECTRA OF AIR AND OF ELEMENTARY SUBSTANCES

There are no data for Ac, Ma, Pa, Po, Re, and UX_2. For basis of selection of lines given, etc., *see* preceding text. Uncertainty in λ is not over 3 units in the last figure. Numbers in the columns A, S, and G indicate the relative intensities of the lines in the arc, spark and Geissler-tube spectrum, respectively; in each case 1 generally denotes the weakest and 10 the strongest line, but very weak lines may be marked 0, and very strong ones 15, 20, 25, or 30. I, II, III . . . indicate that the line is emitted by the neutral, the simply ionized, the doubly ionized . . . atom; R = easily reversed, u = unsharp, broad; U = very unsharp, very broad; r [v] = unsymmetrically broadened, the excess broadening is on the red [violet] side, *i.e.*, towards the longer [shorter] wave-lengths; the number of components of an unresolved multiple line is indicated by the letters d, tr, qr, qn, s; where **d** = 2, tr = 3, qr = 4, qn = 5, s = 6.

Unit of λ = 1 Å = 0.1 mμ = $10^{-4}\mu$ = 10^{-8} cm.

Air (**3, 74, 75, 91, 101, 102, 128, 186, 198, 199, 255, 259, 274**)

λ	S	E*
8 719.2	0	N
12.0	0	N
03.8	0	N
8 692	0	
86.4	0	N
83.7	1	N
80.6	2	N
30.0	0	
8 594	0	
8 446.8	5	O
8 242.8	4	N
30.2	0	O
23.5	4	N
16.7	7	N
11.1	2	N
00.7	1	N
8 188.4	4	N
85.3	4	N
7 952.3	2	O
51.1	3	O
47.8	4	O
7 775.6	6	O
74.3	7	O
72.1	10	O
7 635.7	1	A
7 515.2	0	A
05.8	0	A
7 479	0	O
68.7	10	N
58.7	0	
7 442.7	10	N
32.9	0	
24.0	8	N
7 384.5	1	A
7 157.4	9	O(?)
7 067.6	0	A
6 965.9	1	A
50	0U	
6 887.6	1	
64	0	
11.9	0	
6 721.3	1	
6 654.8	2	
40.7	0	
10.4	6	N
6 563.2	3	H
6 482.0	5	N
56	0	O
6 379.3	2	N
70.7	0	
58.1	0	N
41.5	0	N
6 284.3	1	N
6 171.0	2	O
58.1	0	O
5 952.4	4	N
41.6	10	N
40.5	1	N
31.8	7	N
27.8	4	N
5 767.4	2	N
5 747.5	1	N
30.6	2	N
10.7	2	N
5 686.2	3	N
79.5	10	N
75.9	3	N
66.6	5	N
45.6	1	N
5 592.3	0	O
66	0	N
52.0	2	N
43.4	3	N
35.2	5	N
30.2	3	N
26.2	2	N
5 495.7	2	N
80.1	1	N
78.1	0	N
62.8	1	N
54.1	1	N
52.1	1	N
32.1	0	N(?)
11.5	1	N
5 356.4	0	N
51.2	0	N
41.2	1	N
38.7	1	N
28.6	0	N
25.1	0	O
20.5	1	N
5 281.7	0	N
63	0	
50.6	1	N(?)
06.5	1	O
5 190.6	1	N
85.1	0	N
83.2	0	O
79.4	1	N
75.9	2	N
73.4	1	N
72	1	N
60.1	0	O
50	0	
43.6	0	O
36	0	
5 073.5	0	N
61.8	0	N
45.1	2	N
32	0	
25.7	2	N
22.9	1	N
16.4	2	N
13.9	0	
10.6	2	N
07.4	3	N
05.2	6	N
01.4	6	N
4 994.4	3	N
91.3	1	N
87.4	1	N
64.7	0	N
55	1	O
43.0	1	O
4 942.5	1	N
41.0	1	N
34.8	1	N
24.6	2	O
06.8	1	O
4 895.3	1	N
90.9	0	O
79.7	1	N
71.6	0	O
60.3	1	N
56.8	1	O
47.7	1	N(?)
10.3	2	N
05.9	1	N
03.3	5	N
4 793.7	2	N
88.2	4	N
81.2	0	N(?)
79.8	2	N
74.2	1	N
64.6	1	N
51.2	1	O
35.7	1	N
18.4	2	N
09.9	2	O
05.4	3	O
05.1	1	N
03.1	0	O
4 699.2	3	O
97.6	0	N(?)
76.2	3	O
74.9	1	N
61.6	5	O
54.5	1	N
50.8	2	O
49.1	4	O
43.1	4	N
41.8	3	O
40.5	1	N
38.8	2	O
34.0	1	N
30.53	10	N
21.39	4	N
13.84	3	N
09.4	1	N
07.14	4	N
01.48	4	N
4 596.12	3	O
90.93	3	O
52.5	2	N
44.8	1	N
29.9	2	N
14.8	2	N
07.62	2	N
4 477.7	1	N
69.4	1	O
67.8	2	O
65.4	2	O
60.1	1	N
52.4	2	O
47.04	6	N
43.3	1	O
34.0	0	N

* Symbol of elementary substance to which the line is due.

Air.—(*Continued*)

λ	S	E*
4 432.4	2	N
30.1	1	N
25.9	1	N
17.0	5	O
14.9	6	O
01.2	1	N
4 396.0	1	O
92.4	0	N(?)
79.6	1	N
71.4	1	N
69.2	1	O
66.87	3	O
61.6	0	N
51.3	2	O
49.40	4	O
48.0	2	N
47.44	2	O
45.54	3	O
36.8	2	O
31.9	1	O
31.04	1	N
28.5	1	O
27.5	1	O
25.7	1	O
19.62	3	O
17.11	3	O
03.7	1	O
4 275.9	1	N
66.4	2	N
53.7	2	O
41.75	2	N
36.8	3	N
28	2	N
23.3	1	N
11.1	1	N
06.7	2	N
4 199.3	0	N
89.8	6	O
85.5	4	O
76.2	2	N
69.36	1	O
53.5	3	O
45.90	3	N
43.7	1	O
42.2	1	O
33.70	2	N
32.88	2	O
29.5	1	O
24.1	2	O
21.5	2	O
20.5	2	O
19.3	4	O
14.0	0	O
12.09	1	O
10.84	2	O
05.00	3	O
03.3	2	N
4 097.2	3	N
93.00	2	O
89.1	1	O
85.20	2	O
78.9	2	O
75.93	8	O
72.25	8	O

Air.—(*Continued*)

λ	S	E*
4 069.90	8	O
63.2	1	N
57.8	1	N
41.3	3	N
34.9	2	N
25.7	1	N
14.0	1	O
3 995.1	10	N
82.76	2	O
73.30	4	O
68.4	1	A(?)
55.9	4	N
54.4	1	O
47.45	1	O
45.1	1	O
40.2	1	N
33.6	0	?
19.10	6	N
12.1	3	O
09.1	1	N
07.6	1	O
3 893.3	1	N
82.3	2	O
64.6	1	O
56.7	1	N
51.2	1	O
50.6	1	N
48.04	1	O
45.1	0	N
42.8	1	N
39.1	2	N
30.7	1	N
04.0	1	O
3 770.9	1	N
59.8	1	O
54.5	1	O
49.51	5	O
29.3	1	N
27.34	4	O
12.7	2	O
09.2	1	O
07.3	1	O
02.9	1	
3 639.6	3	
09.8	1	
3 594.6	1	
89.0	1	
77.2	1	
70.3	1	
60.6	1	
14.8	1	
3 491.9	2	
71.2	2	
50.9	1	
37.32	3	N
08.3	2	O
3 390.3	2	O
77.2	2	O
74.0	2	N
70.9	1	N
67.3	1	N
65.8	1	N
54.08	1	O
44.8	1	

Air.—(*Continued*)

λ	S	E*
3 331.8	2	N
29.5	2	N
25	1	O
20.7	2	O
18.8	1	
12.5	1	O
01.9	1	
3 288.9	1	
65.2	1	O
3 158.7	1	
39.3	2	O
35.3	1	O
30.1	1	
3 059.15	2	
47.0	1	
07	1	O
2 927.5	1	
2 858.3	1	
2 795.5	1	
55.9	2	
49	1	
46.7	1	
39.8	1	
2 599.5	2	
14.5	1	
07.2	2	
2 445.5	1	O
33.6	1	O
06.9	1	
04.9	2	
2 399.4	1	
95.62	1	
82.1	2	
18.5	1	O
2 287.9	1	N

A (83, 129, 162, 175, 181, 184, 202, 237)

λ	Rd†	Bl†
13 719	4	
13 505	4	
12 500	30	
I 11 590	8	
I 10 640	12	
I 9 658.9	7	
I 9 225.9	5	
I 9 123.7	10	
I 8 521.442	5	
I 8 424.648	10	
I 08.213	6	
05	6	
I 8 264.523	5	
I 8 115.308	10	
I 03.692	3	
I 8 014.785	3	
I 06.157	8	
I 7 948.176	5	
I 7 724.210		
I 23.759	5	
I 7 635.106	6	
I 7 514.650	4	

A.—(*Continued*)

λ	Rd†	Bl†
I 7 503.868	4	
7 435.5	1	
I 7 383.979	5	
72.119	1	
53.316	1	
15.9	1	
11.6	1	
I 7 272.935	3	
06.986	1	
I 7 147.042	1	
I 7 067.217	5	
30.250	2	
I 6 965.430	6	
37.666	2	
6 888.8	1	
71.290	4	
6 786.3	1	
56.4	1	
52.831	5	
19.2	2	
6 698.9	3	
84.4	1	
I 77.282	5	
64.1	3	
60.7	3	
40.2		0
04.9	3	
6 513.7	1	
6 493.9	2	
81.0	2	
66.5	3	
31.6	3	
16.307	6	
6 384.5	4	
69.6	3	
64.8	3	
07.6	3	
6 296.8	3	
78.6	2	
48.5	3	
43.4		2
15.9	4	
12.4	4	
6 172.9	4	
72.2		4
70.1	3	
65.1	3	
55.1	3	
45.4	4	
27.4	3	
21.7	2	
19.5	2	
14.8		3
13.4	2	
05.8	4	
04.5	2	
01.1	2	
6 098.7	4	
90.8	3	
67.7	1	
64.7	3	
59.4	5	

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† Rd [Bl] = intensity of the line in the red [blue] spectrum.

A.—(*Continued*)

λ	Rd†	Bl†
6 052.6	4	
43.2	6	
32.127	6	
25.4	3	
13.6	3	
05.8	2	
5 999.2	2	
87.3	3	
71.7	3	
68.4	2	
64.5	2	
49.3	3	
43.0	3	
40.9	2	
28.5	4	
27.1	2	
16.6	2	
12.1	5	
00.5	1	
5 888.7	4	
82.7	3	
60.4	3	
32.1	1	
02.2	1	
5 772.3	2	
39.7	3	
5 691.7	1	
82.4	2	
59.2	3	
50.8	5	
48.8	2	
18.1	2	
07.0	6	
5 597.7	2	
81.6	2	
72.6	4	
59.7	2	
58.8	5	
25.1	2	
06.4	2	
5 495.9	6	
73.6	2	
67.2	2	
57.8	2	
51.7	5	
43.3	2	
42.1	1	
40.1	2	
21.6	4	
10.6	2	
5 373.6	2	
05.8		6
5 287.0		3
54.4	2	
52.9	3	
21.6	3	
17.0		2
5 188.3	3	
87.3	3	
77.6	1	
76.4		3
65.8		4
62.4	4	

A.—(*Continued*)

λ	Rd†	Bl†
5 152.5	3	
45.40		4
42.0		4
5 063.0	1	
62.1		6
60.2	3	
54.3	1	
49	2	
24.3		1
17.2		5
09.3		6
4 972.2		3
65.1		4
55.1		2
42.9		2
33.2		4
04.8		2
4 894.8	1	
88.7		2
88.1	1	
82.3		2
79.9		6
67.5		4
65.9		4
47.77		6
05.99		8
4 768.4	1	
64.85		4
35.87		5
26.83		4
02.317	4	
4 657.88		4
37.17		3
I 28.445	5	
09.56		6
4 596.096	5	
89.89		6
79.35		6
47.7		2
45.06		6
I 22.325	4	
I 10.733	8	
02.95		3
01.5	1	
4 498.5		2
91.0		2
88.2		2
81.83		5
33.90		2
31.00		4
30.18		4
25.99		8
01.00		5
00.09		4
4 379.64		6
71.31		5
70.75		5
I 63.78	3	
62.04		3
52.21		4
48.0		10
I 45.168	7	
I 35.29	6	

A.—(*Continued*)

λ	Rd†	Bl†
I 4 333.561	7	
32.04		3
31.17		7
09.15		2
00.66		2
I 00.101	8	
4 282.88		4
77.5		8
I 72.169	8	
66.4		6
66.286	8	6
59.362	9	
I 51.184	5	
37.21		4
28.2		7
26.98		3
22.64		4
18.66		3
03.4		2
01.9	2	
I 00.678	9	
I 4 198.316	8	
I 91.027	8	
I 90.714	5	
I 81.884	7	
79.30		3
78.38		3
I 64.180	7	
I 58.591	9	
56.14		4
52.7	3	
31.78		6
28.6		3
12.82		3
03.95		9
4 099.45		2
82.41		4
80.61		2
79.61		4
77.03		2
76.70		6
72.43		4
72.02		7
I 54.50	3	
52.96		4
45.88	4	
I 44.419	8	
42.89		6
38.83		4
35.45		3
33.85		3
I 32.96	2	
13.84		7
3 992.03		4
79.40		5
74.52		4
68.37		4
60.45		3
58.40		3
I 48.980	7	
I 47.55	4	
46.10		4
44.30		5

A.—(*Continued*)

λ	Rd†	Bl†
3 932.56		5
31.20		3
28.61		8
25.76		4
14.78		5
11.56		3
07.70		3
I 3 899.90	2	
I 94.64	3	
91.99		6
91.39		4
80.29		3
75.25		5
72.14		4
68.55		7
I 66.14	1	
50.56		9
45.37		3
I 34.65	5	
30.43		3
26.80		4
09.46		4
08.58		2
03.23		3
3 799.47		3
95.38		5
86.42		4
I 81.33	3	
80.89		7
I 75.4	1	
70.61		3
70.4	3	
66.14		3
65.32		6
63.59		4
53.5		3
37.92		5
29.33		9
24.53		3
20.46		3
18.25		5
17.21		3
I 3 696.5	1	
I 90.9	1	
80.1	4	
78.31	5	
70.7	3	
60.52		3
59.5	2	
56.12		2
55.35		4
50.9		3
I 49.9	3	
I 43.1	2	
39.86		4
37.86		4
37.08		3
I 34.46	4	
I 32.65	4	
22.18		4
I 06.53	5	
I 3 599.3	1	
88.49		9

A.—(*Continued*)

λ	Rd†	Bl†
3 582.39		6
81.66		5
76.65		8
I 72.27	2	
I 67.68	4	
65.06		3
I 64.41		2
I 64.3	2	
I 63.2	3	
61.06		6
I 59.54		7
56.0	2	
55.31	2	
I 54.31	4	
48.53		3
45.86		7
45.64		7
35.37		5
21.97		2
21.29		3
20.02		4
14.40		6
11.16		5
09.80		4
09.36		2
03.59		2
3 499.68		3
91.57		8
91.29		5
80.51		5
78.26		4
76.79		7
66.3		3
64.20		4
I 61.06	3	
54.15		3
30.48		2
29.69		2
21.67		3
I 3 393.8	3	
92.8	2	
91.77		5
88.54		5
76.47		4
73.5	2	
70.93		2
66.61		2
58.51		4
50.97		4
44.73		4
36.15		4
25.49	2	
I 19.30	2	
11.19		5
07.23		4
01.81		6
3 295.3	2	
93.65		4
85.77		7
81.71		5
63.58		3
49.83		3
43.72		3
12.62		2

A.—(*Continued*)

λ	Rd†	Bl†
3 204.35		3
3 181.09		4
69.71		5
61.44		5
39.06		5
3 093.40		6
34.6	3	
33.6		3
29.0		4
21.8	3	
2 979.1		6
68.3	2	
67.2	5	
55.4		5
43.0		7
31.5		2
24.7		3
2 896.8		2
91.7		4
84.1		4
78.8		3
73.4	3	
65.9		4
55.2		3
42.6		2
33.5	3	
06.2		6
02.1	3	
2 796.7		2
69.6		6
62.0		3
53.8		8
44.8		8
32.6		6
08.3		8
2 647.5		8
14.5	4	
2 562.2		6
44.7		6
16.7		8
16.2	4	
15.5		8
12.2		3
00.3		4
2 499.4		4
90.9		6
80.8		5
79.1		6
52.9		1
38.7		6
15.6		6
04.3		4
2 395.6		4
64.1		4
50.5		4
44.3		5
37.7		5
31.6		4
16.4		4
13.9		4
09.3		4
2 281.5		5
52.3		4
43.6		4

A.—(*Continued*)

λ	Rd†	l† B
2 234.6		4
19.8		4
2 050.4		1
1 886.1		7
79.7		8
77.7		8
73.2		10
68.7		8
65.9		8
55.7		9
43.1		9
36.3		9
31.4		9
30.6		10
20.0		7
1 788.1		5
1 675.6		7
73.5		7
69.7		7
00.7		5
1 589.5		4
1 460.1		5
1 335.8		7
34.5		7
33.7		5

Aldebaranium, *see* **Yb**

Ag (24, 59, 75, 90, 91, 101, 111, 123, 128, 181, 205, 214, 223, 274, 276)

λ	A	S
39 951	8	
889	5	
I 18 382	1	
I 307	1	
I 17 415	1	
I 16 819	3	
I 12 551	1	
I 8 273.58	10	
I 7 687.85	10	
6 037		2
5 970		1
5 666.4	4u	2u
5 590		1u
70		1U
58		1U
45.65	4r	
29.9	2	
23.7	3	
5 494		1U
89		3U
I 71.51	6	5
I 65.43	10	6
03		1U
01		1U
5 333.3	2r	
29.7	4r	
5 276.4	1r	
I 09.04	10R	8
4 888.3	2u	
74.16	2r	1
48.1	2U	

Ag.—(*Continued*)

λ	A	S
4 677.9	2u	1
I 68.54	8r	3
15.9	3U	1
4 556	3U	1
I 4 476.06	6	4
47.0		1
4 396	2u	1
85		1
79.24	2u	
11.05	2r	2
I 4 212.01	8R	4R
4 085.9		3
I 55.25	8R	3
3 985		2
I 81.63	4r	1
49.4	1	2
I 3 840.79	2	1
10.7	2u	1
3 710	1	
I 3 682.3	2u	1
24.2	1u	
16		1
3 542.5	3	2
20	1	
07	1	
05.1		1
01.8	3	1
3 475.8		2
69.2	1	1
56	1	
13	1	
09	1	
I 3 382.88	10R	9R
64		1
52		1
49	1	
31.8		2
12.6		1
05.7	2	
01.5		2
3 299.4		2
89.2		2
80.67	10R	9R
67.33		1
52.8		1
49.8		1
44.97		3
41.3		1
33	3u	1
23		2
16.7		1
15.6	2	1
07.3		1
00.0		1
3 191.8		1
87.8		1
85.1		1
80.7		2
73.6		1
72.3		1
70.6	2	1
53.1		2
30.0	3	1
17.8		1

Ag.—(*Continued*)

	λ	A	S
	3 115		1
	3 099.11	2	1
	12.9		1
	2 983.52		1
	38.5	4	4
	34.2		6
	29.3		5
	20.0		3
I	02.08		4
	2 896.46		4
	73.59	2	4
	24.40	6	1
	15.6		4
	2 799.64		6
	86.5		3
	67.5		8
	56.4		6
	43.9		3
	21.79	3	2
	12.1		4
	2 688.4		3
	81.4		4
	60.4	3	5
	56.8		6
	28.6		2
	14.5		6
	06.14		6
	2 595.6		3
	80.7		6
	75.5	4U	1u
	67.15		2
	64.42		3
	53.41		2
	35.3		5
	06.65	2	5
	04.07		4
	2 486.7		2
	85.78		2
	80.42		4
	77.30		6
	73.88		7
	72.94		2
	62.27		4
	60.32		5
	53.37		6
	47.91	2	7
	44.20		4
	37.77	3	8
	29.65		7
	20.12		5
	13.22	4	8
	11.38		7
	02.57		3
	2 395.66		2
	92.97		2
	90.57		3
	86.8		2
	86.32		3
	83.20		2
	75.0	4U	3
	63.99		4
	62.19		3
	58.85		5

Ag.—(*Continued*)

λ	A	S
2 357.92		6
31.35	4	6
25.1		4
24.63	2	6
21.52		3
20.24	2	6
17.03	2	5
12.4	4U	2
09.54	6R	4
2 279.97	1	5
77.38		2
75.24		2
53.46		2
48.73	3	3
46.38	3	3
40.42		2
38.36		2
29.51	2	4
26.12		2
19.70		2
11.18		2
08.4	1	1
05.9	1	2
02.1	2	2
2 192	1	1
86.76	2	3
71.7		1
70.9		1
66.5	2	2
62.0		2
45.6	1	3
25.4		1
20.4	1	2
13.8	2	3
2 070.0		1
65.9		4
61		1
33.8		4
00.6		3
1 999.5		2
56.9		3
32.3		2
16.3		4
1 889		4
80		4
73		4
60		4
39		3
16		3
02		4
1 794		4
72		4
69		4
51		6
22		3
1 693		6
74		2
56.8		5
1 566		6
39		4
1 496		4
86		4
45		5

Al (**13, 32, 34, 59, 60, 62, 74, 75, 78, 90, 91, 106, 111, 163, 205, 210, 276**)

	λ	A	S
I	39 108		
I	21 166		
I	21 098		
I	16 752		
I	20		
I	13 151		
I	25		
I	11 255		
I	8 774.5	5r	
I	7 836.9	6r	
	7 466		
	7 362.5	2r	
I	6 698.73	3	
I	96.07	3	
II	6 243.347		10
II	31.759		7
	6 176	1u	
	51.7	1u	
II	5 861.53		7
III	5 722.65		6
III	5 696.45		5
II	5 593.23		10
I	57.95	2	
I	57.05	2	
III	5 163.90		7
III	50.86		5
I	05	d	
III	4 701.65		6
II	4 663.054		10
II	4 585.820		6
III	29.176		6
III	12.534		5u
III	4 479.968		5u
II	4 226.812		6
I	3 961.537	10R	8R
I	44.025	10R	8R
II	00.68		2
III	3 713.10		3u
III	02.09		2u
II	3 655.00		8d
III	12.35		7u
III	01.62		7u
II	3 587.06		10u tr
II	3 443.65		6
I	3 092.85	6R	4R
I	92.718	10R	8R
I	82.162	10R	8R
	66.16	4	2
	64.31	4	2
	59.93	2	1
II	57.15	4	10
	54.70	4	2
II	50.08	4	8
III	2 907.5		10
II	2 816.3		10u
III	2 762.81		9
II	2 669.17		10
I	60.394	10R	5R
I	52.484	10R	4R
II	31.73		7u
I	2 575.44	3R	2

Al.—(*Continued*)

	λ	A	S
I	2 575.112	10R	6R
II	67.996	10R	6R
II	45.60		6
I	2 378.43	3	1
I	73.36	2R	2R
I	73.13	8R	4R
I	72.06	3	3
II	69.30	1	4
I	67.06	8R	4R
II	21.56	2	6
I	12.4		1
I	2 269.21	2R	
I	69.09	4R	2R
I	63.73	2	
I	63.45	4R	2R
I	58.0	2	
I	10.05	2R	
I	04.63	2R	
I	2 199.57	1	
I	74.02	1R	1
I	68.00	1R	1
II	2 094.8		5
II	16.1		1
II	1 989.8		8
III	35.2		7
II	30.3		2
III	1 862.90		10
II	62.48		10
II	58.15		7
III	54.67		10
	18.3		2
	1 792		3
	77		4
II	67.6		9
II	65.7		7
II	63.9		10d
II	61.9		7
II	60.1		7
	52		3
II	50		2
II	25		10
II	21		9
II	19		9
II	1 671		10
III	12		8
III	06		8
III	1 384		5
	19?		6
	10?		6
II	1 211.93		1
II	1 191.83		2
II	1 190.07		2
III	856.80		3
III	854.98		3
III	696.23		2
III	695.82		3

As (**13, 23, 59, 90, 91, 118, 138, 154, 280**)

λ	A	S	G
6 170		6	
10		6	

As.—(*Continued*)

λ	A	S	G
6 023		6	
5 837.9			6
5 731.8		1	6
5 684.8		1	7
57.0		1	8
51.3		10	10
20.6		1	10
5 558.1		10	8
5 497.8		10	7
96.9		5	6
5 331.3		8	7
5 205.3		1	6
5 182.2			7
61.1		7	7
07.6		8	8
05.5		8	8
4 985.4		5	9
15.3			7
4 888.6		2	8
11.8		1	6
02.1		1	6
4 799.5		1	6
87.1		1	6
30.7			8
07.6			7
4 672.5			7
29.9			7
19.4			7
07.3		2	5
02.5			7
4 590.8			7
52.2		2	7
49.0		2	9
43.6			7
39.8		3	8
28.4			7
15.9			7
4 494.4		3	7
74.4		4	8
66.4		1	7
61.1			8
58.6		2	7
31.6		4	8
27.2			7
20.9			7
13.5			7
12.0			7
4 371		5	7
52.9			8
52.1		5	7
36.7		5	7
24.0			7
15.7		1	7
02.1			8
4 299.4		3	6
43.1			7
28.2		2	7
21.0			7
07.8		2	7
4 197.5		3	7
90.2		2	7
57.5			7
4 082.4			7

As.—(*Continued*)

λ	A	S	G
4 065.4		2	7
62.6			7
37.0		6	6
06.2		3	6
3 948.6		3	6
31.1		2	7
22.5		10	7
3 842.9		4	7
3 787.2		3	6
3 671.7			6
3 551.6			5
13.0			6
3 255		2	6
3 180.6			6
26.9			6
I 19.6	4	7	5
16.5		3	7
I 3 075.32	2	5	5
I 32.84	4	8	6
03.8		2	6
I 2 990.99	2	4	5
59.6		7	6
26.2		1	6
I 2 898.73	4R	6	6
I 60.46	4R	8	7
30.4		4	8
I 2 780.23	8R	10	8
I 45.00	6R	5	7
2 602.9		2	6
2 492.91	2	5	4
56.52	4R	7	5
37.22	1	5	3
I 2 381.20	4R	5	5
70.77	4R	5	4
69.67	4R	5	4
I 49.84	10R	6	4
I 2 288.14	10R	3	
71.39	4	1	
28.7	2	1	
06.0	2		
05.2	2		
2 192.1		2	
83.0	1	1	
65.5	4	2	
44.2	4	1	
34	2	2	
13	2	3	
2 074		12	
31		10	
1 972		4R	
36		5	
1 890		4R	
1 742.9		20	
33.0		15	
00.2		10	
1 287		10	
67		40	
08		30	
1 171		15	
06		10	
1 093		20	
81		50	
09		10	

As.—(*Continued*)

λ	A	S	G
1 001		10	
984		10	
63		10	
56		8	
52		8	
26		8	
878		8	
73		8	
27		5	
529		1	

Au (18, 24, 59, 60, 62, 75, 90, 91, 111, 136, 154, 222)

λ	A	S
I 7 510.7	5	
I 6 278.2	4	3
I 5 957.0	2	3
I 5 863.0	2	3
I 37.41	4	6
5 759.9		3
I 5 655.8	2	2
5 230.30	2	3
I 5 064.61	2	2
I 4 811.61	3	2
I 4 792.62	8	6
I 4 607.4	4	2
I 4 488.25	4	4
I 37.29	4	3
I 4 315.1	1	3
I 4 241.82	1	3
I 4 084.14	1	2
I 65.08	6	8
52.8		5
I 40.95	2	2
16.1		4
I 3 909.39	2	2
I 3 897.89	4	8
74.7		2
53.6	1	2
25.7		3
04.0		5
3 706.8		4
3 649.1		3
33.25		3
14.0		2
3 586.7		5
53.55	2	4
I 3 320.16	3	2
I 08.31	2	2
3 230.61	3	3
I 04.74	4	3
I 3 194.71	4	2
I 22.79	6R	8
22.5		5
17.0	4	1
3 033.4	2U	2U
I 29.21	6v	5
2 995.0		5
90.3		5
73.25	2U	
70.41	2	

Au.—(*Continued*)

λ	A	S
2 963.77	2	1
54.4		4
32.19	5	4
13.5	4	10
07.1		4
05.90	6	3
I 2 891.95	4	2
I 83.45	4	3
38.0		3
25.4		4
22.7		3
19.98		8
02.21		10
2 780.83		3
I 48.26	6R	4
I 00.88	4	3
I 2 688.70	4	3
88.2		3
87.6		3
I 75.95	10R	10
I 41.50	4	4
I 2 590.07	4	2
I 44.2	4	2
I 10.51	4	2
03.3		5
I 2 427.98	10R	10R
I 2 387.77	4	3
I 76.25	3	2
I 64.58	4	2
I 52.67	4	3
40.22		3
14.67		3
04.80		4
2 291.51		3
83.3		3
42.7		3
29.0		3
01.3		3
2 110.7		2
2 082.0		3
00.6		3
1 977.3		3
I 51.2		3
21.0		4
I 18.9		4
03.9		2
1 889.8		2
86.3		4
I 79.1		3
71.1		3
61.1		3
50.1		2
45.7		3
22.4		4
02		5
1 795		5
84		5
67		3
40		4
27		3
26		4
20		3
1 699		3

Au.—(*Continued*)

λ	A	S
1 694		6
73		6
59		3
39		3
29		3
22		4
00		3
1 590		3
62		3
34		3
00		4d
1 488		4d
35		4
02		2
975		20
864		5
854		4
832		5
458		1

B (28, 33, 36, 48, 80, 90, 91, 124, 191)

λ	A	S
II 3 451.2		10
I 2 497.733	10R	10R
I 96.778	9R	9R
2 266.9		2
66.3		2
I 2 089.6		2
I 88.8		1
III 67.9		2
III 66.4		
I 1 826.41		1
I 25.87		
II 1 624.4		8qn
III 758.68		3
III 758.47		
III 677.16		5
III 677.01		

Ba (59, 60, 62, 74, 75, 78, 90, 91, 135, 148, 163, 174, 224, 252, 258)

λ	A	S
I 30 934	3	
I 687	2	
469	2	
29 791	4	
I 224	5	
27 751	3	
26 221	2	
I 25 516	5	
23 255	3	
22 313	2	
221	2	
I 21 477	2	
I 20 712	4	
19 988	3	
075	2	
18 204	2	
17 182	1	
065	1	
I 15 000	4	
14 325	3	
211	3	
160	3	
078	4	
13 957	2	
811	4	
I 207	4	
057	1	
12 815	1	
554	3	
II 084	5	
11 978	2	
886	5	
608	2	
I 304	2	
116	2	
016	4	
10 692	2	
II 651	8	
474	6	
I 326		
I 273	5	
234	6	
I 189	1	
II 034	6	
002	3	
I 9 832	7	
713	2	
611	10	
527	10	
370.1	3	
219.7	2	
189.4	2	
8 915.00	4	
860.96	4	
I 799.7	2u	
654.03	4	
582.1	4	
567.6	3	
559.91	10	
210.32	10	
147.8	2	
120.5	3	
I 7 911.35	6	
I 905.772	7	
839.577	5	
780.500	8	
672.099	7	
642.9	5	
488.095	5	
459.7	5	
417.55	4	
I 392.44	6	
280.314	8R	
228.815	5	
I 195.262	6	
II 120.30	6	
I 059.96	8R	
6 865.69	5	
I 693.86	6R	2
I 675.29	6R	2
I 595.35	7R	3
I 527.323	8R	3
I 6 498.77	8R	4
II 496.91	10R	10R
482.93	7R	3
I 450.85	7	3
I 341.70	7R	3
II 141.74	10R	10R
I 110.80	8R	5
I 063.16	8R	4
I 019.49	7R	3
I 5 997.102	7R	3
I 71.714	10	3
I 07.6	6	2
II 5 853.7	8R	5
I 26.30	7R	4
05.71	5R	2
00.34	7	2
I 5 777.7	10R	5
5 680.17	5	1
I 5 535.53	10R	6
I 19.11	8R	5
I 5 424.63	7r	3
II 4 934.10	10R	10R
I 02.88	4r	
II 4 899.96	8	10
I 4 726.46	8r	5
I 00.45	6r	1
4 691.63	7R	4
I 73.61	7v	2
I 28.83	5v	1
I 19.98	5r	1
4 599.75	6R	2
79.66	8R	8
73.88	6R	4
II 54.037	10R	10R
II 24.95	8	10r
23.25	8r	3
05.94	8	5
I 4 493.64	5v	2
I 88.97	7v	2
31.91	7	6
02.55	8	6
4 350.38	8	5
I 32.91	4v	1
I 23.00	4v	1
I 4 283.12	8	8
II 4 166.04	5r	10r
32.44	5	3
II 30.68	8R	10R
I 3 993.40	8R	6
I 37.88	5	3
I 35.72	7r	6r
I 09.92	6r	6r
3 892.65	5	
II 91.78	8r	8R
89.32	5	2
3 630.65	8r	2
I 3 579.7	6r	2
I 47.7	4u	
I 44.7	6r	
I 25.0	6r	
I 01.12	8R	2
I 3 421.5	10	
I 21.0		
I 20.3		
I 3 377.4	8	
I 77.0		
I 56.9	6r	
I 3 262.4	3R	
I 3 071.60	8R	6R
I 2 785.26	6r	
II 71.4	2	3r
I 02.65	6r	2
II 2 647.29	4	4
II 34.80	5	8r
I 2 596.68	6r	
II 28.51		6r
II 2 347.58	5	7
II 35.25	6R	10R
II 04.22	6R	8R
II 1 869		5
II 1 694		6
74		4
1 554		3
04		4
1 415		3
1 331		2

Be (35, 90, 91, 230, 273)

λ	A	S
23 110	6	
097		
22 239	2	
21 897	2d	
560	3	
17 571	2	
16 794	2	
15 951		
400	6	
393		
013	3	
006		
14 904	3	
13 227	6	
12 355	6	
329	4	
141	7	
10 674	4	
283	5	
II 5 274.28		4
II 4 674.55		8
4 572.69	8	1
II 4 362.21		7
I 3 322.303	8	2
I 22.042	8	2
I 21.969	8	2
II 3 275.57		5
II 3 198.01		4
II 31.972	9	5
II 31.324	9	10
II 3 047.86		4
I 2 651	10	10s
I 2 494.720	7	3
I 94.575	7	3
I 94.532	7	3
I 2 351.50	6	

Be.—(*Continued*)

λ	A	S
2 348.62	8R	3
I 2 175.72	10	
I 2 056.71	4	
II 1 776.339		8
II 76.118		6
II 1 512.451		10
II 12.303		8
II 1 036.32		3

Bi (13, 59, 74, 75, 78, 90, 91, 138, 154, 170, 200, 223, 276)

λ	A	S
25 554	1	
14 332	3	
12 691	3	
167	4	
11 995	1	
711	10	
556	1	
073	1	
10 540	1	
302	2	
106	2	
9 829	2	
9 657.2	10	
9 342.6	4	
9 058.6	2	
8 907.8	2	
8 761.5	3	
I 8 754.9	2	
8 627.9	1	
8 579.7	1	
44.5	2	
01.8	1	
8 210.8	10	
7 840.3	2	
38.7	3	
7 502.3	2	
7 441.3	1	
7 335.0	1	
7 036.2	2	
6 991.1	4	
6 809.1		7
6 600.1		7
6 497.5		4
76.2	3	
75.5	3	
6 134.85	5	1
28.1		4
5 861.14		4
5 742.55	6	
5 599.41	3	
52.24	8	3
5 209.28		10
5 144.50		6
24.4		4
4 797.5		3
33.8	2r	
29.9		3
22.7	8	8
22.5	10	8
22.2	10	5
4 561.15		8

Bi.—(*Continued*)

λ	A	S
4 340.6		4
28.6		3
08.56	4	2
08.20	4	2
02.13		10
4 259.64		10
4 121.85	6	4
21.52	6	4
4 079.22		10
3 888.22	2	1
87.94	2	1
3 792.9		8
3 695.53		8
3 596.11	3R	4
10.85	6R	5
3 405.23	2R	1
3 397.21	5R	2
3 076.67	3	2
67.73	9R	6R
24.64	8R	4R
2 993.34	9R	4
89.04	9R	5R
38.31	10R	8R
2 897.98	10R	5R
09.63	8R	2
2 780.52	7R	4
30.50	5Rd	2R
2 696.76	6Rd	4R
27.93	8 R	4
2 524.52	7R	2
15.68	6R	1
2 489.4	5U	1
30.5	2u	
00.89	8R	7
2 328.2	2u	
09.3	4U	
2 276.57	5R	2
30.62	8R	4R
28.25	6R	2R
14.1	3	1
03.1	4u	1
2 189.59	6R	
77.3	6R	1
64.1	4R	
56.9	4R	
53.5	4R	
52.9	7R	
44.4		2
43.6		2
34.4	8R	1
33.6	7R	
13.8	3	
10.3	8R	2
2 061.7	8R	3
1 973.2		3
59.6		3
02.5		1
1 823.5	3	5
1 791.7	4	4
87.1	3	4
76.7	3	4
1 533.7	5	3
1 346		10
17		15

Bi.—(*Continued*)

λ	A	S
1 306		10
1 051		10
45		10
967		3
791		2
670		1

Br (25, 86, 91, 104, 147, 195, 268)

λ	S	G
6 682		2
31.8		5
6 560.0		4
6 350.8		10
6 149.7		10
23.3		3
18.7		4
5 940.6		4
5 852.2		5
30.8		7
5 719.0		4
11.0		4
5 657.6		4
00.7		4
5 589.9		8
36.3		4
5 490.4		7
88.8		6
66.2		5
35.1		5
25.0		5
22.8		7
5 396.5		5
32.0		10
04.1		7
5 272.7		4
38.3	2	8
5 183.9		4
82.4	3	7
64.4		5
5 054.7		4
4 979.77		4
30.6	1	5
28.7	1	5
4 848.80	1	6
16.72	8	8
4 785.48	10	10
80.33		6
76.43	2	7
67.1	2	8
66.07	2	5
42.70	3	8
35.47		5
19.76	3	8
04.83	10	10
4 693.30	5	3
78.70	8	8
72.58	1	6
52.00	1	6
22.7	3	8
14.6		6

Br.—(*Continued*)

λ	S	G
4 601.4		5
4 575.77		6
42.93	2	8
38.75	1	5
29.80		5
25.6		8
13.47	1	5
4 490.48		5
77.78		10
72.64		8
41.74		8
25.13		5
4 365.58	4	8
4 291.38	2	6
36.85		6
23.85		6
4 193.45	1	6
79.62	1	8
75.76		5
40.22	1	6
35.64		5
4 024.04		5
08.78		6
07.30		5
3 986.53	1	8
80.43		10
80.01		5
68.65		5
55.35		8
50.60	1	7
39.70	2	5
35.16		6
29.57		6
24.09	2	8
23.36		6
20.68		6
19.6		6
14.26	1	10
3 891.64	1	8
71.23		6
57.21		6
34.71		6
3 794.00	3	4
3 693.5	3	
3 562.4	10	
40.1	8	
17.4	5	
06.5	5	
3 417	5	
3 396.9	4	
33.0	5	
3 282.1	3	
3 168	3	
3 074	4	
20.8	4	
2 968	4	
26	5	
2 892	3	
72	3	
2 660	3	
2 594	3	
57	4	
41	4	
22	4	

Br.—(*Continued*)

λ	S	G
2 389.8	3	
86.8	3	
1 633.6		10
1 582.4		8
76.5		6
75.0		9
40.8		6
31.9		7
1 488.6		8
1 384.6		8
1 251.8		4

C (27, 32, 33, 60, 79, 90, 91, 98.1, 154, 166, 167, 190, 193, 262, 262.1, 287)

λ	A	S	G
II 7 236.19			8u
II 31.12			6u
II 6 582.85			8
II 78.03			10
III 4 652.68		7	
III 51.46		2	
III 48.70		3	
II 4 267.27			10u
II 67.02			8u
II 3 920.773			8
II 19.061			6
II 2 992.63			4
II 2 837.602			8
II 36.710			10
II 2 747.31			6u
II 46.50			4u
I 2 478.3	10	10	10
III 2 297.59	2	10	
III 1 930.98	5	7d	
1 657	6	6qr	
I 1 561.3	5	5	5
IV 50.9		3	
1 335.7	10	10	
34.5	10		
29.6	8	4	
29.1	8		
23.7	7	7	
1 176	10	15qn	
II 1 036.8		10	5
II 36.2			5
I 10.1	9	10	
III 977.02		12	
II? 904	4	10qr	
II 858.2	8	8	8
II 687.1	8	7	8
651	2	6d	
II 636.2		2	
II 594.9	4	5	
574.4		6	
II 560.5		2	
II 543.4		2	
III 538.4		7	
II 533.9		1	
III 459.7		6	
372		1	
313		1	

Ca (1, 61, 74, 78, 90, 91, 119, 154, 158, 163, 170, 174, 181, 192, 203, 250)

λ	A	S
I 22 656	4	
I 625	3	
I 610	1	
I 19 947	1	
I 936	3	
I 918	1	
I 865	4	
I 857	4	
817	1	
I 777	6	
I 507	3	
I 453	5	
I 311	4	
16 433	1	
I 200	3	
I 162	2	
I 145	2	
13 038	3	
I 12 822	5d	
I 10 345	10	
9 695	7	
9 547	7	
9 251	3	
II 8 662.1	9	
II 8 542.1	10	
II 8 498.0	8	
7 610	6r	
I 7 326.12	8	
7 202.18	8	
7 148.18	10	
I 6 717.7	8	2
I 6 572.75	2	1
I 6 499.64	5	4
I 93.762	8	5
I 71.68	5	5
I 62.57	6R	6
55.57	3	2
49.82	5	3
I 39.060	10R	8
I 6 169.60	7	3
I 69.08	4	3
I 66.49	4	2
I 63.80	4	2
I 62.20	10R	8R
I 61.32	5	2
I 22.24	10R	10R
I 02.73	8R	8R
5 867.62	4r	
57.49	10	10
5 602.84	8	5
I 01.26	8	4
5 598.46	10	8
I 94.47	8	6
90.10	10	6
88.74	10	10
81.96	8	4
I 12.93	8	2
5 349.46	10	5
I 5 270.27	10	10
65.55	8	8
I 64.23	6	5
62.23	6	5

Ca.—(*Continued*)

λ	A	S
5 261.70	6	5
I 60.39	4	3
I 5 188.84	6	5
41.65	8r	3
I 4 878.17	10r	8r
I 4 685.2	4v	1
I 4 585.91	2	8
I 85.84	6	
I 81.45	8	6
I 78.57	8	5
I 26.98	6	5
4 499.90		10
I 56.62	4	5
I 55.880	8R	8
I 54.780	10R	10R
I 35.682	8R	8
I 34.964	10R	10R
I 25.444	10R	10
I 4 355.2	6u	2
I 18.645	8R	8R
I 07.74	8R	8R
I 02.527	10R	10R
I 4 298.987	6	8R
I 89.362	8R	8R
I 83.003	8R	8R
I 40.44	4	2
I 26.728	10R	10R
I 4 098.6	4r	2r
I 3 973.7	6r	3r
II 68.473	10R	10R
I 57.07	6r	2
I 48.91	4r	1
II 33.673	10R	10R
I 3 875.7	3	
II 3 736.905	6	10R
II 06.03	6	8r
I 3 644.76	5	
I 44.39	10	4
I 30.96	5	1
I 30.73	6	1
I 24.10	6	1
I 3 487.61	6r	1
I 74.78	4r	
I 68.48	4r	
I 3 361.91	6v	1
I 50.19	6v	1
I 44.49	5v	
I 3 286.1	5	
I 25.8	4r	
I 15.1	3v	
II 3 181.3	4	10
II 79.34	6	10R
II 58.87	8	10R
19.66		8
I 3 009.21	2	2
I 06.85	4	4
I 00.87	4	2
I 2 997.31	3	2
I 94.95	3	2
24.33	8	
2 899.78	9	
2 493.00	7	
I 2 398.58	8R	1R
I 2 275.5	1	4R

Ca.—(*Continued*)

λ	A	S
II 2 208.7	3	3
II 2 197.8	3	3
II 12.7	2	3
II 03.2	2	3
2 040	4	
35	4	
II 1 851.3		7
II 43.7		6
II 40.2		10
II 38		9d
II 15.0		8
II 07.8		7
1 667		5
1 562		4
II 55		8d
II 53		7
II 1 434		6
902		10
840		6
832		10
718		6
688		5
669		6
655		6
537		5
410		6
404		6

Cb* (78, 90, 91)

λ	A	S
6 828.14	4	
6 723.66	6	1
6 677.34	8	1
6 544.67	6	1
6 430.50	8	1
5 983.26	7	2
00.62	10d	2
5 866.5	6	3
38.66	8	5
19.47	6	3
5 787.53	6	2
29.2	6	2
5 671.1	7	1
65.57	6	3
64.72	6	2
5 551.38	6	2
5 437.29	7	2
5 350.72	7	3
44.15	10	5
5 276.20	10	3
71.53	9	3
5 180.30	6	2
64.36	7	2
60.33	6	3
34.73	5	2
5 095.29	10	3
78.95	8	3
39.04	6	2
4 989.0	5	2
24.84	3	8

* Columbium = Niobium.

Cb.—(*Continued*)

λ	A	S
4 816.33	7	1
10.57	6	3
4 733.88	5	3
13.48	5	3
08.26	7	4
4 675.38	10	8
72.10	10	9
63.83	9	4
48.94	7	3
30.12	10	10
06.76	10	10
4 581.64	10	5
73.09	10	5
46.83	10	4
23.40	8	3
4 447.22	10	3
37.23	10	8
10.22	10	3
4 377.90	10	4
51.60	10	3
31.42	10	3
26.37	10	3
01.10	10	5
4 299.63	8	4
62.10	8	3
29.15	10	3
17.95	10	3
14.74	10	3
05.32	10	3
4 192.07	10	3
90.91	10	4
68.13	10	5
64.66	10	5
63.64	10	10
52.63	10	5
39.74	10	4
37.13	10	4
29.97	10	3
23.85	10	4
00.97	10	6
4 079.73	10	6
58.97	10	10
32.55	10	3
3 966.23	10	3
37.47	10	3
14.71	10	3
3 818.92	1	8
10.48	10	3
02.98	10	4
3 798.11	10	4
91.24	10	4
90.14	10	3
87.08	10	3
59.57	10	3
42.41	10	3
40.80	10	5
39.82	10	3
26.24	10	3
13.05	10	3
3 697.84	10	3
I 3 580.27	10	3
I 75.85	10	2
I 63.53	10	2
I 3 554.62	10d	2
I 37.50	10	2
I 35.30	10	3
I 10.30	3	8
3 498.62	10	2
3 358.38	10	
41.95	10	4
II 3 236.44	3	10
II 25.47	5	10
II 3 194.95	5	10
II 63.37	5	10
II 30.78	8	10
II 3 094.19	10	10
II 2 950.91	6	10
II 41.57	4	8
II 27.82	8	10
II 2 697.07	3	7
2 584.03	2	6

Cd (13, 16, 59, 74, 75, 81, 90, 91, 132, 154, 176, 204, 205, 206, 207, 247, 251, 273, 276, 284, 287)

λ	A	S
I 39 086		
I 16 482	6	
I 432	6	
I 402	2	
I 15 711	7	
258	7	
I 154	10	
I 14 849	2	
I 473	8	
I 354	8	
I 327	10	
I 13 979	10	
I 11 630	2	
I 268	4	
I 10 394.6	10	
I 8 200.1	1u	
I 7 399	5	
I 82.3	2u	
I 46.0	1u	
I 6 777.7	2u	
II 25.83		15
II 6 464.98		10
I 38.4696	10	10R
II 6 359.93		10
I 29.94	5	
I 25.1	5	1
I 6 116.12	3	1
I 11.5	3	
I 6 099.1	5	
I 31.4	3	
5 637.3	5	
I 04.7	2	
I 5 598.8	3	
5 497		10u
II 5 381.82		10
II 78.12		10
78	3	
I 39	2	
38.5		10
II 5 337.49	3	25
I 5 297.7	3	
I 5 085.823	10R	10
II 4 881.73		10
I 4 799.912	10R	10
I 4 678.151	10	10
4 415.68	1	6
II 12.31		10
4 245.6		4
16.9		6
4 191.6		4
II 34.78		15
27.0		4
4 094.8		4
57.5		5
II 29.08		10
3 988.2		4
77.3		5
76.6		5
40.3		5
3 852.1		3
I 3 729.06	4r	
I 3 614.4	7	7
I 12.875	8R	9
I 10.510	10R	10R
II 3 535.67		20
II 3 495.36		15
I 67.656	8R	10
I 66.200	10R	8R
II 17.40		10
I 03.653	10R	10
3 298.97	4	4R
I 61.05	10R	7
I 52.525	8r	6u
II 50.29		25
3 185.53		5
I 33.167	2r	5r
29.23		5u
3 095.5		5r
I 80.828	8r	3r
I 2 980.622	8R	6
I 2 881.24	4R	3U
I 80.78	8R	6
I 68.3	6r	3r
I 36.92	8R	6U
I 2 763.9	6R	3U
II 48.58		10
I 12.6	6r	1u
I 2 677.6	8d	3u
I 39.50	6R	1u
II 2 573.04	4	10
I 53.6	4r	
2 469.76		4
2 329.27	8R	6
II 21.15	1	7
II 12.88	4	10R
06.63	4R	3
I 2 288.03	10R	10R
67.47	4R	2
II 65.03	4R	10R
39.86	6R	3
II 2 194.62	1	4R
II 44.39	4R	6R
2 062.0		5
55.3		3
04.2		5
1 995		3
I 42		2
39		2
21.8		2
00.7		6
1 873.6		15
56.0		15
44.5		10
1 773.1		6
68.8		6
47.9		6
07.5		8
1 628.7		6
1 514		20
1 472		8
66		8
62		20
1 397		20
69		20
847		10
396		1

Ce (6, 61, 78, 90, 91, 145, 151, 154, 155)

λ	A	S
8 772.08	3	
8 647.59	2	
12.62	2	
8 560.60	2	
8 495.64	3	
8 396.20	2	
71.90	2	
63.82	2	
55.32	2	
10.22	2	
00.58	2	
8 261.03	2	
45.10	2	
34.12	3u	
8 171.32	2	
8 025.59	2	
02.66	2	
7 860.54	2	
59.05	2	
35.81	2	
7 797.73	2	
7 689.13	2	
7 397.78	2	
29.92	2	
7 252.72	3	
38.38	2	
7 150.21	2	
7 086.31	3	
61.69	3	
30.98	2	
6 999.87	2	
86.00	2	
24.80	3	
6 899.07	2	
98.49	2	

Ce.—(*Continued*)

λ	A	S
6 774.27	2	
04.40	3	
00.67	3	
6 665.65	3	
52.75	3	
28.90	3	
06.87	3	
6 555.65	3	
13.63	3	
6 473.69	3	
67.40	3	
66.89	3	
58.06	3	
6 393.06	3	1
71.13	4	
43.98	4	1
10.03	3	
00.22	3	
6 295.58	3	
72.05	4	2
32.47	3	1
28.98	4	1
09.00	3	
6 186.16	3	
23.66	4	
6 098.35	4	1
69.48	3	
57.99	3	
43.39	5	2
24.18	5	
13.41	5	
5 975.87	4	
40.86	4	1
34.40	4	
28.34	4	
10.00	5R	
5 871.58	3	
62.49	4	
38.12	4	1
12.9	5	
04.42	4	
5 788.15	4	
73.12	4	
68.94	4	1
43.54	5	
25.84	4	
19.04	5	
5 699.22	5	1
96.99	5	1
77.74	4	1
69.96	5	1
55.14	5	1
14.73	3	
01.28	5	1
5 556.27	4	1
12.06	8	3
5 472.27	5	3
09.23	6	3
5 393.39	7	3
30.53	5	2
5 274.23	5	3
11.91	4	
5 191.63	5	1
87.44	6	2

Ce.—(*Continued*)

λ	A	S
5 117.14	4	1
5 079.68	5	2
44.02	4	1
22.85	4	1
4 971.50	4	2
4 893.93	3	2
82.44	4	3
4 773.93	4	3
37.24	4	3
25.09	4	2
14.01	4	3
4 684.61	4	3
54.28	4	2
28.15	10	10
06.41	4	5
4 593.93	10	10
72.28	10	10
62.35	10	10
39.74	10	5
28.47	10	5
27.35	10	5
09.18	4R	3
4 471.24	10	5
60.21	10	10
49.33	9	4
18.78	7	5
4 396.58	3R	2
91.66	8	8
82.17	8	5
75.18	8	3
49.79	8	4
37.76	9	4
20.73	8	3
06.73	8	4
4 296.68	9	8
89.94	9	6
55.79	8	3
48.67	8	6
22.62	10	5r
4 186.60	10	10
65.61	9	10
52.01	8	10
49.94	10R	10
37.64	9	10
33.82	10	10
06.89	5R	3
4 083.24	10	5
73.49	9	4
40.76	9	8
12.40	10	10
3 999.25	10	6
93.83	9	4
92.39	9	3
56.29	9	3
52.58	9R	8r
42.75	10	5
3 890.00	8	3r
78.37	9	2
75.04	6R	2
53.16	8	2
01.53	10	8
3 786.63	8	3
64.12	8	3r
16.36	9	3

Ce.—(*Continued*)

λ	A	S
3 709.29	8	3r
3 679.42	6	2
67.97	9	3
55.85	10	3
23.84	7	3
13.70	10R	2
3 577.45	8	4r
60.82	8	4r
39.08	7	2
17.38	7	2
3 488.55	7	1
85.06	8	2
76.84	6	2
42.38	7	1
26.20	8	1
3 377.13	7	2
66.56	7	1
44.76	7	2
04.84	7	1
3 285.23	6	1
72.25	7	2
34.17	7	1
21.17	7	1
01.72	7	1
3 194.83	7	1
71.63	6R	1
46.40	6	1
03.38	6	1
3 063.00	6	2
51.98	5	1
17.18	4	1
2 976.90	4	1
2 896.75	4	
33.30	4	
2 791.42	4	
2 696.06	4	
51.02	4	1
1 373		20
32		20
830		20
741		5
399		1

Cl (2, 29, 31, 32, 85, 91, 125)

λ	S	G
5 634.9		1
5 457.1		3
44.2		3
43.4	1	5
23.2	2	6
5 392.1	2	4
21.3	1	4
17.8	1	3
5 078.2	2	4

Cl.—(*Continued*)

λ	S	G
4 904.7	2	4
4 896.7	2	5
19.4	10	9
10.0	10	9
4 794.5	10	10
81.3	3	5
68.6	2	4
4 601.0		4
4 572.6	1	5
26.3		5
4 490.0	1	3
75.3		4
69.4		5
38.6		4
03.4		5
4 389.8		8
87.6		5
79.9		8
73.0	2	6
71.6		5
69.5		6
63.3		8
43.7	5	10
36.3	2	5
23.4		6
07.6	3	6
04.1	1	4
4 291.8	2	5
53.4	2	9
41.3		8
34.0		5
26.4		7
09.7		5
4 158.0	2	4
32.5	10	3
04.8		4
4 032.2		5
3 914	2	5
3 868.7	1	6
61	5	10
51.5	3	8
51.0		10
45.7	2	8
45.4		8
43	2	5
33.4	2	8
27.7	2	5
20.3	1	5
05.2	2	6
3 798.8	2	5
81.2		5
50.0		5
3 650.1	1	4
02.1	4	2
3 522.0		6
3 392.8		8
53.3	3	7
40.3	3	8
29.0		8
20.5	2	8
15.3	1	6
3 289.7	1	6
59.2	2	4
3 191.4	3	7

Cl.—(*Continued*)

λ	S	G
3 139.2		6
3 076.6		7
71.3	1	6
63.0		6
2 996.5		5
2 782.4		6
10.37		6
2 691.49		6
88.03		6
85.40		5
84.75		5
65.5		6
61.5		4
58.7		4
24.72		6
20.07		6
16.99		8
11.4		5
09.50		7
03.5		6
01.2		5
2 580.7		8
77.1		6
32.5		7
19.5		6
2 471.1		4
48.6		4
34.5		5
03.2		5
2 370.4		4
59.6		4
2 283.9		4
51.5		5
51.0		5
2 093.4		4
87.1		5
1 821.9		2
1 577.7		2
47.2		3
1 145.0		2
1 070.9		4
14.9		4
08.6		4
984.8		4
60.4		6
888.0		4
40.9		6
VII 13.00		2
VII 00.70		3
787.8		4
VI 30.31		4
12.6		4
663.2		4
53.7		4
V 39.24		5
V 35.31		6
V 33.18		6
V 29.33		6
586.9		4
74.3		4
61.5		4
56.4		4
IV 38.08		3

Co (12, 16, 24, 54, 75, 90, 91, 153, 154, 177, 216, 226, 267)

λ	A	S
19 779	3	
18 274	2	
176	3	
17 080	3	
005	5	
16 574	3	
447	2	
388	3	
257	5	
133	5	
15 210	2	
14 958	3	
681	2	
611	4	
559	2	
062	4	
11 895	1	
634	2	
453.4		
340.8		
293.5		
275.5		
10 366.6		
284.6		
272.9		
236.4		
213.3		
210.8		
206.1		
189.2		
020.7		
9 597.9	2	
44.5	2	
9 357.0	10	
9 095.4	6	
37.9	8	
8 958.5	6	
26.2	10	
04.7	8	
8 870.8	4	
50.7	10	
35.2	8	
19.2	10	
8 575.3	4	
8 378.4	7	
72.8	10	
8 299.0	5	
69.4	8	
08.7	8	
8 193.1	8	
52.0	6	
16.4	7	
8 094.0	10	
66.5	7	
56.0	8	
43.3	8	
29.3	7	
22.2	7	
07.3	10	
7 987.4	7	
26.6	8	

Co.—(*Continued*)

λ	A	S
7 908.8	10	
7 871.4	6	
69.9	6	
55.9	7	
40.1	7	
38.2	8	
7 734.3	6	
12.7	9	
7 610.3	6	
7 590.6	6	
54.0	8	
7 457.4	8	
I 17.4	8	
7 388.7	7	
I 54.6	6	
7 285.3	7	
7 193.60	8	
59.16	8	
I 54.7	8	
34.33	8	
I 7 084.97	10	
54.04	8	
I 52.85	10	
27.82	8	
I 16.6	10	
6 937.8	7	
6 872.38	7	2
I 14.96	10	1
I 6 771.05	10	2
I 6 678.81	6	
32.44	6	2
17.30	10d	1
6 595.90	6	3
63.40	9	3
6 490.32	7	1
77.89	9	
55.02	10	5
I 50.23	10	6
29.89	7	
17.80	8	1
6 395.19	7	1
47.79	10	1
20.35	10	2
I 6 282.65	10	4
71.40	10	
57.61	10	3
I 31.02	7	3
11.13	8	1
I 6 188.98	8	3
22.68	10	2
07.93	7	1
I 6 093.14	6	2
86.66	7	2
82.46	10	5
49.06	10	2
07.63	8	2
06.30	8	2
00.71	8	1
5 991.88	10	5
I 84.19	10	2
46.51	8	1
15.53	8	3
5 890.48	7	2
30.06	7	

Co.—(*Continued*)

λ	A	S
5 647.22	8	1
I 5 590.73	8	1
I 30.77	8	1
I 5 483.35	10	2
54.55	9	1
44.56	8	1
I 5 369.59	7	1
62.76	8	1
53.48	7	2
I 52.05	8	2
43.38	7	2
42.68	8	2
I 5 280.63	5	1
66.49	6	1
I 30.21	5	1
I 12.70	5	1
5 176.07	6	
33.45	5	1
I 22.76	5	1
I 4 971.95	6	
I 4 867.88	8	8
I 40.28	8	8
I 13.49	8	10
I 4 792.87	7	7
I 49.69	8	3
I 4 682.36	7	3
I 63.41	8	4
I 29.38	8	4
4 596.90	6	3
94.62	6	3
I 81.62	8	8
65.61	7	7
49.664	6	5
I 30.97	7	10
I 4 469.57	8	5
4 339.64	5	3
4 252.30	5	2
I 4 190.71	7	4
60.7	1	8
I 21.327	10R	10R
I 18.78	8R	10
I 10.54	9	10
I 4 092.40	8R	8
I 86.32	8	9
I 66.39	7R	5
I 45.40	8R	5
I 20.898	7R	5
I 3 997.905	7R	10
I 95.312	8R	10
I 74.731	5R	4
I 57.935	6R	4
I 41.736	5R	4
I 35.974	6R	10
I 3 894.085	9R	10
I 76.84	8R	5
I 73.117	9R	10
I 61.168	7R	10
I 45.478	10R	10
I 42.06	6R	10
3 755.450	6R	4
I 45.50	6R	10
32.398	8	7
I 04.06	8	7
3 683.054	8	8

Co.—(*Continued*)

	λ	A	S
	3 676.555	8	6
	39.44	10	2
I	27.81	8R	4
I	02.083	5R	4
I	3 587.19	8R	10
I	75.36	6R	5
I	74.96	5R	4
I	69.38	7R	10
I	64.95	5R	4
I	50.60	5R	3
I	33.361	6R	4
I	29.814	8R	6
I	29.037	4R	3
I	26.853	9R	6
I	23.438	4R	5
	21.57	5R	5
I	20.087	4R	3
I	18.352	6R	7
I	13.483	4R	4
I	12.642	4R	6
I	10.419	4R	4
I	09.847	4R	5
I	06.316	6R	8
I	02.282	5R	6
I	3 495.683	6R	5
I	89.404	5R	7
	85.345	7	3
I	74.019	9R	8
I	65.794	6R	5
I	62.808	6R	5
I	53.514	6R	10
I	49.445	6R	5
I	49.172	6R	5
I	43.646	3R	6
I	33.041	6R	6
I	12.335	4R	4
I	09.177	4R	6
I	05.120	7R	10
I	3 395.379	10R	5
I	88.175	9R	5
I	85.228	9R	4
	77.06	8R	1
I	54.383	6R	4
	46.941	10	2
I	34.151	5R	4
	19.48	10	2
	3 283.45	10R	3
	65.347	6R	1
	60.814	7R	2
	54.20	10R	2
	47.17	7R	2
	43.84	8R	2
I	3 159.66	6R	1
I	58.76	6R	3
I	49.30	6R	2
I	47.06	7R	3
I	39.94	7R	3
I	37.32	6R	3
I	3 086.77	6R	3
I	82.61	5R	3
I	72.34	5R	3
I	44.00	8R	4
I	2 989.59	6R	3
I	87.17	5R	3
	2 886.45	5	2
	15.55	4	1
	2 766.22	4	2
	45.10	4	3
	31.11	4	2
	2 675.99	4	4
	63.53	4	10
	48.65	4	10
	32.4		10
	2 574.36	3R	
	64.04	3	10
	59.40	3	10
	41.95	2	10
I	28.97	3R	2
	19.8	1	10
	11.1	2R	4
	06.4	3	10
	2 464.2	2	8
	47.7		10
	32.3	3R	5
	24.9	3R	
I	15.3	3R	2
I	11.6	3R	3
I	07.3	3R	2
	2 397.4	1	10
	88.9	2	10R
	78.6	2	10
	63.8	2	10
	07.9	2	6R
	2 286.2	2	6R
	76.6	3	1
	13.9	3	1
	2 196.6	5	
	65.6	3	2
	05	4	1
	2 011.5		7
	1 974.1		4
	69.4		5
	56.6		5
	55.2		4
	50		4
	40.3		6
	28		5
	1 882.2		4
	46		4
	1 790.4		4
	72.7		5
	1 631.6		3
	1 580		5
	74		5
	02		3
	1 128		3
	937		5
	342		1

Cp, *see* **Lu**

Cr (74, 75, 78, 90, 91, 108, 146, 154, 181, 192, 212, 213, 226)

	λ	A	S
	26 232	2	
	25 902	1	
	850	2	
	25 816	1	
	785	1	
	709	1	
	665	1	
	584	2	
	560	1	
	490	1	
	460	2	
	18 717	2	
	654	3	
	584	3	
	479	3	
	15 861	3	
	680	3	
	13 462	2	
	11 611	10	
	483	4	
	392	5	
	337	4	
	312	2	
	158	9	
	016	8	
	10 906	6	
	820	4	
	673	3	
	486	4	
	082	2	
	9 948	2	
	9 734.5	10	
	9 670.5	5	
	9 574.2	10	
	9 447.0	10	
	9 294.1	8	
	90.4	10	
	9 142.6	1	
	41.1	1	
	40.4	1	
	9 035.9	3	
I	21.8	4	
I	17.08	5	
I	09.97	10	
	8 976.8	3	
	47.2	2	
	8 548.8	2	
	8 455.2	2	
	50.3	2	
	8 348.3	2	
	8 235.9	2	
	8 163.2	3	
	7 942.0	2	
	08.3	2	
	7 722.9	2	
I	7 462.4	10	
I	00.3	10	
I	7 355.97	10	
I	6 979.81	7	
	78.50	10	
I	25.23	9	
I	24.15	10	
	6 883.04	9	
I	82.41	9	
I	81.65	9	
	6 715.42	3	
	6 669.26	4	
	61.12	5	2
	6 537.95	3	
	01.23	3	
I	6 362.87	5	3
I	30.11	6	3
	6 261.27	3	1
	6 102.71	3	1
	5 884.44	3	2
	5 791.02	10	8
	87.98	9	6
	85.02	8	3
	83.93	9	3
	83.13	8	3
	81.81	7	1
	12.77	4	2
	5 698.33	5	2
	94.73	5	2
	64.03	4	2
I	5 409.80	10	8
I	5 348.31	10	5
I	45.80	10	6
I	28.35	10	8
I	5 298.28	6	10
I	96.69	5	6
I	75.16	4	5
I	65.73	5R	3
I	64.15	6R	5
I	47.56	5R	3
I	08.429	10R	10
I	06.039	10R	10
I	04.54	9R	10
	5 166.24	3	4
	5 013.31	3	2
	4 954.80	4	2
	22.26	4	3
	4 887.01	3	3
	70.80	3	3
	29.36	5	4
	01.04	5	2
	4 789.35	5	3
	56.13	6	8
	37.34	5	3
	18.45	7	6
	08.04	7	3
I	4 652.165	6R	5
I	46.172	7R	10
I	26.187	6R	5
I	16.132	6R	6
I	00.75	6R	4
I	4 591.41	6	2
I	80.06	7	3
I	45.96	5R	6
	40.71	4	6
	11.92	4	6
I	4 496.860	6R	10
	65.35	4	4
	58.53	4	3
I	4 384.98	6R	7
I	71.28	6R	9
I	59.63	6R	8
I	51.770	7R	9
I	51.05	5R	4

ELECTRICALLY EXPLODED WIRES

J. A. ANDERSON

A fine metallic wire a few centimeters in length, weighing 1 or 2 mg, is placed in the discharge circuit of a large condenser. During the discharge the wire is heated and vaporized so rapidly that the earlier observers of the phenomenon (2, 4) described it as an explosion. The mechanical effects of such an explosion are fully described by Singer (4) and Nipher (2). The explanation of the phenomenon recorded by Nipher is probably incorrect, since recent work has shown that the rapid evaporation of the wire is quite competent to account for all observed effects. For quite recent work, *see* (7, 8, 9, 10).

Circuit.—The constants of a circuit used by Anderson and by Smith are: Capacity (C) = 10^{-6} farad; inductance (L) = 3.35×10^{-6} henry; potential applied (V) = 2×10^4 volt; observed frequency of oscillation (N) = 87 000 cycles. If R be the total resistance of the circuit, including that of the wire, or of the vapor formed from it, the value of the current (i) at any time (t) is given by equation (1)

$$i = V\sqrt{\frac{C}{L}} \cdot e^{-\frac{Rt}{2L}} \sin 2\pi Nt \qquad (1)$$

$$= 10\ 900\, e^{-\frac{Rt}{2L}} \sin 2\pi Nt \text{ amp.}$$

The rate of development of heat energy in the wire is given by i^2r, and its maximum value is shown by the experiments to be above 10^7 watt.

Spectrum.—If the wire is in open air the spectrum consists of a moderately strong continuous background upon which is superposed a system of bright and dark lines. The latter are low and moderate temperature arc lines while the former are either spark or high temperature arc lines. If the wire is confined between two parallel planes placed 2 to 10 mm apart, few, if any, bright lines appear, the spectrum being continuous, with numerous absorption lines. All arc lines and many spark lines especially those of wavelength shorter than λ3000 are dark in the spectrum of an iron wire. The absolute brightness of the continuous spectrum is approximately equal to that of a black-body at 20 000°C.

Variation of Spectrum with Time (5).—During the first half oscillation the spectrum is continuous and without bright lines, but all arc lines and many belonging to the spark spectrum appear as absorption lines. In the succeeding half oscillation bright lines appear gradually, the enhanced lines first, followed in order by the high and medium temperature arc lines. In the later stages of the explosion, when the oscillations of the circuit are no longer discernible, even the low temperature arc lines appear bright.

Pressure.—In an open air explosion the pressure,[1] which initially is high, reaches a value of from 4 to 2 atm. at the end of the first half cycle, depending upon the size of wire employed. During the second half cycle it falls to a value not very much above that of the atmosphere. When the explosion is partially confined, the pressure falls more slowly, and is likely to be considerably above 1 atm. even during the second cycle. Hence it follows that at these high temperatures the spectrum is essentially continuous at pressures above 4 atm.; from 4 down to about 2 atm. the continuous spectrum diminishes somewhat in intensity, and below 2 atm. it weakens rapidly. Anderson (1) has shown that the vapors emitting a continuous spectrum have a high opacity, so that they appear to behave very much like a black-body.

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[1] Computed from the measured values of mass and volume, assuming a temperature of 20 000°C.

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PHOTOMETRIC STANDARDS

E. C. CRITTENDEN

The standards of candlepower on which all precise photometry is based are groups of carbon-filament electric incandescent lamps maintained in several national laboratories. These lamps are burned at temperatures below those of ordinary operation so that they change very slowly with use. Since 1909 the laboratories of France, Great Britain, and the United States of America have thus maintained a common unit of candlepower variously known as the international candle, British candle, and bougie décimale. This unit, together with the procedure for maintaining it until a reproducible primary standard shall be evolved, has been accepted by the International Commission on Illumination, which includes representatives of Belgium, Italy, Spain, and Switzerland, in addition to the three countries named above. It is also used by the national laboratories of Japan and Russia, and has been adopted by the national standards committees in Australia, Canada, Czechoslovakia, Poland, and Sweden.

The Hefner candle, the unit used in the Germanic countries, is 0.9 of the international candle, this ratio being exact within the limits of accuracy with which comparisons have been made. The legal primary standard on which this unit is based is the Hefner lamp burning amyl acetate, but the light produced by any flame depends on atmospheric conditions. The precise value of the Hefner unit actually used was determined (3) in 1895 by comparisons between the flame lamps and electric lamps, and in recent years has been maintained by the electric standards, the flame standard serving as a check which would detect significant changes in the electric reference standards. No drift of the latter amounting to as much as 1% has been found (2, 3).

Secondary standards of the more recent types of electric incandescent lamps (tungsten-filament vacuum and gas-filled lamps) have been established by different procedures in the several national laboratories, and there are differences as large as 3 or 4 % between the values assigned to them. The adjustment of these differences depends upon the acceptance of a standard method of comparing lights of different colors. Experiments and comparative measurements leading toward such an agreement are in progress.

While flame standards of candlepower are now little used, individual lamps of two types (Hefner, and Vernon-Harcourt 10-candle pentane) are tested and certified by the national laboratories. The variation of their intensity with atmospheric conditions is commonly represented by an equation of the following form:

$$I = I_0[1 + a(e_0 - e) - c(760 - b)],$$

where e is the humidity expressed in liters of water vapor per cubic meter of dry air, e_0 is a normal humidity, b is the barometric pressure in millimeters of mercury, I_0 is the intensity (candlepower) of the particular lamp under normal atmospheric conditions, and I is the intensity under the conditions represented by observed values of e and b; it is assumed that variations of room temperature have a negligible effect. The accepted values of the constants are as follows:

Lamp	e_0	a	c	Lit.
Hefner	8.8	0.0055	0.00015	(3, 6)
Pentane:				
Great Britain	8.0	0.0063	0.0008	(1, 4)
United States	8.0	0.0057	0.0006	(5, 6, 7)
Japan	8.0	0.0064		(8)

The differences in the values of a for the pentane lamp arise from the fact that this "humidity factor" includes a temperature effect and that seasonal variations of humidity have a systematic relation to temperature which is nearly the same in England and Japan, but different in America. The real humidity factor is 0.0052; this combined with a temperature term, $+0.001(15 - t)$, brings observed results in the three countries into complete accord; t = room temperature, °C. The variation with barometric pressure is not actually linear, but over the range of natural pressure changes either the British or American coefficient gives results correct within the accuracy with which the lamp will reproduce its values.

For very complete bibliography, *see* (9).

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PHOTOMETRIC FILTERS

E. C. Crittenden

Introduction.—In visual photometry, filters are used (1) to equalize the intensity or the color of the two lights to be compared, (2) to test the characteristics of observers, (3) to transmit a spectral band so chosen that the ratio of its intensity to the integral light is the same for each of the lights (method of Crova). The Crova method can give correct results only when the filter is chosen in accordance with the spectral distribution of the particular sources to be compared. It is more convenient to use color equalizing filters, as they can be produced much more easily and no error is introduced by a failure in exactly equalizing the colors of the lights to be compared.

Equalizing Filters.—The color filters most commonly used are blue glasses and dyed gelatin films of a yellowish or amber tint. These are not reproducible; individual filters must be calibrated.

Continuously variable color filters using the rotatory dispersion of quartz plates between nicol prisms have been devised. The relative transmissions of these can be accurately calculated; *see* (5, 9).

Reproducible color-equalizing filters of known transmissions can be prepared from the following stock solutions. (A) Yellow solution: 100 g $Co(NH_4)_2(SO_4)_2.6H_2O$ + 0.733 g $K_2Cr_2O_7$ + 10 cm³ HNO_3 (d = 1.05 g/cm³) + H_2O to make 1 l of solution at 20°C. To dilute, use H_2O.

(B) Blue solution: 50 g $Ni(NH_4)_2(SO_4)_2.6H_2O$ + 10 g $(NH_4)_2SO_4$ + 55 cm³ NH_4OH (d = 0.90 g/cm³) + H_2O to make 1 l of solution at 20°C. To dilute, use aqueous solution of 10 g $(NH_4)_2SO_4$ per l of solution.

These solutions suitably diluted are used to equalize various color differences. The following transmission data refer to a flicker photometer using a 2° field and an effective brightness of 2.5 millilambert. Transmission measurements made with the usual Lummer-Brodhun field (about 8° by 15°) give a somewhat higher transmission for the blue, and lower for the yellow solution.

For the light from a standard 4 watt-per-candle carbon filament lamp (color temperature about 2077°K), the transmission of the diluted yellow solution is given by $\log_{10} T = -0.245C^{0.9}$, and of the blue by $\log_{10} T = -0.539C^{1.03}$, where C = concentration = number of cm³ of stock solution (A or B) per cm³ of the diluted solution, and T = relative transmission of 1 cm of solution at 20°C = τ_s/τ_w, where τ_w = transmission of a 1-cm cell having colorless glass walls and filled with clear H_2O at 20°C, and τ_s = transmission of same cell filled with the diluted solution at 20°C. Transmission = L_2/L_1 where $L_1[L_2]$ = light incident upon front [leaving rear] face of cell.

For the light from a source with a spectral distribution of light like that of a black-body at a temperature >2077°K the transmission of the yellow solution, when adjusted to give a color match with the 4 watt-per-candle carbon lamp, is given by $\log_{10} T = -0.366C^{1.05}$; *see* (1, 2, 3, 8).

Filters for Testing Observers.—For a normal or average observer using a flicker photometer under standard conditions and the light from a 4-watt-per-candle lamp, the two following aqueous solutions have equal transmissions at 20°C when contained in 1-cm cells of colorless glass. Yellow solution: 72 g $K_2Cr_2O_7$ to 1 l solution at 20°C. Blue solution: 57 g $CuSO_4.5H_2O$ to 1 l solution at 20°C; *see* (2, 4, 6, 7).

Filters for Physical Photometers.—Any receiver which responds to radiant energy in a definite and quantitative manner can be used as a photometer if covered by such a filter that the resultant spectral sensitivity curve is like that of the eye. All such known receivers which are accurately reproducible are non-selective, and for such the best filter appears to be a 1-cm thickness of the following solution, supplemented by clear H_2O sufficient to absorb practically all the infra-red (about 2 cm): 61.25 g $CuCl_2.2H_2O$ + 14.5 g $Co(NH_4)_2(SO_4)_2.6H_2O$ + 1.9 g K_2CrO_4 + H_2O to make 1 l; *see* (4, 6).

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(For a key to the periodicals see end of volume)

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MECHANICAL EQUIVALENT OF LIGHT

HERBERT E. IVES

CONTENTS

DEFINITIONS[1] AND SYMBOLS

1. *The efficiency of a source* is the ratio of the total luminous flux to the total power consumed (A. E. S. C. 46)(E_s).

2. The *luminous efficiency of the radiation* from any source is the ratio of the luminous flux to the radiant flux from the source (A. E. S. C. 22)(E).

3. The *visibility factor for the radiation* of a particular wave-length is the ratio of the luminous flux at that wave-length to the corresponding radiant flux (A. E. S. C. 18)(V_λ). (It is the luminous efficiency of monochromatic radiation of that wave-length.)

4. The *relative luminous efficiency of a source* or a *radiation* is the ratio of its efficiency to that of monochromatic radiation of maximum efficiency (about $\lambda = 0.555\mu$)(E_{sr}, E_r).

5. The *relative visibility factor* for a particular wave-length is the ratio of the visibility factor for that wave-length to the maximum value of the visibility factor (A. E. S. C. 19)($V_{\lambda r}$). (It is the relative luminous efficiency of monochromatic radiation of that wave-length.)

6. *Mechanical equivalent of the light* of a given radiation = power radiated per unit of luminous flux emitted = reciprocal of the luminous efficiency of the radiation.

7. *Least mechanical equivalent of light* = mechanical equivalent of monochromatic radiation of greatest luminous efficiency (about $\lambda = 0.555\mu$)(m).

If L = total luminous flux, R = total radiant flux, $L = \int_0^\infty L_\lambda d\lambda = \int_0^\infty V_\lambda R_\lambda d\lambda$, $R = \int_0^\infty R_\lambda d\lambda$, $E = L/R$, $E_r = E/(E_\lambda)_{\max.} = E/(V_\lambda)_{\max.} = mE$.

The value found for L, and hence for m, depends to some extent upon the conditions of observation (intensity of illumination, size of field, type of photometer, etc.). As there is no general agreement regarding what these conditions should be, the following data have a tentative character and those obtained by different observers are not always comparable.

TABLE 1.—RELATIVE VISIBILITY FACTOR ($V_{\lambda r}$) OF MONOCHROMATIC RADIATION (7)

These values, applying to photometric fields of relatively high brightness, have been tentatively adopted by the International Commission on Illumination. They are accurately represented by the formula: $V_{\lambda r} = 0.9896(R_1e^{1-R_1})^{200} + 0.0820(R_2e^{1-R_2})^{550} + 0.0650(R_3e^{1-R_3})^{2000} + 0.0375(R_4e^{1-R_4})^{630}$, where the R's are pure numbers defined by the equations $\lambda = \frac{0.555}{R_1}\mu = \frac{0.607}{R_2}\mu = \frac{0.523}{R_3}\mu = \frac{0.467}{R_4}\mu$; λ is the wave-length of the radiation considered. Mechanical equivalent $= m/V_{\lambda r}$, m = the least mechanical equivalent of light = 0.00161 watt/lumen; luminous efficiency of the radiation $= V_{\lambda r}/m$. Unit of $\lambda = 0.001\mu$ = 10 Å; of $V_{\lambda r}$ = 1%, *see* Fig. 1; *see also* (2, 9, 11, 18, 19, 20).

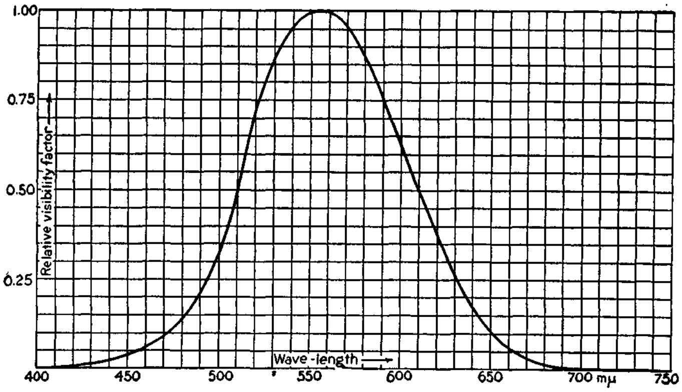

FIG. 1.—Relative visibility factor of monochromatic radiation (7.) Relative visibility factor = relative luminous efficiency. 1mμ = 10^{-7} cm = 10 Å. (*See* Table 1.)

λ	$V_{\lambda r}$	λ	$V_{\lambda r}$	λ	$V_{\lambda r}$
400	0.04	530	86.2	660	6.1
410	0.12	540	95.4	670	3.2
420	0.40	550	99.5	680	1.7
430	1.16	560	99.5	690	0.82
440	2.3	570	95.2	700	0.41
450	3.8	580	87.0	710	0.21
460	6.0	590	75.7	720	0.105
470	9.1	600	63.1	730	0.052
480	13.9	610	50.3	740	0.025
490	20.8	620	38.1	750	0.012
500	32.3	630	26.5	760	0.006
510	50.3	640	17.5		
520	71.0	650	10.7		

TABLE 2.—LEAST MECHANICAL EQUIVALENT OF LIGHT

Value for green Hg-line, λ = 5461 Å, was derived from direct radiometric and photometric measurements; that for black-body (B. B.), from photometric measurements and computation of total radiation, using indicated values of σ and C_2; that for carbon lamp (C. L.), from measurement with and without a luminous efficiency screen. In column $V_{\lambda r}$ is indicated the relative visibility factor used in the reduction; $m_0[m]$ = value of the least mechanical equivalent as reported by observer (as corrected to basis of Table 1, $\sigma = 5.709 \times 10^{-12}$ watt cm^{-2} deg^{-4}, and C_2 = 14 330 micron degree). The value found for m depends to some extent upon the conditions of observation (illumination, size of field, type of photometer), and there is no general agreement regarding what these conditions should be. Unit of $\sigma = 10^{-12}$ watt cm^{-2} deg^{-4}; of C_2 = micron degree; of m_0 and m = 0.001 watt lumen^{-1}.

Source	T, °K	σ	C_2	$V_{\lambda r}$	m_0	m	Lit.
5461 Å	(Assumed to be λ of max. efficiency)				1.44	1.42	(1)
5461 Å and C. L.				I (11)	1.59	1.61	(14, 15)

---

[1] The definitions, that are followed by the letters A. E. S. C. and a number, are those given by the American Engineering Standards Committee, and follow closely those adopted by the International Illumination Commission. The remaining quantities are not defined by those bodies, and it has accordingly been necessary to complete the list by definitions so worded as to be consistent with those adopted. Various authorities differ in terminology, and the definitions here given are not those elsewhere used and advocated by the writer.

TABLE 2.—(*Continued*)

Source	T, °K	σ	C_2	$V_{\lambda r}$	m_0	m	Lit.
5461 Å	(Observations of (14, 15)			C. E. (2)	1.61	1.61	(3)
B. B.		5.7	14 350	H. F. C. (9)	1.50		(9)
B. B.		5.7	14 350	C. E. (2)	1.65*		(3)
B. B.	1 336(Au)	†	14 300	I (11)	1.68		(8)
B. B.	1 336(Au)	†	14 350	I (11)	1.59	1.62	(8)
B. B.	2 035(Pt)	5.7	14 330	G. T. (7)	1.61	1.61	(13)
	Recommended value					1.61	

* Recomputation of observations (9); here corrected to agree with their later values (10). † $C_1 = 3.704 \times 10^{-12}$ watt cm².

TABLE 3.—LUMINOUS CHARACTERISTICS OF A BLACK-BODY

The relative luminous efficiency (E_r) of the radiation from the black-body is computed on the bases of Table 1 and the radiation constants ($\sigma = 5.709 \times 10^{-12}$ watt cm^{-2} deg^{-4}, $C_2 = 14\ 330$ micron deg) chosen for I. C. T. (*cf.* (17)). $E_r = \left(\int_0^\infty V_{\lambda r} J_\lambda d\lambda\right) \div \left(\int_0^\infty J_\lambda d\lambda\right)$; J_λ = monochromatic intensity of the radiation. B = brightness if least mechanical equivalent = 0.00161 watt lumen^{-1}; $B = b \times 10^n$; $E_r = e \times 10^{n'}$. Unit of B = 1 candle cm^{-2}.

T, °K	E_r		B*	
	e	n'	b	n
1 200	6.02	−6	1.41	−2
1 400	5.57	−5	2.42	−1
1 600	2.82	−4	2.08	0
1 700	5.41	−4	5.10	0
1 750	7.26	−4	7.69	0
1 800	9.57	−4	1.13	+1
1 850	1.24	−3	1.64	1
1 900	1.58	−3	2.32	1
1 950	1.98	−3	3.23	1
2 000	2.46	−3	4.44	1
2 050	3.01	−3	5.96	1
2 100	3.64	−3	7.98	1
2 150	4.36	−3	1.05	2
2 200	5.17	−3	1.37	2
2 250	6.06	−3	1.75	2
2 300	7.06	−3	2.23	2
2 350	8.16	−3	2.81	2
2 400	9.35	−3	3.50	2
2 450	1.07	−2	4.33	2
2 500	1.20	−2	5.31	2
2 550	1.35	−2	6.45	2
2 600	1.51	−2	7.80	2
2 650	1.68	−2	9.34	2
3 000	3.09	−2	2.83	3
4 000	8.07	−2	2.33	4
5 000	1.190	−1	8.40	4
6 000	1.353	−1	1.98	5
7 000	1.352	−1	3.67	5
8 000	1.258	−1	5.82	5
10 000	9.87	−2	1.115	6

* Between T = 1700 and 2650°K these values agree satisfactorily with observations of (6, 10), as recomputed to basis C_2 = 14 330 but are a little greater; greatest difference is 1.2 %.

TABLE 4.—LUMINOUS EFFICIENCY OF RADIATION FROM ELECTRICALLY EXCITED GASES AND VAPORS (4); *cf.* (5)

E = luminous efficiency; E_r = relative luminous efficiency; color = color of light emitted; p = probably. Unit of E = 1 lumen/watt; of E_r = 1%.

Gas	Color	E	E_r
A	Red	0.24	0.04
As		0	0
Br	Blue-white	0.06	0.01
Cd	Blue-white	1.6	0.26
Cl	Blue	0.08	0.01
Cs	Blue-white	<0.4	<0.06
F		0.1p	0.02p
H	Red	0.08	0.01
He	White	4.4	0.71
Hg	Blue-green*	11	1.82
Hg	Blue-white†	126	20.3
I	White	1.1	0.18
K	Purple	1.8	0.28
Kr	Violet	<0.6p	<0.1p
Li	Red	‡	
N	Yellow-orange	1.6	0.26
Na	Yellow	214	34
Ne	Red-orange	23.0	3.6
O	Blue-white	0.05	0.01
P	Blue-white	§	
Rb	Red	0.24	0.04
S	Blue-white	0.89	0.14
Se		0p	0p
Tl	Green-white	0.08	0.01
Xe	Blue-green	<1p	<0.20p
Zn		0.13	0.02

* Without condenser. † With 0.14 microfarad condenser in parallel with tube. ‡ Vapor pressure too low for continuous discharge. § Too low to measure.

TABLE 5.—RELATIVE LUMINOUS EFFICIENCY (E_r) OF RADIATION FROM COMMERCIAL ILLUMINANTS (16)

Unit of E_r = 1%

Source	Description	E_r
Incandescent electric lamps:		
Carbon, point source	4 w.p.c., 99 volt	0.45
Tungsten, vacuum	9.16 volt, 1.25 w.p.c.	1.65
Tungsten, vacuum	97.0 volt, 1.1 w.p.c.	1.84
Tungsten, vacuum	102.6 volt, 1 w.p.c.	1.99
Tungsten, nitrogen	6.6 amp., 0.65 w.p.c.	2.93
Mercury arc	1.7 amp., Pfund type	30.5
Nernst glower	0.8 amp., stereopticon type	1.08
Gas lamps:		
Incandescent mantle	0.25% ceria	0.5
Incandescent mantle	0.25% ceria	0.7
Incandescent mantle	0.75% CeO_2, solid chimney	1.2
Incandescent mantle	0.75% CeO_2, perforated chimney	1.26
Incandescent mantle	2% ceria	0.8
Open burner		0.19
Standard candle	Sperm	0.24

TABLE 6.—EFFICIENCIES OF COMMERCIAL ILLUMINANTS (12)

Rating = commercial rating of lamp; E_s = luminous efficiency of lamp; E_{sr} = relative luminous efficiency of lamp = mE_s, m = least mechanical equivalent of light; w.p.c. = watts per mean horizontal candlepower; cp. = candlepower; amp. = ampere; D.C. [A.C.] = direct [alternating] current; BTU = British thermal unit; h.p.[l.p.] = high [low] pressure; 60 ~ = 60 cycles per second. Unit of E_s = 1 lumen per watt consumed; of E_{sr} = 1%.

Lamp	Rating	E_s	E_{sr}
Incandescent electric:			
Carbon	4 w.p.c.	2.6	0.42
Treated carbon*	1.25 w.p.c.	8	1.3
Tungsten, vacuum	600 cp., 20 amp., 0.5 w.p.c.	19.6	3.2

TABLE 6.—(*Continued*)

Lamp	Rating	E_s	E_{sr}
Incandescent electric (*Cont'd*)			
Tungsten, Mazda-C	500 watt, multiple, 7 w.p.c.	15	2.4
Electric arc:			
Carbon, open	9.6 amp., clear globe	11.8	1.9
Carbon, enclosed†	6.6 amp., D.C.	5.9	0.96
Carbon, enclosed†	7.5 amp., A.C.	5.6	0.91
Magnetite	6.6 amp., D.C.	21.6	3.5
Mercury in glass	40 to 70 volt, 3.5 amp.	23	3.7
Mercury in quartz	147 to 197 volt, 4.2 amp.	42	6.8
Flaming,‡ enclosed:			
White, carbon	10 amp., A.C.	26.7	4.3
White, carbon	6.5 amp., D.C.	35.5	5.8
Yellow, carbon	10 amp., A.C.	31.4	5.1
Yellow, carbon	6.5 amp., D.C.	34.2	5.5
Flaming,‡ open:			
White, inclined	10 amp., A.C.	29	4.7
White, inclined	10 amp., D.C.	27.7	4.5
Yellow inclined	10 amp., A.C.	41.5	6.7
Yellow, inclined	10 amp., D.C.	44.7	7.2
Moore nitrogen tube	220 volt, 60~, 113.17 ft.	5.21	0.85
Nernst lamp		4.8	0.77
Gas lamps:			
Acetylene	1.0 liter per hr	0.67	0.11
Incandescent, l.p.	0.350 lumen per BTU hr^{-1}	1.2	0.19
Incandescent, h.p.	0.578 lumen per BTU hr^{-1}	2.0	0.32
Open flame	Bray 6 in., h.p.	0.22	0.036
Petroleum lamp		0.26	0.04

* Oval, anchored filament.

† Inner, light opal; outer, clear; lamp provided with street reflector. A resistance is in series with the A.C. arc.

‡ Ornamental type of lamp, clear globe, standard electrodes, series resistance.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Buisson and Fabry, *34*, **153**: 254; 11. (2) Coblentz and Emerson, *31A*, **14**: 167; 17. (3) Coblentz and Emerson, *31A*, **14**: 255; 17. (4) Compton, A. H., Univ. Pittsburgh, *0*. (5) Compton and Van Voorhis, *2*, **21**: 210; 23. (6) Forsythe, Nela Park, Cleveland, Ohio, *0*. (7) Gibson and Tyndall, *31A*, **19**: 131; 23. (8) Holst and Visser, *64P*, **20**: 1036; 17. (9) Hyde, Forsythe and Cady, *21*, **48**: 65; 18.

(10) Hyde, Forsythe and Cady, *2*, **13**: 45; 19. (11) Ives, *3*, **34**: 149; 12. (12) Ives, *2*, **5**: 390; 15. (13) Ives, *48*, **9**: 635; 24. (14) Ives, Coblentz and Kingsbury, *2*, **5**: 269; 15. (15) Ives and Kingsbury, *2*, **6**: 319; 15. (16) Karrer, *2*, **5**: 189; 15. (17) Kingsbury, *2*, **7**: 161; 16. (18) Koenig, *Gesammelte Abhandlungen zur physiologischen Optik*, p. 144. Leipzig, Barth, 1903. (19) Langley, *12*, **36**: 359; 88.

(20) Nutting, *48*, **4**: 55; 20. (21) Tyndall and Gibson, *48*, **9**: 403; 24.

THE PROPERTIES OF PHOTOGRAPHIC MATERIALS

PART I: S. E. SHEPPARD, PART II: L. A. JONES

TABLE 6.—(*Continued*)

Lamp	Rating	E_s	E_{sr}
Incandescent electric (*Cont'd*)			
Tungsten, Mazda-C	500 watt, multiple, 7 w.p.c.	15	2.4
Electric arc:			
Carbon, open	9.6 amp., clear globe	11.8	1.9
Carbon, enclosed†	6.6 amp., D.C.	5.9	0.96
Carbon, enclosed†	7.5 amp., A.C.	5.6	0.91
Magnetite	6.6 amp., D.C.	21.6	3.5
Mercury in glass	40 to 70 volt, 3.5 amp.	23	3.7
Mercury in quartz	147 to 197 volt, 4.2 amp.	42	6.8
Flaming,‡ enclosed:			
White, carbon	10 amp., A.C.	26.7	4.3
White, carbon	6.5 amp., D.C.	35.5	5.8
Yellow, carbon	10 amp., A.C.	31.4	5.1
Yellow, carbon	6.5 amp., D.C.	34.2	5.5
Flaming,‡ open:			
White, inclined	10 amp., A.C.	29	4.7
White, inclined	10 amp., D.C.	27.7	4.5
Yellow inclined	10 amp., A.C.	41.5	6.7
Yellow, inclined	10 amp., D.C.	44.7	7.2
Moore nitrogen tube	220 volt, 60∼, 113.17 ft.	5.21	0.85
Nernst lamp		4.8	0.77
Gas lamps:			
Acetylene	1.0 liter per hr	0.67	0.11
Incandescent, l.p	0.350 lumen per BTU hr^{-1}	1.2	0.19
Incandescent, h.p	0.578 lumen per BTU hr^{-1}	2.0	0.32
Open flame	Bray 6 in., h.p.	0.22	0.036
Petroleum lamp		0.26	0.04

* Oval, anchored filament.

† Inner, light opal; outer, clear; lamp provided with street reflector. A resistance is in series with the A.C. arc.

‡ Ornamental type of lamp, clear globe, standard electrodes, series resistance.

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(10) Hyde, Forsythe and Cady, *2*, **13**: 45; 19. (11) Ives, *3*, **34**: 149; 12. (12) Ives, *2*, **5**: 390; 15. (13) Ives, *48*, **9**: 635; 24. (14) Ives, Coblentz and Kingsbury, *2*, **5**: 269; 15. (15) Ives and Kingsbury, *2*, **6**: 319; 15. (16) Karrer, *2*, **5**: 189; 15. (17) Kingsbury, *2*, **7**: 161; 16. (18) Koenig, *Gesammelte Abhandlungen zur physiologischen Optik*, p. 144. Leipzig, Barth, 1903. (19) Langley, *12*, **36**: 359; 88.

(20) Nutting, *48*, **4**: 55; 20. (21) Tyndall and Gibson, *48*, **9**: 403; 24.

THE PROPERTIES OF PHOTOGRAPHIC MATERIALS

PART I: S. E. SHEPPARD, PART II: L. A. JONES

Part I

The Photochemical Equivalent of the Silver Halides (10); *cf.* (9, 38, 41, 42, 43)

$\Sigma h\nu$ = sum of quanta absorbed per cm², N_{Ag} = number of silver atoms produced per cm² without development, $N/\Sigma h\nu$ = photochemical equivalent.

Fast plate				Process plate			
$10^{-16} \times \Sigma h\nu$	$N/\Sigma h\nu$	$10^{-16} \times \Sigma h\nu$	$N/\Sigma h\nu$	$10^{-16} \times \Sigma h\nu$	$N/\Sigma h\nu$	$10^{-16} \times \Sigma h\nu$	$N/\Sigma h\nu$
0.39	0.88	3.00	0.92	0.85	0.82	5.50	0.79
0.41	0.88	6.00	0.79	0.95	0.88	6.40	0.78
0.68	0.93	8.00	0.71	1.80	1.08	9.20	0.73
0.90	1.01	8.80	0.67	2.80	1.06	11.40	0.62
0.99	0.92	9.30	0.68	3.40	0.83	22.50	0.38
1.76	0.99	13.00	0.50	4.70	0.76	30.00	0.33
2.30	0.98						

The Silver Reduction Equivalent of Photographic Developers

By silver reduction equivalent (E_{Ag}) is meant the *number of atoms of metallic silver reduced per molecule of developer oxidized.* Temperature = 20°C and Ag is added as excess AgBr except as otherwise indicated.

Grams developer	Grams alkali	Grams Na_2SO_3	Vol., cm³	Duration of experiment	E_{Ag}	Lit.
1. Quinol						
1.4	K_2CO_3, 20	20	*ca.* 300	20 min	4.3	(1)
1.4	K_2CO_3, 20	20	*ca.* 300	20 min	5.0*	(2)
1.4	K_2CO_3, 20	20	*ca.* 300	30 min	4.3	(3)
1.4	K_2CO_3, 20	20	*ca.* 300	60 min	7.8	(3)
0.11	NaOH, 2.2	0	25	6 hr	6.4	(14)
0.11	NaOH, 2.2	0	25	6 hr	9.3†	(14)
0.11	NaOH, 2.2	0	25	18 da	7.8	(14)
0.055	NaOH, 2.2	0.063	25	18 da	7.8	(14)
0.055	NaOH, 2.2	0.63	25	18 da	8.9	(14)
0.055	NH_4OH, *aq.* 20‡	0	40	8 da	8.0§	(14)
0.055	NaOH, 2.2	0	25	15 hr	10.5‖	(14)
2. Pyrogallol						
	NH_4OH	0			*ca.* 4¶	(18); *cf.* (37)
0.063	NaOH, 2.2	0	25	1 hr	3.2	(14)
0.063	NaOH, 2.2	0.315	25	1 hr	3.4	(14)
3. Pyrocatechol						
0.055	NaOH, 2.2	0	25	2 hr or 21 da	4.5	(14)
0.055	NaOH, 2.2	0.315	25	21 da	5.9	(14)
1.4	K_2CO_3, 20	20	*ca.* 300	21 min	1.9	(1)
4. *p*-Aminophenol						
1.4	K_2CO_3, 20	20	*ca.* 300	20 min	3.9	(1)
5. *o*-Aminophenol						
1.4	K_2CO_3, 20	20	*ca.* 300	20 min	0.7	(1)
6. Chlorquinol						
1.9	K_2CO_3, 20	20	150	1 hr	6.7	(3)
7. Quinone						
0.054	NaOH, 2.2	0	25	1 hr	3.9	(14)
0.054	NaOH, 2.2	0.63	25	1 hr	4.9	(14)
8. Hydroxylamine as $NH_2OH.HCl$						
0.70	NaOH, 25**		100	60 min	1.1	(34)
0.70	NaOH, 50**		100	60 min	0.98	(34)
0.70	NaOH, 12.5**		100	60 min	1.01	(34)
0.70	NaOH, 12.5**		100	60 min	1.00	(34)
0.044	NH_4OH			60 min	2.00††	(34)
9. Hydrogen peroxide						
1.720	NaOH			60 min	1.00	(34)

* Excess AgBr added progressively.

† t = 95–100°.

‡ Sp. gr. 0.9.

§ Ag as $AgNO_3$, 1.7 g.

‖ Ag as excess Ag_2O.

¶ Ag as excess ammoniacal $AgNO_3$.

** cm³ of 1N NaOH.

†† Ag as ammoniacal Ag_2O.

It is clear that the so-called silver equivalent of a given developing agent varies with the other constituents of the developer, the temperature, duration of run, and the form and manner in which the silver is added. Gordon (3) found, further, that the equivalent varies markedly with the method of shaking. It is probable that none of the values represents an equilibrium system and all are therefore to be regarded as tentative. Lüppo-Cramer (24), believes all determinations on silver halides in absence of emulsifying substances to be without photographic significance.

Photographic Development Velocity Functions and Constants

The rate of development may be measured by the increase of *density*, D, at a single exposure with time of development, t, or more satisfactorily, and in closer relation to photographic theory and practice, by the increase of *gamma*, γ, (constant or development factor) with time, t.

The function for (γ, t) will be of the same form as for (D, t), provided the straight line portions of the characteristic curves (*q.v.*, p. 442) meet on the axis of exposures. If they converge to a point below the axis, as when soluble bromide is present, then if a is the depression of density at the convergence point (*cf.* (28)) the function for ($D + a$), t will be the same as for γ, t.

For some emulsions the convergence point is above the axis, in which case the function for γ, t should be compared with ($D - a$), t.

FORMS OF DEVELOPMENT VELOCITY EQUATION

	Log form	Exponential form	First derivative	Lit.
1	$Kt = \log_e \dfrac{D_\infty}{D_\infty - D}$	$D = D_\infty(1 - e^{-Kt})$	$\dfrac{dD}{dt} = K(D_\infty - D)$	(37)
2	$K(t - t_0) = \log_e \dfrac{D_\infty}{D_\infty - D}$	$D = D_\infty(1 - e^{-K(t-t_0)})$	$\dfrac{dD}{dt} = K(D_\infty - D)$	(37)
3	$K(\log_e t - \log_e t_0) = \log_e \dfrac{D_\infty}{D_\infty - D}$	$D = D_\infty(1 - e^{-K \log_e t/t_0})$	$\dfrac{dD}{dt} = \dfrac{K}{t}(D_\infty - D) = Kt^{-1}(D_\infty - D)$	(28)
4	$\log_e K + b \log_e (t - t_0) = \log_e \log_e \dfrac{D_\infty}{D_\infty - D}$	$D = D_\infty(1 - e^{-K(t-t_0)^b})$	$\dfrac{dD}{dt} = Kbt^{b-1}(D_\infty - D)$	(44)
5	$Kt = \log_e \dfrac{p\xi}{p\xi - D} - \dfrac{d}{(d + h)(D_\infty - p\xi)} \log_e \dfrac{D_\infty}{D_\infty - D}$		$\dfrac{dD}{dt} = K\dfrac{b - aD}{h(D_\infty - D) + d}(D_\infty - D)$	(33)

K = velocity constant of development. t = time of development in any unit selected. t_0 = empirical correction for the induction period in development. D_∞ = theoretical silver image density at infinite development. D = measured silver image density at time, t. a, b, d, h = empirical constants. $p\xi = D_\infty$ as used in 1–4. In 5, D_∞ represents the mass (unknown) of the latent image.

Equation 1 holds only for simple iron oxalate development, and for pyrogallol-soda (fairly). Equation 2 is of much wider application but in many cases fails in the advanced stages of alkaline development. Equation 3 has been found generally satisfactory by Nietz (28) in his extensive experimental work. Equation 4 is equally satisfactory and sometimes holds over a wider range but is more difficult of application. Equation 5 is of theoretical significance as being based upon the conception of the reversibility of the development process; it contains too many undeterminable terms to be practically useful.

DEVELOPMENT VELOCITY CONSTANTS AND RELATED DATA FOR VARIOUS DEVELOPERS ON THE SAME EMULSION (28)

Each developer contained 50 g Na_2SO_3, 50 g Na_2CO_3 and 1.19 g KBr per liter. Developing agents marked with an asterisk were of high purity, and others, excepting only edinol, duratol and eikonogen, which were the commercial product, were of better than commercial quality. D_∞, t_0, K as previously defined. γ_∞ = theoretical plate contrast reached on infinite development.

Developing agents all at 0.05 molal concn.	Constants of Eq. 3			
	D_∞	γ_∞	t_0, min	K
Toluquinol	4.40	1.67	1.35	0.63
Diaminophenol + alkali*	4.2	1.40	0.6	0.60
p-Aminophenol*	4.2	1.84	1.0	0.44
p-Amino-*m*-cresol	4.0	1.33	1.24	0.72
Methyl-*p*-amino-*o*-cresol	4.0	1.26	0.33	0.60
Pyrogallol*	4.0	1.22	0.78	0.57
Chlorquinol*	4.0	1.82	1.3	0.52
Quinol*	3.8	1.26	1.80	0.95
Dibromquinol	3.8	1.27	0.80	0.80
p-Amino-*o*-cresol	3.8	1.27	0.87	0.70
Bromquinol	3.8	1.73	1.27	0.66
Eikonogen	3.8	1.43	1.7	0.47
Monomethyl-*p*-aminophenol*	3.6	1.50	0.70	0.58
Diaminophenol, no alkali	3.6	1.63	0.36	0.55
Pyrocatechol	3.6	1.68	0.60	0.52
Dichlorquinol	3.6	1.29	0.80	0.53
Edinol	3.6	1.22	1.9	0.46
Phenylhydrazine, no alkali	3.5		8.5	0.03
p-Dimethylaminophenol	3.2	1.18	0.75	0.61
Ferrous oxalate*	3.1	1.29	0.97	0.55
Benzyl-*p*-aminophenol (duratol)	2.4	0.98	2.27	0.34
p-Phenylenediamine	1.7	0.58	2.10	0.34

The Temperature Coefficient of Development

Sheppard and Mees (36) found that in the case of ferrous oxalate development the temperature-development velocity relation was represented quite accurately by the integrated form of the Van't Hoff reaction isochore: $\log K = -\frac{A}{T} + C$, where K = development velocity constant, A, C = experimentally determined characteristic constants, T = absolute temperature.

The temperature coefficient for any development process for which the above relation holds is given by:

$$\alpha_{10} = \frac{K_T + 10}{K_T}$$

Ferguson (11) has proposed and successfully applied to general alkaline development the formula

$$\log b = \frac{\log M - \log m}{\Delta t}$$

in which b = temp. coeff. for 1°C. M, m = time of development giving equal factors at the higher and lower temperatures, respectively. Δt = temp. difference in °C.

TEMPERATURE COEFFICIENT OF DEVELOPMENT

Developing agent	Plate or emulsion	α_{10}	Lit.
Ferrous oxalate	"A"	1.60	(37)
Ferrous oxalate	"B"	1.90	(37)
Ferrous oxalate	"C"	1.70	(37)
Hydroxylamine	"C"	2.00	(37)
Quinol	"B"	2.20	(37)
Quinol	"C"	2.80	(37)
Quinol (tabloid)		2.25	(40)
p-Aminophenol	"C"	1.50	(37)
Metol	"C"	1.25	(37)
Pyrocatechol	"B"	2.80	(37)
Glycine (tabloid)		2.3	(40)
Metol-quinol		1.9	(40)

TEMPERATURE COEFFICIENT.—(*Continued*)

Developing agent	Plate or emulsion	α_{10}	Lit.
Rytol (tabloid)		2.2	(40)
Rodinal (*p*-aminophenol)		1.9	(40)
Pyrogallol soda, no bromide		1.5	(40)
Pyrogallol soda with bromide		1.9	(40)
Pyrogallol soda, no bromide	Wratten Panchromatic	2.0	(20)
Pyrogallol soda, no bromide	Imperial Ordinary	1.71	(12)
Pyrogallol soda, no bromide	Wratten Instantaneous	1.68	(12)
Pyrogallol soda, no bromide	Ilford Empress	1.55	(12)
Pyrogallol soda, no bromide	Imperial Special Rapid	1.76	(12)
Pyrogallol soda, no bromide	Ilford Special Rapid	1.85	(12)
Pyrogallol soda, no bromide	Wellington Rapid Special	1.99	(12)
Pyrogallol soda, no bromide	Barnet Extra Rapid	2.01	(12)
Pyrogallol soda, no bromide	Monarch	1.9	(12)
Pyrogallol soda with 0.1% bromide*	Barnet Extra Rapid	2.01	(12)
Pyrogallol soda with 0.1% bromide*	Ilford Empress	2.09	(12)

* Ferguson's results (12) for bromided pyrogallol, only two of which are quoted for illustration, gave a temp.-coeff. of approximately 2 for all the plates tested, irrespective of the unbromided values. Bromide apparently stabilizes the temp.-coeff., eliminating the emulsion effect observed by Sheppard and Mees (37). Watkins records a like conclusion (40). The temp.-coeff. of a developer is in general independent of its dilution.

Suggested Watkins' Factors (40)

Multiplication of the time of first appearance of the image by the suggested factor should give a negative of average contrast; the factor may then be adjusted to fit the peculiar requirements of the individual worker. Where the factor is evenly divisible into 60, a divisor is given: $\frac{\text{Time of appearance in seconds}}{\text{Divisor}}$ = correct development time in minutes.

Except in the case of pyrogallol and amidol the factor is independent of the developer strength. Variation in alkali does not alter the factor.

For sky, snow, and water negatives use a somewhat smaller factor, *e.g.*, ⅔ normal. For negatives devoid of high lights calculate development time on the basis of ¾ of time of appearance.

Developer	grams/fl. oz. developer		mg/ml developer		Factor (and divisor)
	Pyro	Bromide	Pyro	Bromide	
Pyrogallol with Na_2CO_3	1	0	2.16	0	18
	2	0	4.32	0	12 (div. 5)
	3	0	6.48	0	10 (div. 6)
	4	0	8.64	0	8
	5	0	10.80	0	6.5
Pyrogallol with Na_2CO_3	1	2.16	0.25	0.54	9
	2	4.32	0.5	1.08	5 (div. 12)
	3	6.48	0.75	1.62	4.5
	4	8.64	1	2.16	4 (div. 15)
	8	17.28	2	4.32	3.25
Adurol					5 (div. 12)
Kachin					10 (div. 6)
Pyrocatechol					10 (div. 6)
Pyrocatechol cristoid					30 (div. 2)
Quinol (minimum bromide)					5 (div. 12)

Developer	Factor (and divisor)
Quinol (maximum bromide)	4.5
Eikonogen	9
Metol (Elon)	30 (div. 2)
Glycine with Na_2CO_3	8
Glycine with K_2CO_3	12 (div. 5)
p-Aminophenol	16
Amidol (2 grains/fl. oz)	18
Rodinal	40
Ortol	10 (div. 6)
Diogen	12 (div. 5)
Edinol	20 (div. 3)
2, 4-Diaminophenol (dianol)	60 (div. 1)
Quinomet	30 (div. 2)
Metol-quinol*	14

* The factors of combination developers depend upon the proportion of the two constituents, and when they contain pyrogallol, no rule can be given for finding the factor when diluted. The use of potash as an alkali instead of soda seems, with most developers, to require factors from one-quarter to one-half longer.

Reduction Potentials of Developers

The reduction potentials of developers were originally defined electrochemically (4)[1] but it has been shown that stable potentials, corresponding to equilibrium mixtures of reducer/oxidation-products, are not obtainable for alkaline organic developers (35). Relative reduction potentials were defined by Sheppard by relation to the theoretical equilibrium in development, and an empirical method of determining them worked out (34).

The relative reduction potentials π_{Br} determined by the bromide-depression method of Sheppard as applied by Nietz (28) is defined by the equation

$$\pi_{Br} = kC_0$$

where C_0 is the concentration of KBr required to produce an initial depression in the intersection point of the Hurter and Driffield curves; k is a constant as yet undetermined.

RELATIVE REDUCTION POTENTIALS OF PHOTOGRAPHIC DEVELOPERS (28)

Developer	Mole/l	π_{Br}, hydroquinol = 1.0
Ferrous oxalate	0.10	0.3
p-Phenylenediamine hydrochloride	0.05	0.3
p-Phenylenediamine hydrochloride + alkali	0.05	0.4
Methyl-*p*-phenylenediamine hydrochloride	0.05	0.7
Quinol	0.05	1.0
p-Phenylglycine	0.05	1.6
Hydroxylamine hydrochloride	0.10	2.0
Toluquinol	0.05	2.2
Methyl-*p*-phenylenediamine hydrochloride + alkali	0.05	3.5
p-Aminophenol hydrochloride	0.05	6.0
Chlorquinol	0.05	7.0
p-Amino-*o*-cresol	0.05	7.0
p-Dimethylaminophenol sulfate	0.05	10.0
Pyrogallol	0.05	16.0
Monomethyl-*p*-aminophenol sulfate	0.05	20.0
Bromquinol	0.04	21.0
Methyl-*p*-amino-*o*-cresol	0.05	23.0
2, 4-Diaminophenol	0.05	30 to 40

The Photometric Constant of the Developed Silver Image

D = density of the image, m_{Ag} = grams of silver per dm², $P = m_{Ag}/D$ = photometric constant, E = exposure in mcs. (*see* "Sensitometric constants" *below*).

DENSITY RANGE WITH FERROUS OXALATE DEVELOPMENT; *cf.* (7, 17, 37)

10^3P =	1.21	1.31	1.03	1.031	1.19*
D range	0.525–1.97	0.76–2.54	0.5–2.0	0.5–3.5	0.08–1.64
Lit.	(13)	(13)	(7)	(37)	(32)

* No specific developer mentioned. Scheffers found that quinol, pyrogallol, metol, ferrous oxalate, and glycine gave identical results in his solarization experiments. Scheffers' results indicate that the photometric constant of the developed solarized image progressively diminishes, due to smaller silver grains being formed.

EFFECT OF EXPOSURE (32)

$\log_{10} E$	D	P	$\log_{10} E$	D	P
$\bar{5}.15$	0.08	1.125	$\bar{0}.95$	1.52	1.184
$\bar{4}.55$	0.16	1.250	$\bar{0}.35$	1.64	1.195
$\bar{3}.95$	0.34	1.176	0.25	1.55	1.200
$\bar{3}.35$	0.54	1.295	0.85	1.50	1.133
$\bar{2}.75$	0.86	1.139	1.45	1.35	1.126
$\bar{2}.15$	1.01	1.248	2.05	1.23	1.089
$\bar{1}.55$	1.34	1.149	2.65	1.12	1.062

Meidinger (27), developing with metol, has found that P varies with the grain size of the emulsion, a conclusion in accord with Higson (15) and Nutting (29). Meidinger concludes that for a given density, other factors constant, P is independent of exposure and development time.

EFFECT OF GRAIN SIZE (27)

E, relative	D, range	m_{Ag}, range	Number of observations	P, average
Fast plate, large grain emulsion				
1–25 600	0.76–2.55	1.45–4.63	11	1.82
Process plate, fairly fine grain emulsion				
1–32	0.26–4.20	0.26–3.8	6	1.0
Transparency plate, very small grain emulsion				
1–512	0.05–3.05	0.04–2.95	10	0.83

The "covering power" of silver grains is proportional to the reciprocal of the photometric constant and increases with decreasing grain size. Thus Meidinger (27) found that the covering powers of a given mass of silver in the developed images of fast, process and transparency plates stood in the ratio 5: 9.1: 10.5, a conclusion in qualitative agreement with Higson and Toy (16).

Part II

Sensitometric Constants of Type Plates and Films

The definition of the sensitometric constants usually employed for expressing the characteristics of photographic materials can best be accomplished by referring to Fig. 1 which shows typical characteristic curves.

Density (D).—The blackness, or light absorbing power of a photographic deposit is expressed in terms of density defined as follows: Let F_0 = the luminous flux incident upon the deposit; F_1 = the luminous flux transmitted by the deposit; O = opacity; D = density; T = transmission.

Then

$$T = \frac{F_1}{F_0}$$

$$O = \frac{1}{T} = \frac{F_0}{F_1}$$

$$D = \log_{10} O = \log_{10} \frac{1}{T} = \log_{10} \frac{F_0}{F_1}$$

Exposure (E).—$E = It$ (expressed in meter candle seconds, mcs.); I = the illumination (in meter candles, mc.) incident on the photographic material during exposure; t = exposure time (expressed in seconds, s).

Spectral Composition of Exposing Radiation.—The values of speed given in the following table were obtained by using a light

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[1] *Cf.* Vol. VI, section by Conant.

source approximately equivalent to noon sunlight in spectral composition. The unit of photographic intensity is defined as one visual candlepower of radiation equivalent in spectral composition to mean noon sunlight.

Gamma (γ).—γ = tangent of angle α which the straight line portion of the characteristic curve makes with the exposure axis.

Gamma Infinity (γ_∞).—γ_∞ is defined as the theoretical limiting value to which γ approaches as the development time is increased. The values of γ_∞ given in the table are computed by the formula (37).

$$\gamma_\infty = \frac{\gamma_1}{1 - e^{-Kt_1}}$$

where γ_1 is the slope of the straight portion for the development time t_1, and K is the velocity constant of development.

Velocity Constant of Development (K).—$K = \frac{1}{t}\log_e \frac{\gamma_1}{\gamma_2 - \gamma_1}$.

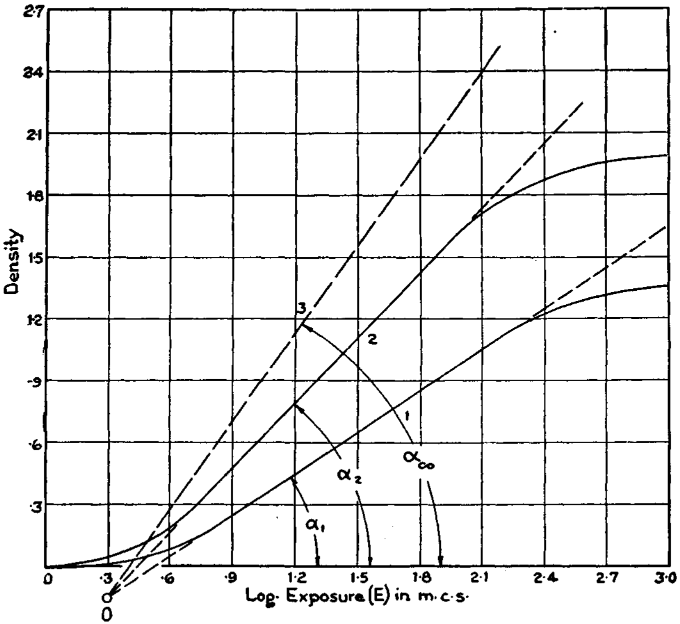

FIG. 1.

Time of Development for Gamma of Unity (t_γ = 1.0).—The rate of development for practical purposes may be indicated by the time of development required to give a gamma of unity. The values determined experimentally for the various type plates and with the developer made up according to the appended formula are given in the table of constants.

Fog (F).—Fog is defined as the density produced when the plate is developed without exposure. This value naturally depends upon the extent to which development is carried and the values given in the table are for a development time which would result in a gamma of unity.

Latitude (L).[1]—L = length of the projection (expressed in exposure units) of the straight line portion on the $\log_{10} E$ axis, assuming development to a gamma of unity.

Inertia (i).—i = the value of exposure where the straight line portion of the characteristic curve extended cuts the $\log_{10} E$ axis. The straight line portions of curves plotted for different development times in general intersect in a point 0 which may lie above, on, or below the $\log_{10}$ exposure axis. The value of i, therefore may depend upon the extent to which development is carried. The values of i given in the table were determined for a gamma of unity.

Speed (S).—$S = \frac{1}{i} \times 10$. Values in table do not include the factor of 10.

SENSITOMETRIC CONSTANTS FOR TYPE PHOTOGRAPHIC MATERIALS

Material	Fog $\gamma = 1$	K	γ_∞	t (for $\gamma = 1.00$)	L	i
1. Cine, Extra Fast	0.20	0.10	1.4	8.5	100	0.0083
2. Cine, Normal	0.15	0.14	1.3	8.5	64	0.014
3. Cine, Panchromatic	0.15	0.15	2.0	3.5	50	0.025
4. Cine, Positive	0.03	0.23	2.7	1.2	32	0.500
5. Portrait, Extra Fast	0.18	0.10	1.4	8.5	100	0.0083
6. Portrait, Normal	0.15	0.10	1.8	5.0	64	0.0166
7. Amateur Film	0.15	0.10	1.8	5.0	32	0.022
8. "Focal Plane" Plates	0.15	0.10	1.7	6.0	64	0.010
9. Commercial, Ordinary	0.05	0.10	2.2	3.0	32	0.050
10. Commercial, Orthochromatic	0.12	0.14	2.2	4.0	50	0.033
11. Commercial, Panchromatic	0.15	0.15	2.3	3.5	32	0.050
12. Process, Ordinary	0.03	0.18	3.0	1.5	16	0.250
13. Process, Panchromatic	0.10	0.12	3.0	2.0	16	0.143
14. Lantern Slide Plate	0.03	0.22	3.0	1.2	16	0.500

FORMULA FOR LABORATORY PYROGALLOL DEVELOPER

Solution A	g	Solution B	g
Na_2SO_3	70	Na_2CO_3, anhyd	75
$NaHSO_3$	17	KBr	1
Pyrogallol	20	Water to 1 liter	
Water to 1 liter			

Temperature 20°C. For use, mix equal volumes of A and B.

Spectral Sensitivity of Photographic Materials

The spectral distribution of sensitivity for practical purposes is shown qualitatively by means of wedge spectrograms. These are made by the use of a spectrograph over the slit of which is mounted a wedge of neutral gray glass, the transmission of which decreases logarithmically from the thin to the thick end. The wedge constant was 0.75/mm. In this way the exposure incident on the photographic material for any particular wave-length decreases logarithmically in a direction parallel to the slit of the instrument. When such an exposure is developed the silver deposit on the plate outlines approximately a curve which is the resultant of the *spectral sensitivity* function of the material and the *spectral distribution of energy* in the radiation emitted by the source used for illuminating the slit of the instrument.

The source used in making the spectrograms (Figs. 2 and 3) was the acetylene flame which operates at the color temperature of 2360°K. All plates were given the same exposure. Since the same source was used in all cases, the curves as outlined by the light areas show the *relative spectral sensitivity* of the various materials. By the application of a correction based upon the spectral distribution of energy radiated by a black-body at 2360°K, an approximation to the actual spectral sensitivity of these materials may be obtained. The neutral glass wedge used over the slit of the instrument while fairly non-selective in absorption for radiation of wave-lengths longer than 450 mμ, increases in density for radiation of wave-lengths shorter than 450 mμ. The apparent falling off in sensitivity in the region of wave-lengths shorter than 450 mμ is therefore due to excessive absorption of the neutral wedge rather than to a decrease in the spectral sensitivity of the material (26, 39).

Resolving Power, Sharpness, and Astro Gamma

Resolving Power

The capacity of the photographic plate or film to render fine detail is usually referred to as its resolving power (R). Resolving power is usually determined by photographing on the material a

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[1] Sometimes called Scale, *see* (5).

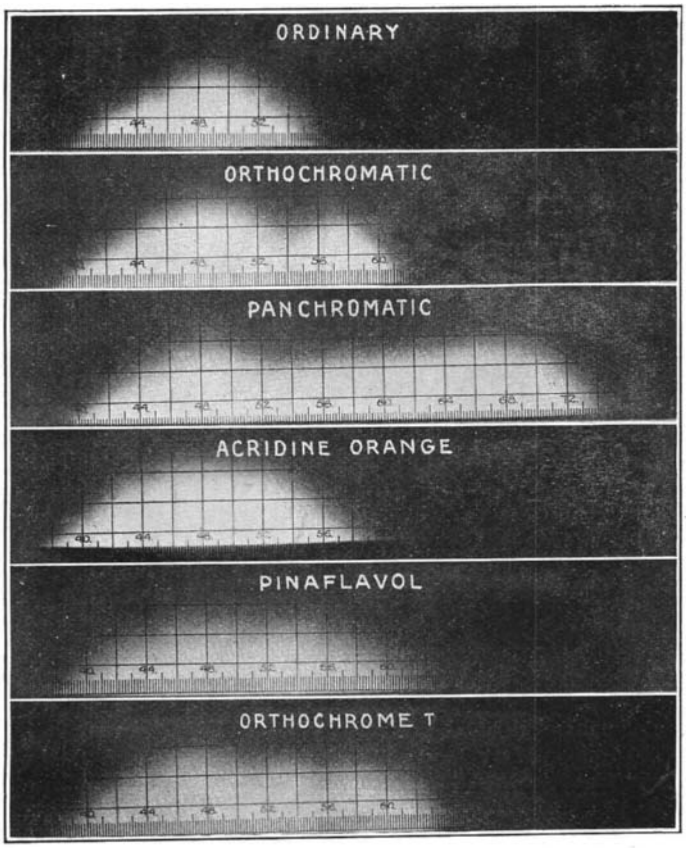

Fig. 2.

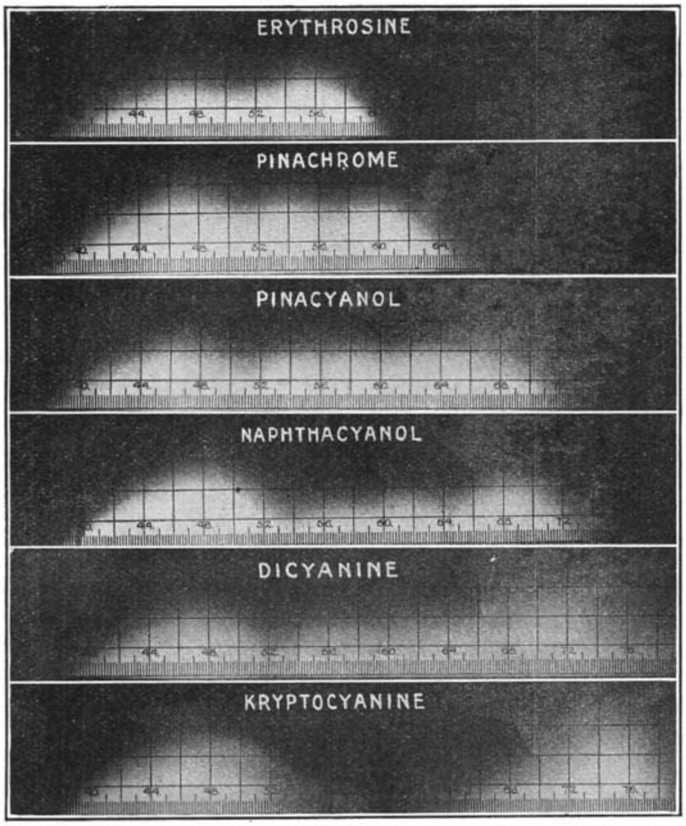

Fig. 3.

grating consisting of alternate light and dark lines, each line being of a width equivalent to the space between the consecutive lines. Resolving power is then specified by stating the number of lines per mm resolvable by the material. For detailed descriptions of methods, *v.* (25, 31).

In Table 1 are given the values of resolving power, as determined by the fan method (25), for a group of materials differing widely in sensitivity. Pyrogallol developer was used in all cases with the exception of the albumen plate, which was developed physically. The light source used in making the exposure was a gas-filled tungsten lamp operated at approximately 2800°K.

Table 1 (19)

Plate	Relative speed	Resolving power
Albumen	0.01	125
W and W Resolution	3.0	81
W and W Slow Process Pan	5.0	67
Seed Lantern (yellow label)	6.0	62
Positive Motion Picture Film	10.0	42
Seed 23	150.0	35
W and W Panchromatic	200.0	31
Seed 30	400.0	29
Seed Graflex	450.0	25

The resolving power of a photographic plate is dependent to a certain extent upon the reducing agent used in the developing solution. It is also dependent to a certain extent upon the length of time of development and upon exposure. For any given photographic material and developing solution there is a combination of development time and exposure which gives a maximum resolving power. Values of maximum resolving power, as determined by the fan method (25), for various developers are given in Table 2, the light source being a gas-filled tungsten lamp operated at 2800°K.

Table 2 (19)

Developer	Maximum resolving power	Exposure (in sec)	Development (in min)
Pyrogallol, NaOH	77.0	4	2
Glycine	69.0	3	1
Quinol	64.0	3	2
Pyrogallol, Na_2CO_3	64.0	3	2
Metol-quinol	64.0	3	2
Metol	63.0	3	2
Nepera	62.0	3	2
Pyrocatechol	62.0	8	2
Pyro-metol	62.0	8	2
Eikonogen-quinol	61.0	4	3
Ferrous oxalate	61.0	2	4
Caustic quinol	57.0	4	2
Eikonogen	57.0	4	4
Amidol	51.0	2	4
Kachin	54.0	2	5
Ortol	49.0	4	2
p-Aminophenol	49.0	8	2
Edinol	47.0	4	16

Curves showing the relation between *wave-length* and *resolving power* (fan method) for Seed 30 (S30), Seed 23 (S23), Seed Process (SP), and Wratten and Wainwright Process Panchromatic (WWPP) are shown in Fig. 4 (30, 31).

The increase in resolving power resulting from bathing the material in a solution of yellow dye prior to exposure is shown by the curves marked (YD). The ordinate values are in lines per mm (fan method) which can be resolved under the conditions specified.

Values of resolving power determined by using series of parallel lines may be more directly applicable for practical purposes especially from the standpoint of spectroscopy. In Table 4 (^{6}) are given values determined in this way for a series of typical photographic materials. The test object was illuminated by light of daylight quality. An image, at a magnification of 0.05, was projected on the surface of the photographic material by means of a highly corrected lens. The exposures were such that a development to gamma of unity in pyrogallol at 20°C gave the maximum resolving power.

Sharpness

The "sharpness" characteristic of a photographic material is defined as the differential of density (D) with respect to distance (s) in a direction perpendicular to the edge of the image; sharpness (S) = dD/ds, where s is expressed in microns (0.001 mm).

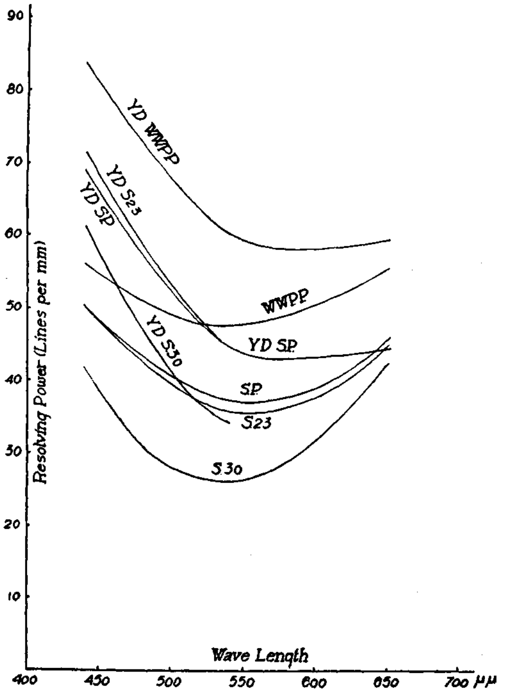

FIG. 4.

The images used for determination of sharpness are obtained by making a contact print of a very carefully prepared knife edge. The exposing radiation used in making the print is carefully collimated and incident normal to the surface of the material being examined.

The sharpness of the developed image depends upon the extent to which development is carried and this is specified by the value of gamma (γ), $\frac{\mathrm{d}D}{\mathrm{d}\log_{10}E}$.

The curves of Fig. 5 ($^{30, 31}$) show the relation between sharpness and gamma for various developers. The plate used in obtaining these values was a Seed Panchromatic and the exposing radiation was monochromatic of wave-length 440mμ.

Sharpness is independent of exposure, at least over a considerable range, as shown in Table 3. The term "light exposure" is used to designate an exposure resulting in an image density of approximately 1.0, while the term "heavy exposure" is used to designate an exposure resulting in an image density between 2.0 and 3.0. The plate used was a Seed Panchromatic developed in caustic hydroquinol.

TABLE 3.—DENSITY GRADIENTS

	λ = 420mμ			λ = 520mμ			λ = 660mμ		
Development time, min.	0.75	1.5	3.0	0.75	1.5	3.0	0.75	1.5	3.0
For light exposure....	0.107	0.136	0.143	0.051	0.059	0.069	0.053	0.070	0.082
For heavy exposure...	0.112	0.133	0.151	0.045	0.061	0.063	0.056	0.064	0.086

The relation between sharpness and wave-length of the exposing radiation is shown in Figs. 6 and 7 ($^{30, 31}$), the former applying to a panchromatic (Seed Panchromatic) and the latter to an orthochromatic (Standard Orthonon) material.

Values of sharpness for a group of typical materials are given in Table 4 (^{6}). The quality of light used in making the exposures was equivalent to average daylight. The exposure was so adjusted that development to gamma of unity in pyrogallol at 20°C gave an image density of unity. The values of sharpness express the diffuse-density gradient (dD/ds) of the straight line portion of the sharpness curve obtained by plotting diffuse-density (D) as a function of the distance (s) from the geometrical edge of the image.

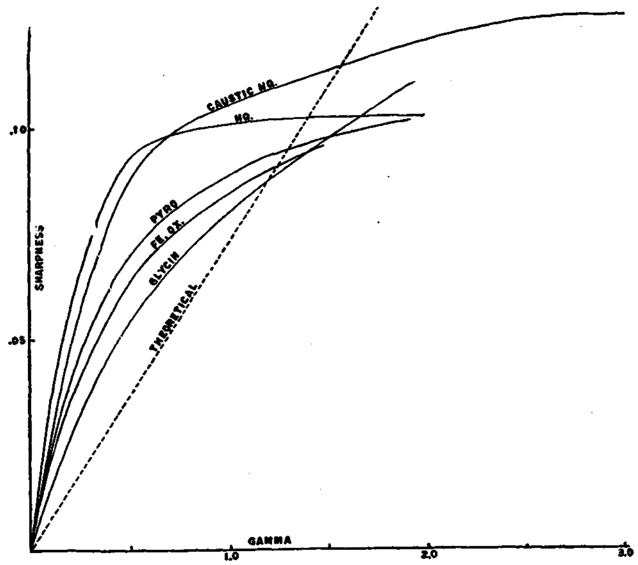

FIG. 5.

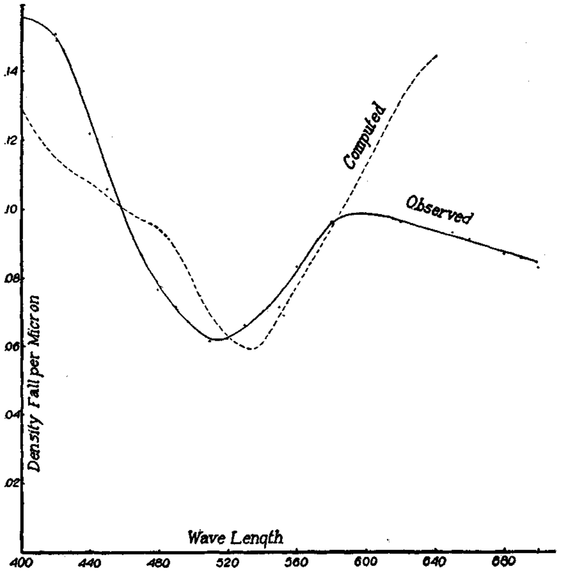

FIG. 6.

Astro Gamma

Astro gamma is defined as the coefficient (b) of $\log_{10} E$ in the Scheiner equation, which gives the relation between the diameter (D) of a stellar image and the exposure (E): $D = \mathrm{a} + \mathrm{b}\log_{10} E$.

Since exposure (E) = intensity (I) × time (t) this equation offers a means of determining the relative brightness of stars by measurement of the diameter of the stellar images obtained under known conditions of exposure and development. The ordinate values used in plotting Fig. 8 are relative and must be multiplied by 3.33 ($1/\log_{10} 2$) in order to obtain actual values of astro gamma as defined above.

In Table 4 ([6]) are given values of astro gamma for a group of typical photographic materials. These values were determined by photographing with a highly corrected lens, using a magnification of 0.05, a circular aperture having a diameter of 0.56 mm. Exposing radiation was of daylight quality and intensity was so adjusted that an exposure of 1 second was just above the threshold value. Keeping the intensity factor constant, the exposure time was increased by consecutive powers of 2 from 1 to 512 seconds. The exposed plates were developed to a gamma of unity in standard pyrogallol at 20°C.

TABLE 4

Emulsion	Resolving power	Sharpness	Astro gamma
Eastman Lantern	140	0.168	39*
Eastman Process	140	0.156	30*
Eastman Cine Positive	120	0.103	26*
W and W Process Panchromatic	102	0.092	33
Eastman 33	95	0.088	32
Eastman D. C. Ortho	80	0.097	41
Eastman Universal	70	0.093	40
Eastman 40	70	0.071	49*
Eastman Speedway	60	0.080	44
Eastman Cine, Par Speed	60	0.085	35
Eastman Cine Superspeed	50	0.080	36
Eastman Superspeed Portrait	50	0.065	43

* The growth of the diameter with the log exposure deviates much from a linear relationship. The value given is the average of the values over the whole range of exposures.

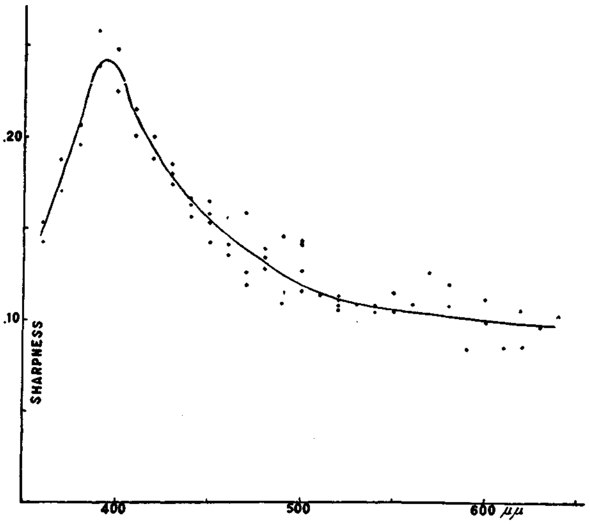

FIG. 7.

Relative Photographic Efficiency of Illuminants ([23])

C = luminous efficiency of source (lumen/watt). E_r = relative photographic efficiency of source evaluated on basis of equal visual intensities, sunlight = 100%. E_e = relative photographic efficiency of source evaluated on basis of equal energy consumption by the source, sunlight = 100%.

Efficiency of Illuminants.—(*Continued*)

Source	C	Photographic material				Panchromatic	
		Ordinary		Orthochromatic			
		E_r	E_e	E_r	E_e	E_r	E_e
Sun	150	100	100	100	100	100	100
Sky		181		155		130	
Acetylene	0.7	30	0.14	44	0.21	52	0.24
Acetylene (screened)*	0.07	81	0.037	85	0.040	89	0.042
Pentane	0.45	18	0.053	28	0.086	42	0.13
Mercury arc in quartz	40.0	600	158	500	132	367	99
Mercury arc in nultra glass	35.0	218	50	195	46	165	39
Mercury arc in crown glass	37.0	324	79	275	68	249	62
Carbon arc, ordinary	12.0	126	10	112	9	104	8.5
Carbon arc, white flame	29.0	257	52	234	45	215	4.2
Carbon arc, enclosed	9.0	175	11	177	11	165	10
Carbon arc, "Aristo"	12.0	796	62	1070	86	744	60
Magnetite arc	18.0	106	12	115	14	82	10
Carbon glow lamp	2.4	23	0.37	32	0.52	42	0.68
Carbon glow lamp	3.2	25	0.51	35	0.74	45	0.95
Tungsten (vacuum)	8.0	33	1.7	41	2.2	50	2.7
Tungsten (vacuum)	9.9	37	2.4	45	3.0	53	3.5
Tungsten (gas filled)	16.6	56	6.1	62	6.8	70	7.7
Tungsten (gas filled)	21.6	64	8.9	68	9.8	76	11.0
Tungsten (C_3)	8.9	95	5.5	87	5.2	95	5.6
Tungsten (C_3)	11.0	108	7.8	99	7.3	106	7.9
Mercury vapor	23.0	316	47	354	54.2	273	42.0

* Screened with Wratten No. 79 filter.

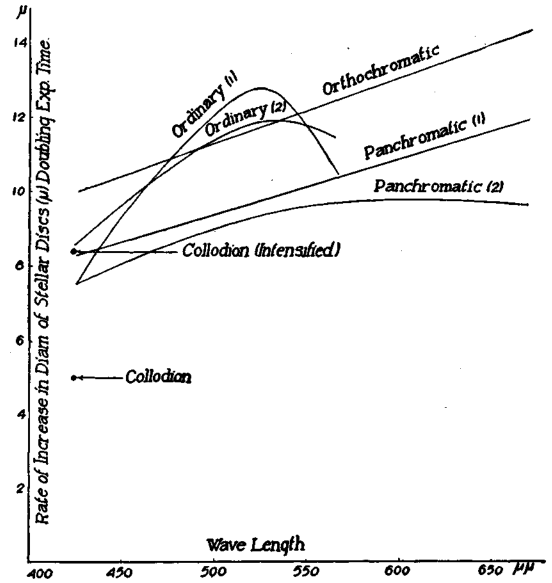

FIG. 8.

Gloss of Photographic Papers

Definition of Gloss.—With the surface illuminated by a collimated beam of light incident at 25° from the normal to the surface, B_a is the brightness of the sample as observed on the line of specular reflection (angle of observation equal to angle of incidence) and B_d is the brightness of the surface observed normally.

Specular brightness, $(B_s) = B_a - B_d$; diffuse brightness, $(B_d) = B_d$; gloss $(G) = \frac{B_s}{B_d} = \frac{B_a - B_d}{B_d} = \frac{B_a}{B_d} - 1$.

RANGE OF GLOSS VALUES

Matte	Semi-matte	Semi-gloss	Gloss
0–1	1–3	3–7	7–∞*

* Actual limit = 75.

These values apply to samples which were fixed out without exposure and hence represent the white paper without any developed silver deposit ([22]).

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(For a key to the periodicals see end of volume)

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(10) Eggert and Noddack, *96*, **20**: 299; 23. (11) Ferguson, *204*, **30**: 182; 06. (12) Ferguson, *204*, **34**: 412; 10. (13) Ferguson, *The Photographic Researches of F. Hurter and V. C. Driffield*. London, The Royal Photographic Society, 1920. (14) Gordon, *50*, **17**: 47; 13. (15) Higson, *204*, **44**: 161; 20. (16) Higson and Toy, *204*, **47**: 68; 23. (17) Hurter and Driffield, *54*, **9**: 455; 90. (18) Hurter and Driffield, *204*, **22**: 186; 98. (19) Huse, *48*, **1**: 119; 17.

(20) Huse, Eastman Kodak Co., Rochester, N. Y., *0*. (21) Jones, *48*, **6**: 140; 22. (22) Jones and Fillius, *547*, **69**: 216, 229; 22. (23) Jones, Hodgson and Huse, *84*, **10**: 963; 15. (24) Lüppo-Cramer, *545*, **40**: 670, 710; 03. (25) Mees, *5*, **83**: 10; 09. (26) Mees, *143*, **201**: 525; 26. (27) Meidinger, *7*, **114**: 89; 24. (28) Nietz, *B97*. (29) Nutting, *128*, **3**: 322; 13.

(30) Ross, *21*, **52**: 201; 20. (31) Ross, *Physics of the Developed Photographic Image*. New York, Van Nostrand, 1924. (32) Scheffers, *96*, **20**: 109; 23. (33) Sheppard, *4*, **87**: 1311; 05. (34) Sheppard, *4*, **89**: 530; 06. (35) Sheppard, *78*, **39**: 429; 22. (36) Sheppard and Mees, *5*, **76**: 217; 05. (37) Sheppard and Mees, *Investigations on the Theory of the Photographic Process*. London, Longmans, 1907. (38) Toy and Edgerton, *3*, **48**: 947; 24. (39) Walters and Davis, *31A*, **17**: 353; 21.

(40) Watkins, *Photography, Its Principles and Applications*. New York, Van Nostrand, 1911. (41) Weigert, *7*, **99**: 499; 21. (42) Weigert, *76*, **1921**: 641. (43) Weigert, *96*, **18**: 232; 23. (44) Wilsey, *in B97*.

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Symbols and Molecular Weights

N_w (resp. N_v) = Gram-moles per kg H_2O (resp. per l solution), % = weight per cent

Symbol	Name	Mol. wt.	Symbol	Name	Mol. wt.
NaC_6	Caproate or hexoate.	138.082	KC_{18}	Stearate.	322.365
KC_6		154.180	NaC_{22}	Behenate.	362.328
NaC_8	Caprylate or octoate.	166.113	$C_{16}SO_3H$	Cetylsulfonic or hexadecanesulfonic acid. .	306.327
KC_8		182.211	$C_{16}SO_3Na$	Cetylsulfonate.	328.316
NaC_9	Nonylate.	180.128	$NaC_{18}^{=}$*	Oleate.	304.251
NaC_{10}	Caprate or decoate.	194.143	$KC_{18}^{=}$*	Oleate.	320.349
KC_{10}		210.241	$NH_4C_{18}^{=}$	Oleate.	299.293
NaC_{12}	Laurate.	222.174	$NaC_{18}^{==}$	Linolate.	302.236
KC_{12}	Laurate.	238.272	$KC_{18}^{==}$	Linolate.	318.334
NaC_{14}	Myristate.	250.205	$NaC_{22}^{=}$	Erucate.	360.313
KC_{14}	Myristate.	266.303	$KC_{22}^{=}$	Erucate.	376.411
NaC_{16}	Palmitate.	278.236	$NaC_{18}^{===}$	Linolenate.	300.22
KC_{16}	Palmitate.	294.334	$KC_{18}^{===}$	Linolenate.	316.318
NH_4C_{16}	Palmitate.	273.278	$NaC_{18}^{=}OH$	Ricinoleate.	320.251
NaC_{18}	Stearate.	306.267	$KC_{18}^{=}OH$	Ricinoleate.	336.349

* The symbol $C_{18}^{=}$ is used in the tables for oleates only, the stereoisomeric elaidates being named in full.

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* The symbol $C_{18}^{=}$ is used in the tables for oleates only, the stereoisomeric elaidates being named in full.

Conversion Formulae

$$\text{Wt. \%} = \frac{\text{Mol. wt.} \times N_w}{\text{Mol. wt.} \times N_w + 1000} \times 100$$

$$N_w = \frac{\text{Wt. \%}}{\text{Mol. wt.}} \times \frac{1000}{100 - \text{Wt. \%}}$$

$$N_v = \frac{\text{Wt. \%} \times \text{density of solution} \times 10}{\text{Mol. wt.}}$$

Equilibria within Soap Solutions

The diagrams, Figs. 1–19, represent the proportions of the various constituents in equilibrium with each other in the soap solutions. They are obtained primarily from a comparison of conductivity and osmotic data but some of the results are confirmed by measurements of Na and K ion by emf, ultrafiltration, etc. In each *concentration* the sum total of *constituents containing* fatty acid radical is taken as 100% (the total height of the diagram) which is the sum of the following: Colloidal neutral undissociated soap, crystalloidal undissociated soap, fatty ion and fatty ion aggregated as ionic micelle; in addition there is free Na or K ion equal in amount to the number of equivalents of free fatty ion plus the fatty ion in ionic micelle. To read off the actual concentration of any one constituent at a given concentration the width of the field representing that constituent must be multiplied by the total concentration of the solution. The uncertainty in the position of the boundaries between fields is estimated as about 10% of the total amount of soap. For further description, *see* (89). Constituents of a soap solution containing added salt (109).

SYMBOLS

N	Neutral colloid, *e.g.*, $(KC_{18})_x$.
S	Simple soap molecules, *e.g.*, KC_{18}.
S′	Simple fatty ions, *e.g.*, C_{18}^{-}.
A	Acid soap.
M	Ionic micelle, *e.g.* $(C_{18}^{-})_n$.

Viscosity

Values of η in poises

SOLUTIONS OF PURE SOAPS. *See* FIGS. 20, 21, AND 22

Capillary viscometer with absolute dimensions such that kinetic correction did not exceed 1%. Viscosity compared with that of water at 20° taken as unity (51).

Soap	N_v at 90°	20°	30°	45°	60°	90°
KC_{12}	0.1	1.15		0.671	0.532	0.352
	0.2	1.41	1.13	0.846	0.661	0.434
	0.375	1.96		1.16	0.906	0.604
	0.4	2.08	1.65	1.24	0.962	0.626
	0.6	3.28	2.61	1.97	1.54	1.03
	0.8	4.97	4.01	3.04	2.37	1.55
	1.0	8.42	6.94	5.38	4.24	2.81
KC_{14}	0.054	1.14	0.895	0.672	0.519	0.346
	0.216	1.70	1.32	0.983	0.752	0.497
	0.431	2.83	2.17	1.63	1.25	0.825
	0.649	4.94	3.84	2.87	2.22	1.45
	0.815	9.34	7.67	5.86	4.56	2.85
	1.035	39.1	36.2	28.3	17.7	6.47
KC_{18}^{-}	0.052	1.19	0.95	0.709	0.545	0.364
	0.2	1.87	1.47	1.10	0.837	0.500
	0.375	4.19		1.91	1.39	0.919
	0.4	8.02	4.69	3.12	1.99	1.13
	0.6	1573		60.22	18.03	3.80

See further the following references: NaC_{16}, KC_{16} (3, 99), KC_{18}^{-} (11), NaC_{18} (99), NaC_{18}^{-} (99), $NH_4C_{18}^{-}$ (2, 33, 34, 35), Na salt of fatty acids from tallow and from coconut oil (99). K and NH_4 salts of fatty acids from palm kernel oil (27, 28, 51).

VISCOSITY OF SOAP SOLUTIONS WITH ADDITIONS OF OTHER SOLUTES

Bibliography only

Soap	Addition	Lit.
KC_{12}	KOH	(51)
KC_{12}	KC_{18}^{-}(I + KOH)	(51)
KC_{18}^{-}	KOH	(51)
K (palm)*	KOH	(27)
	KCl	
K (palm)*	Glycerol	(28)
	Acetone	
K (palm)*	K_2CO_3	(51)
	KOH	
K (coco)†	KCl	(56)
	KC_{18}	
NaC_{12}	NaOH	(108)
NaC_{16}	NaCl	(44, 91)
	Na_2CO_3	
	$NaC_2H_3O_2$	
	NaOH	(22)
	NaCl	
	KCl	
NH_4 (palm)*	NH_3	(28)
	NH_4Cl	
	Both	

* Palm kernel oil acids. † Coconut oil acids.

Density (Specific Gravity)

$d_4^t = \text{A} + \text{k}N_w$; VALUES OF d_4^{18}; A = 0.9986 = d_4^{18} of H_2O

Soap	$0.05N_w$	$0.1N_w$	$0.2N_w$	$0.5N_w$	$1.0N_w$	k	Lit.
NaC_8*	1.003	1.004	1.008	1.016	1.030	†	(54)
NaC_{12}*	1.001	1.002	1.004			†	(54)
$NaC_{18}^{=}$	0.9990	0.9995	1.0005	1.0035		+0.0098	(53, 77)
$KC_{18}^{=}$	0.9992	0.9998	1.0010	1.0047		+0.0122	(77)
K elaidate	0.9990	0.9994	1.0001	1.0024		+0.0076	(90)
$NaC_{18}^{\equiv}$	0.9993	1.0001	1.0016	1.0060		+0.0148	(84)
$NaC_{18}^{=}OH$	1.000	1.0013	1.0038	1.0097	1.017	†	(71)

* Volume normality (N_v) and d_{18}^{18}. † Not linear.

VALUES OF d_4^{90}; A = 0.9653 = d_4^{90} of H_2O

Soap	$0.2N_w$	$0.5N_w$	$1.0N_w$	k	Lit.
KC_6	0.972	0.982	0.998	+0.033	(16)
KC_8	0.9702	0.9777	0.9902	+0.0249	(16)
NaC_9	0.9690	0.9744	0.9833	+0.0180	(26)
KC_{10}	0.9689	0.9743	0.9833	+0.0180	(16)
NaC_{12}	0.9668	0.9692	0.9731	+0.0029	(70)
KC_{12}	0.9676	0.9712	0.9770	+0.0117	(16)
NaC_{14}	0.9658	0.9665	0.9678	−0.0025	(70)
KC_{14}	0.9667	0.9688	0.9723	+0.0070	(16)
NaC_{16}	0.9647	0.9639	0.9624	−0.0029	(18)
KC_{16}	0.9659	0.9667	0.9680	+0.0027	(16)
NaC_{18}	0.9631	0.9599		−0.0108	(18)
KC_{18}	0.9650	0.9645	0.9637	−0.0016	(16)
NaC_{22}	0.96312	0.96		−0.011	(26)
$C_{16}SO_3H$	0.9637	0.9613		−0.0080	(100)

For the K salt of palm-kernel oil (also with added KOH) at 20°, 60°, and 90°, *v.* (27). For the NH_4 salt of palm-kernel oil at 20°, 45°, and 60°, *v.* (28).

VALUES OF d_4^t FOR $0.1N_v$ SOLUTIONS (3)

	35°	45°	55°	65°	75°	85°
NaC_{16}			0.986	0.981	0.974	0.968
KC_{16}	0.994	0.991	0.987	0.982	0.975	0.969

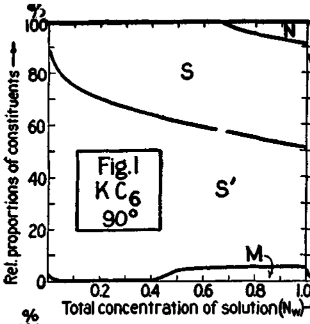


Fig.1 KC_6 90°

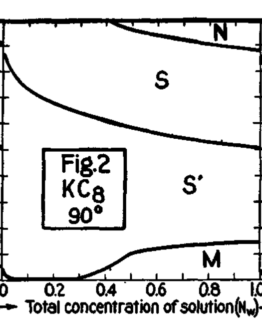


Fig.2 KC_8 90°

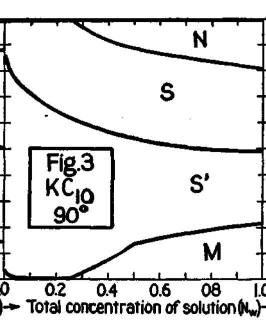


Fig.3 KC_{10} 90°

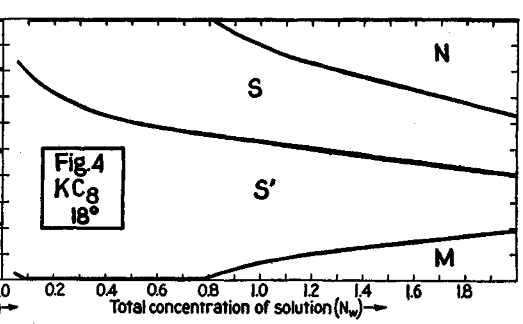


Fig.4 KC_8 18°

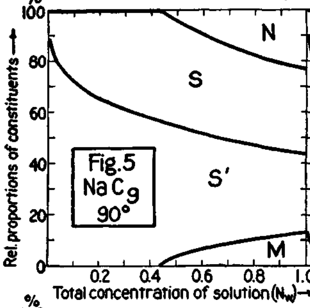


Fig.5 NaC_9 90°

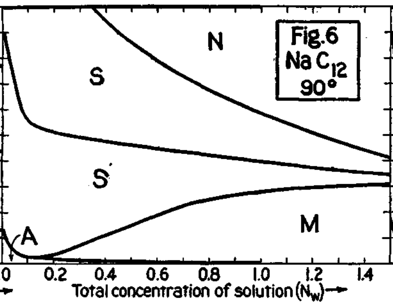


Fig.6 NaC_{12} 90°

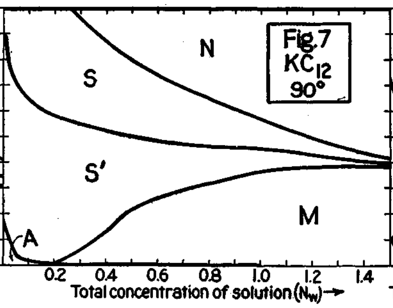


Fig.7 KC_{12} 90°

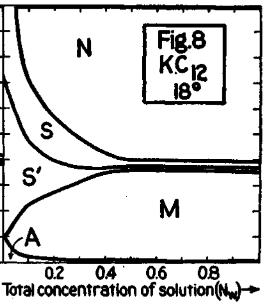


Fig.8 KC_{12} 18°

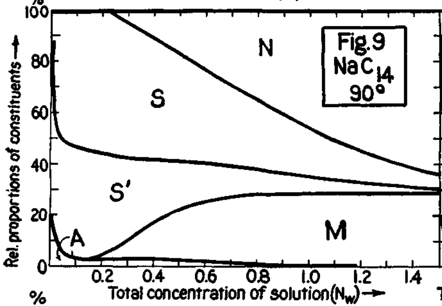


Fig.9 NaC_{14} 90°

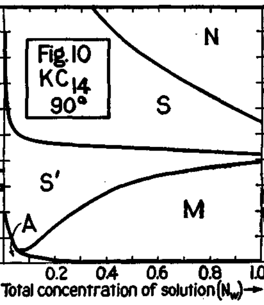


Fig.10 KC_{14} 90°

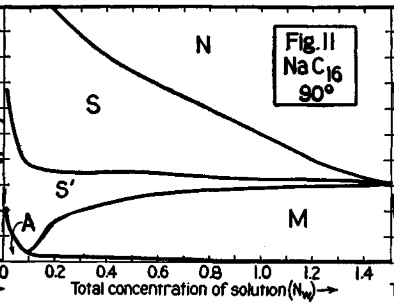


Fig.11 NaC_{16} 90°

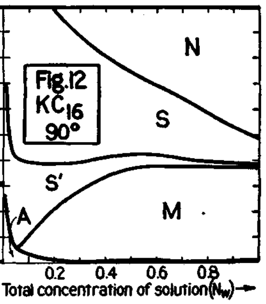


Fig.12 KC_{16} 90°

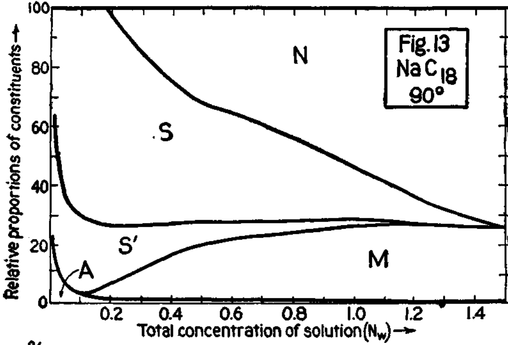


Fig.13 NaC_{18} 90°

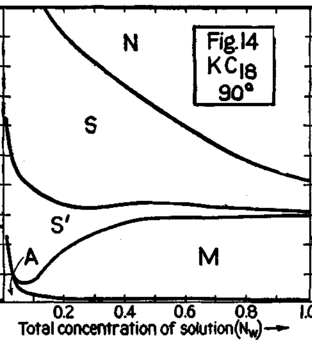


Fig.14 KC_{18} 90°

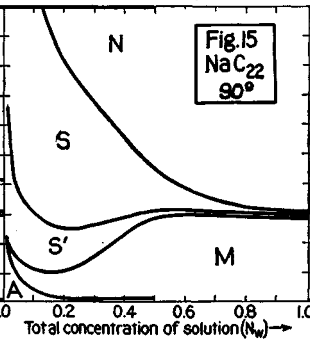


Fig.15 NaC_{22} 90°

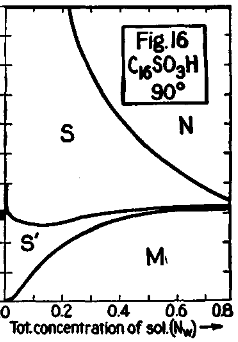


Fig.16 $C_{16}SO_3H$ 90°

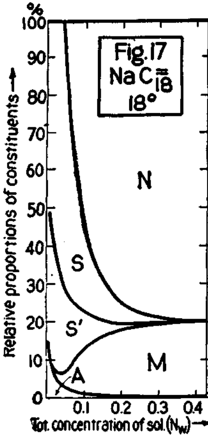


Fig.17 $NaC_{\overset{=}{18}}$ 18°

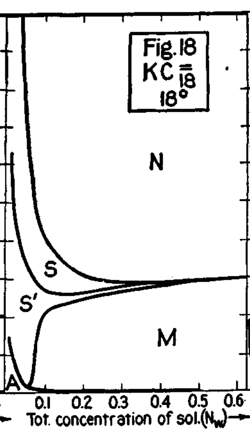


Fig.18 $KC_{\overset{=}{18}}$ 18°

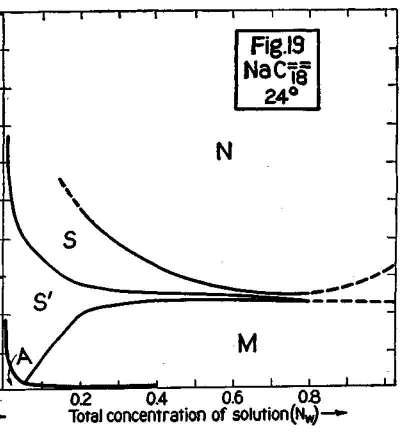


Fig.19 $NaC_{\overset{\equiv}{18}}$ 24°

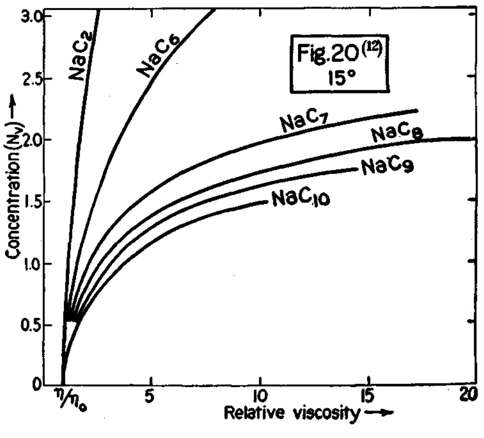


Fig.20(12) 15°

VALUES OF d_4^t FOR $NaC_{18}^{=}$

For the anhydrous soap, $d_4^{20} = 0.821$ (101)

N_v \ t, °C	16 (54)	20 (32)	N_w \ t, °C	0 (53)	10 (53)
0.005	1.001*	0.9983	0.2	1.0012	1.0005
0.01	1.001*	0.9984	0.4	1.0040	1.0029
0.1	1.003*	0.9989	0.6	1.0068	1.0062
0.2	1.004*				

* d_{16}^{16}.

VALUES OF d_4^t

N_v =	0.0001	0.001	0.01	0.05	Lit.
NaC_6, d_{15}^{15}	0.9991	0.9991	1.001	1.003	(54)
NaC_9, 20°	0.9484	0.9985	0.9986		(30)
NaC_{12}, 25°			0.9973	0.9985	(70)
$NaC_{18}^{==}$* 23.8°	0.9973	0.9973	0.9974	0.9977	(66)

N_v =	0.1	0.5	0.75	1.0	1.5	Lit.
NaC_6, d_{15}^{15}	1.004	1.020	1.031	1.040	1.057	(54)
$NaC_{18}^{==}$,* 23.8°	0.9981	1.0011	1.003	1.005		(66)

* Concentrations are weight-normal (N_w).

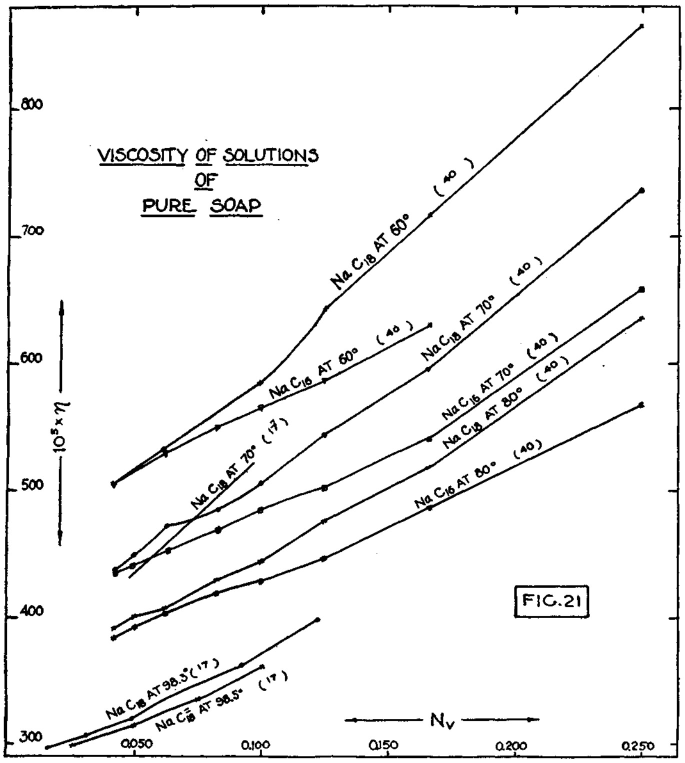


FIG. 21

SOLUTIONS OF SOAPS WITH ADDITIONS OF ALKALI, FATTY ACID AND SALTS

NaC_9 (30); NaC_{12} (70); KC_x, x = 6, 8, 10, 12, 14, 16, 18 (16); KC_{12} (109); NaC_{16} (18, 44, 89, 91); $NaC_{18}^{=}$ (32).

Surface Tension

INTERFACE AIR-AQUEOUS SOLUTION

Sodium oleate has been by far the most frequently and carefully measured, but rarely are the effects of age of solution and of age of surface mentioned. For the effect of the latter, *v.* (42). Values of γ in dyne/cm for aqueous solutions of various soaps are shown in Figs. 23, 24 and 25. For mixtures of soaps in water at 60°C, *v.* (126).

Additional Lit.: $NaC_{18}^{=}$ (7, 10, 31, 42, 63, 94, 95, 96, 97, 101, 102, 110, 111, 126, 129); NaC_{16} (127); NaC_{18} (8, 127); NaC_9 (30); $KC_{18}^{=}$ (8, 11); $NaC_{6\text{ to }10}$ (12); $MgC_{18}^{=}$ (31).

LIQUID-LIQUID INTERFACE

See (19, 31, 32, 43, 63, 103, 113, 114, 117) and Vol. IV, p. 438. In no case have the compositions of both phases been completely determined and all factors controlled. For example, interfacial tension of benzene against aqueous solutions of $NaC_{18}^{=}$ at 20°C (32):

10^3N_v	0.0	0.1	0.25	0.5	1.0	2.5	5.0	10.0	100
γ	35.0	32.6	22.6	19.5	10.8	5.37	2.76	2.29	1.46

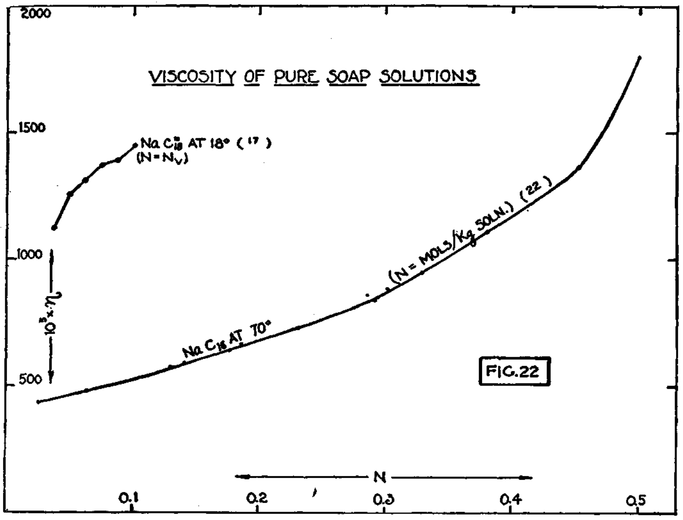


FIG. 22

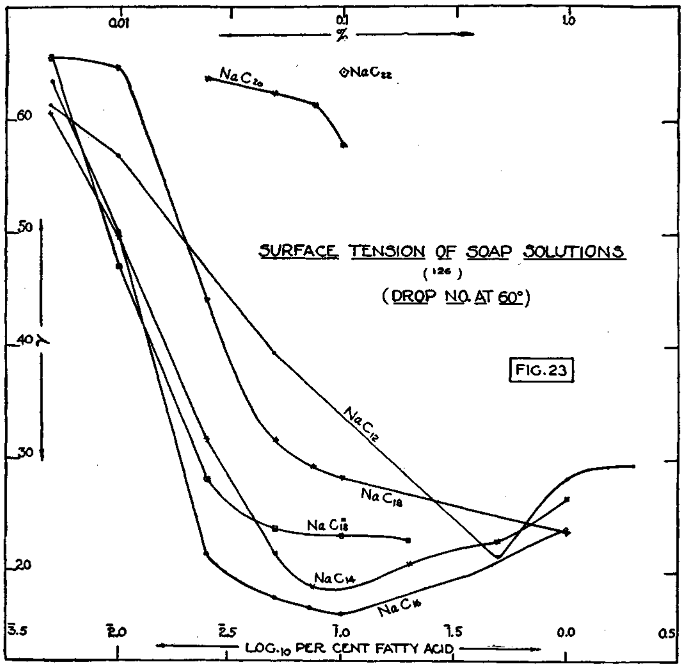
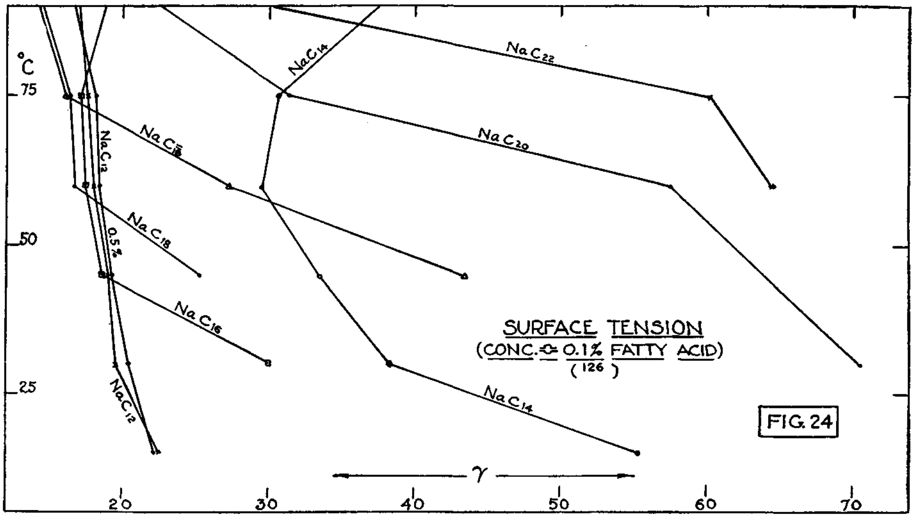


FIG. 23

Melting Points of the Pure Soaps

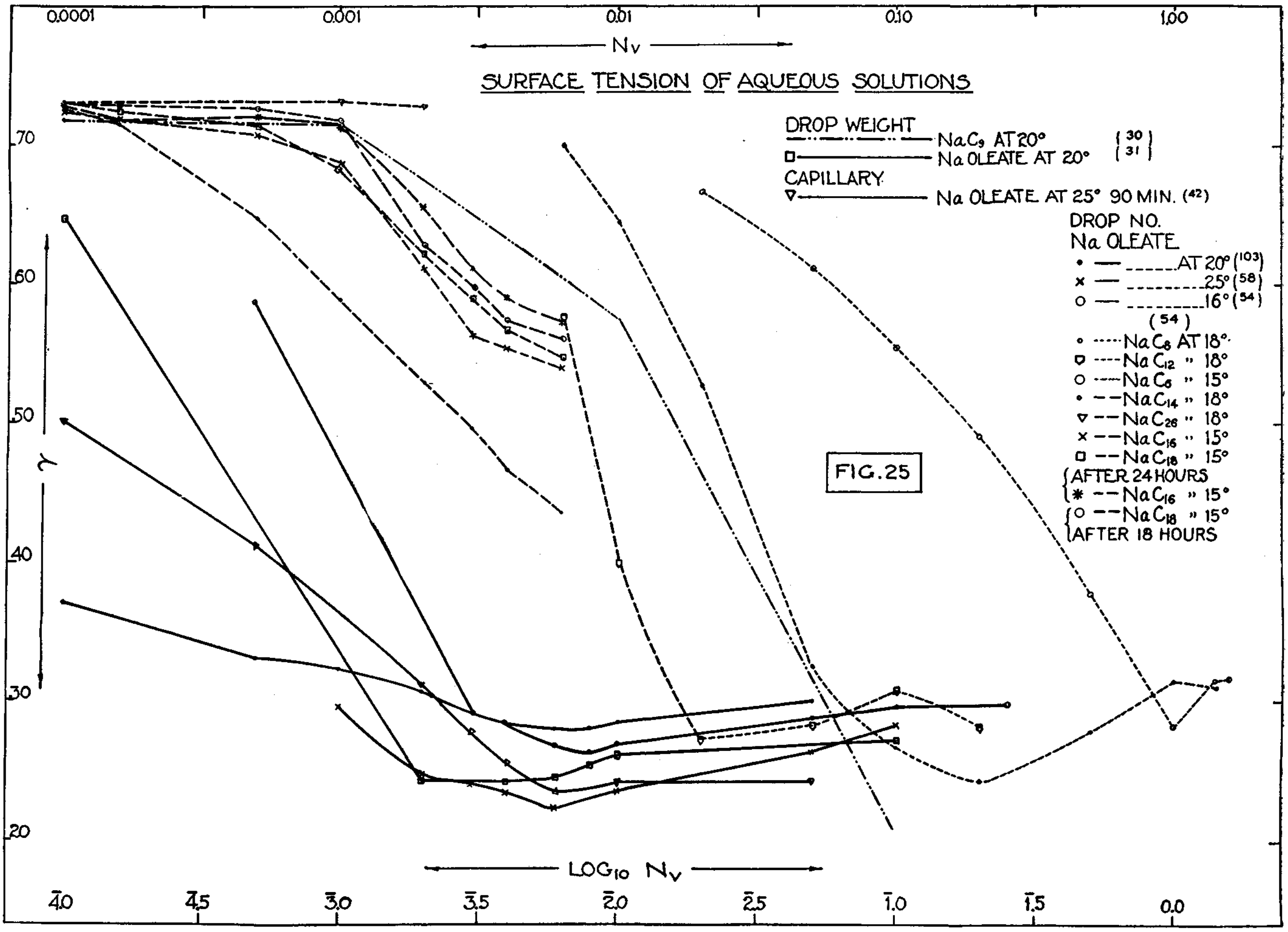
MP_1 is the melting point to form an anisotropic liquid, MP_2 the transition to an isotropic liquid.

Soap (125)	MP_1, °C	MP_2, °C	Soap (125)	MP_1, °C	MP_2, °C
NaC_6	225	350	NaC_{14}	240	330
NaC_7	240	350	NaC_{16}	220	265
KC_7	225	(400)	NaC_{18}	225	270
NaC_8	225	355		215	316
NaC_9	218	242	NaC_{18}	220	305
NaC_{10}	220	318	KC_{12} (73)	264	276
NaC_{12}	229	310			



SURFACE TENSION
(CONC. ≈ 0.1% FATTY ACID)
(126)

FIG. 24



SURFACE TENSION OF AQUEOUS SOLUTIONS

FIG. 25

Melting Points.—(*Continued*)

Soap	MP, °C	Soap	MP, °C
(46)		AgC_{16}	209 (39)
NaC_{12}	255–260	AgC_{18}	205 (39)
NaC_{14}	250	(98)	
NaC_{16}	270	PbC_6	73.5
NaC_{18}	260	PbC_7	91
$NaC_{\overline{18}}$	232–235	PbC_8	84
Na elaidate	225–227	PbC_9	94.5
Na erucate	230–235	PbC_{10}	100
Na brassidate	245–248	PbC_{12}	103.5
(39)		PbC_{14}	107
PbC_{12}	104.7	PbC_{16}	112
PbC_{14}	108.7	PbC_{18}	125
PbC_{16}	112.3	$PbC_{\overline{18}}$	45–50
PbC_{18}	115.7	(59)	
MgC_{12}	150.4	NH_4C_8	70–85
MgC_{14}	131.6	NH_4C_{12}	75
MgC_{16}	121.5	NH_4C_{14}	79–90
MgC_{18}	132	$NH_4C_{\overline{\overline{18}}}$	57.5
LiC_{12}	229.5	CuC_{16}	>100
LiC_{14}	223.9	$CuC_{\overline{18}}$	100
LiC_{16}	224.5		
LiC_{18}	221		
AgC_{12}	212.5		
AgC_{14}	211		

For MgC_{16}, and MgC_{18}, *v.* (36); for other NH_4 soaps, *v.* (13); for mixtures of NaC_{16} and HC_{16}, *v.* (20).

Phase Equilibria

Systems soap-water and soap-water-salt

Explanatory Notes.[1]—Any soap mixed with water in various proportions and under suitable conditions, can be made to assume any one of five different forms, each of which behaves as a single phase when in equilibrium with another phase. They are: (1) Lamellar crystals of soap. (2) The crystalline curd fibers of soap curd. (3) "Neat soap"—clear, transparent, plastic anisotropic liquid. (4) "Middle soap"—anisotropic. (5) Isotropic soap solutions, which includes all the more dilute solutions.

Addition of the third component, salt, introduces no new forms but the limits of concentration for the existence of the separate phases are affected.

Figures 26, 27 and 28 illustrate the limits of existence and the compositions of the various forms of soap solution with varying temperatures in the two-component system, soap-water. Figures 29–34 are the equilibrium diagrams for systems soap-water-salt at various fixed temperatures. Compositions on these triangular diagrams are in "mole fractions" based upon a fictitious molecular weight of 1000 for H_2O and using the gram-formula-weights for the soap and the salt.

Similar phase-rule diagrams (such as Figures 35, 36 and 37) have been partially constructed for commercial soaps from the scattered fragmentary data of the early workers (4, 93, 115, 123, 124); *see also* (1), demonstrating that the phase rule is of general application to all soaps, pure and commercial, and that the same phases occur in every soap system, the limits of concentration for the existence of each phase varying with the soap.

Tables 1–4 show the relative and minimum absolute amounts of various salts required to produce phase separation at 100°, Tables 1–3 referring to formation of liquid layers and Tables 3 and 4 to beginning separation of crystalline curd fibers. These ratios are approximately independent of the nature of the soap. The effects of mixtures of electrolytes are approximately additive. A mixture of soaps behaves as expected from the constituents when forming liquid layers but not when crystallizing in either curd or fiber form. These rules applied to the tables enable approximate prediction of the behavior of any soap or soap mixture. The following are maximum concentrations of salt for the formation of the liquid-liquid system nigre-lye with soaps made from separate oils studied by Merklen (93) the numbers being accurate to 0.1 or 0.2 of the values given: Sesame oil 6.8, olive 8.1, poppy seed 6.6, poppy seed reheated 7.7, lard 6.0, lard without salt 7.2, tallow 7.0, linseed 7.5, sulfur oil 13.3, saponification olein 8.6, saponification olein with glycerol 9.1, saponification stearin 6.2, cottonseed oil 8.9, peanut oil 6.7, castor oil 25.1, castor oil and peanut oil 17.6%.

Table 1 (1, 115).—Minimum Number of Grams of Various Electrolytes in 100 Cm³ of Lye at 100° Required to Maintain Two Liquid Layers (Nigre and Lye) from Potassium and Sodium Soaps, in Dilutions between $N/8$ and $N/4$ (1).

Electrolyte	KOH*	KCl	K_2CO_3	NaOH	NaCl†	Na_2CO_3
Stearate C_{18}	7	8	13	3		6
Oleate $C_{\overline{18}}$	8		15	4	5	7
Palmitate C_{16}	10	12	18	4	5	8
Linolate $C_{\overline{\overline{18}}}$	10	13	19			
Myristate C_{14}	15	20	26	8	8	16
Laurate C_{12}	21		34	12	13	
Ratios	1.50	2.00	2.78	0.87	1.00	1.84

N.B.—An equal mixture of sodium oleate and sodium myristate is half way between pure sodium oleate and pure sodium myristate.

* $KC_{\overline{22}}$ by 3 g of KOH.

† NaC_{22} by 2.3 g NaCl per 100 cm³ = $0.4N_w$ (52).

Table 2 (83).—Concentrations, N_w, of Various Sodium Salts Required to Salt Out $0.25N_w$ Solutions of Sodium Palmitate at 90°.

Anion	N_w	Anion	N_w	Anion	N_w
OH	1.13	Br	0.90	CNS	0.76
NO_3	1.05	$C_2H_3O_2$	0.89	WO_4	0.65
Cl	0.95	CO_3	0.89	Tartrate	0.65
I	0.91	SO_4	0.83		

Table 3 (1, 115).—Relative Number of Moles of Hydroxide, Chloride, and Carbonate of Sodium and Potassium Required for Salting Out Liquid Layers or Curd at 100°.

	OH	Cl	CO_3
K	1.02	1.00	0.70
Na	1.27	1.00	1.01

Table 4 (1, 115).*—Minimum Number of Grams of Various Electrolytes in 100 Cm³ Lye at 100° for Curd Fibers to Appear in Neat Soap Layer.

Electrolyte	KOH	KCl	K_2CO_3	NaOH	NaCl	Na_2CO_3
Stearate C_{18}	(17)	13	20	4		7
Oleate $C_{\overline{18}}$	10		19.5	4	5	9
Palmitate C_{16}	11		22	5	6	12
Linolate $C_{\overline{\overline{18}}}$	13	19	24			
Myristate C_{14}	18	>23	>38	9	10	17.8
Laurate C_{12}	25		>37	13	14	
Ratios	1.50	2.00	2.78	0.87	1.00	1.84

N.B.—Notice that the values for sodium salts are about half those for the corresponding potassium salts.

*Langdon (78) for NaC_{16} found 7 % NaCl, Stiepel (123) for NaC_{12}, NaC_{14}, NaC_{16} and NaC_{18} found 18, 9, 7, and 5 % NaCl respectively, as compared with Richert's 14, 10.6 and 5 %. Kronacher (25) for NaC_{10}, NaC_{12}, NaC_{14}, NaC_{16} and NaC_{18} found approximately 23, 13, 10, 7 and 5 % NaCl.

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[1] For full discussion, *see* (1).

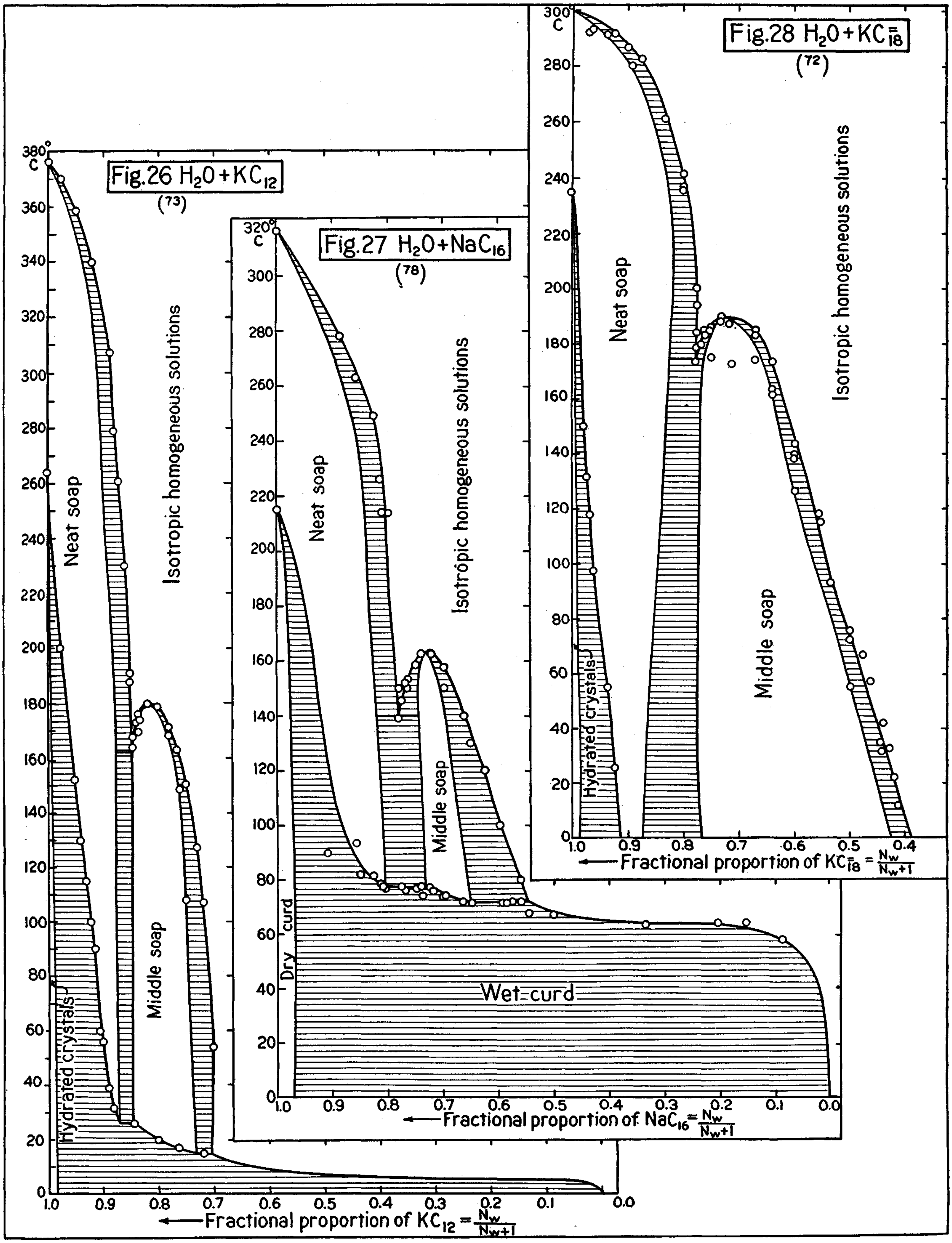


Fig. 26 $H_2O + KC_{12}$ (^{73})

Fig. 27 $H_2O + NaC_{16}$ (^{78})

Fig. 28 $H_2O + KC_{\overline{18}}^{=}$ (^{72})

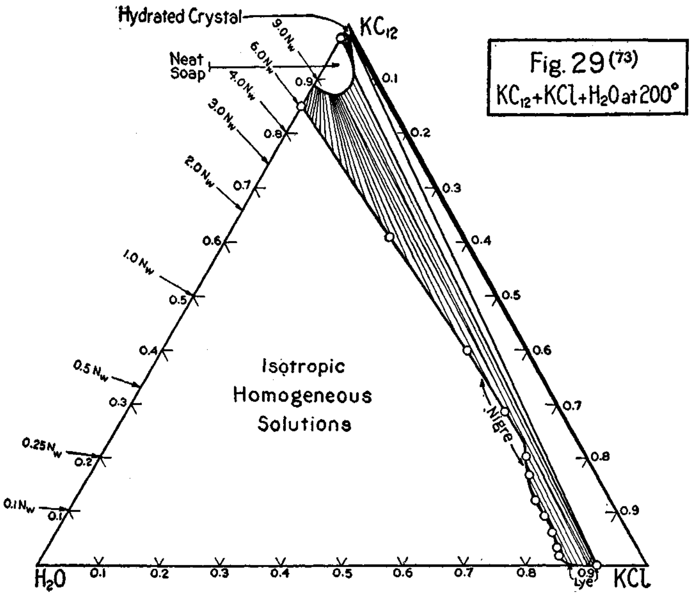


Fig. 29 (73)
$KC_{12}+KCl+H_2O$ at 200°

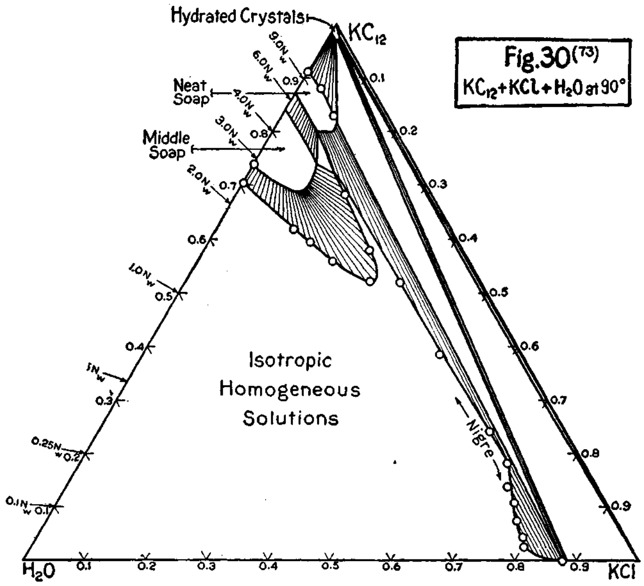


Fig. 30 (73)
$KC_{12}+KCl+H_2O$ at 90°

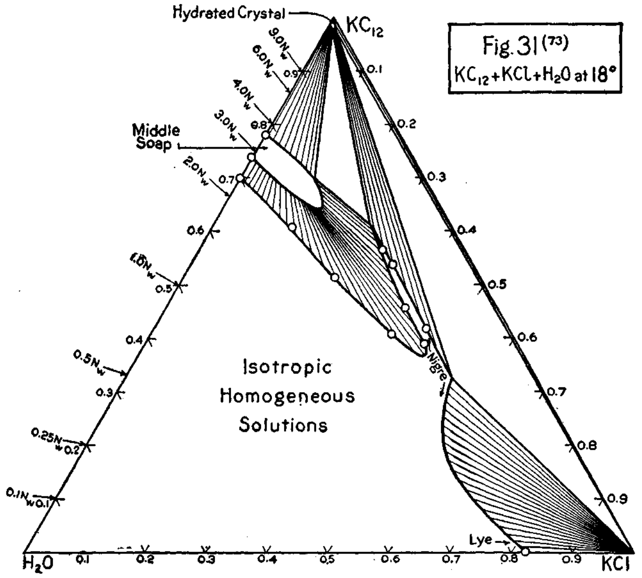


Fig. 31 (73)
$KC_{12}+KCl+H_2O$ at 18°

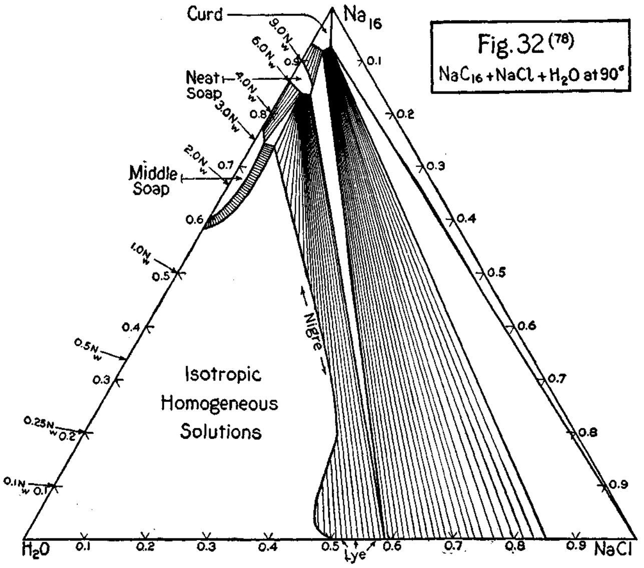


Fig. 32 (78)
$NaC_{16}+NaCl+H_2O$ at 90°

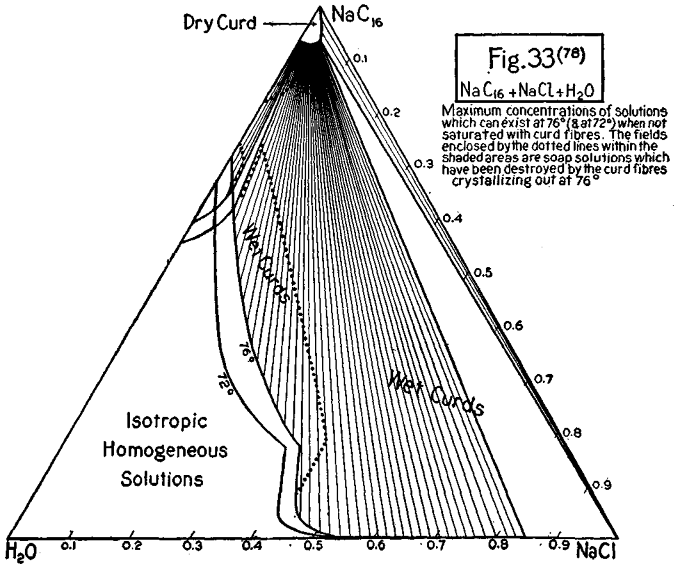


Fig. 33 (78)
$NaC_{16}+NaCl+H_2O$
Maximum concentrations of solutions which can exist at 76° (& at 72°) when not saturated with curd fibres. The fields enclosed by the dotted lines within the shaded areas are soap solutions which have been destroyed by the curd fibres crystallizing out at 76°

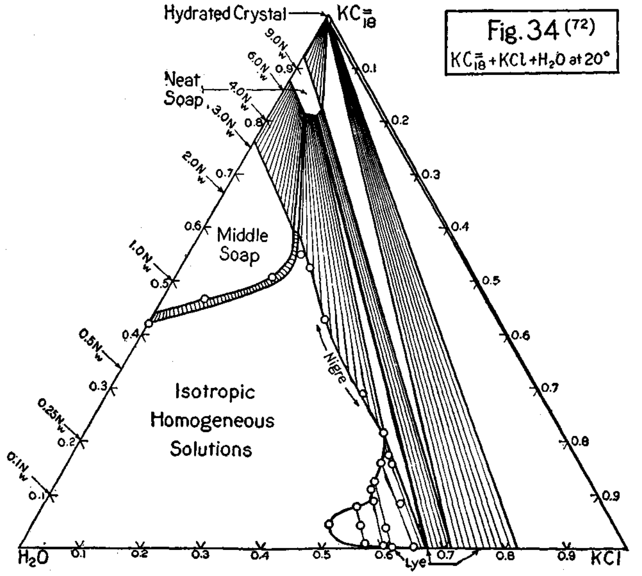
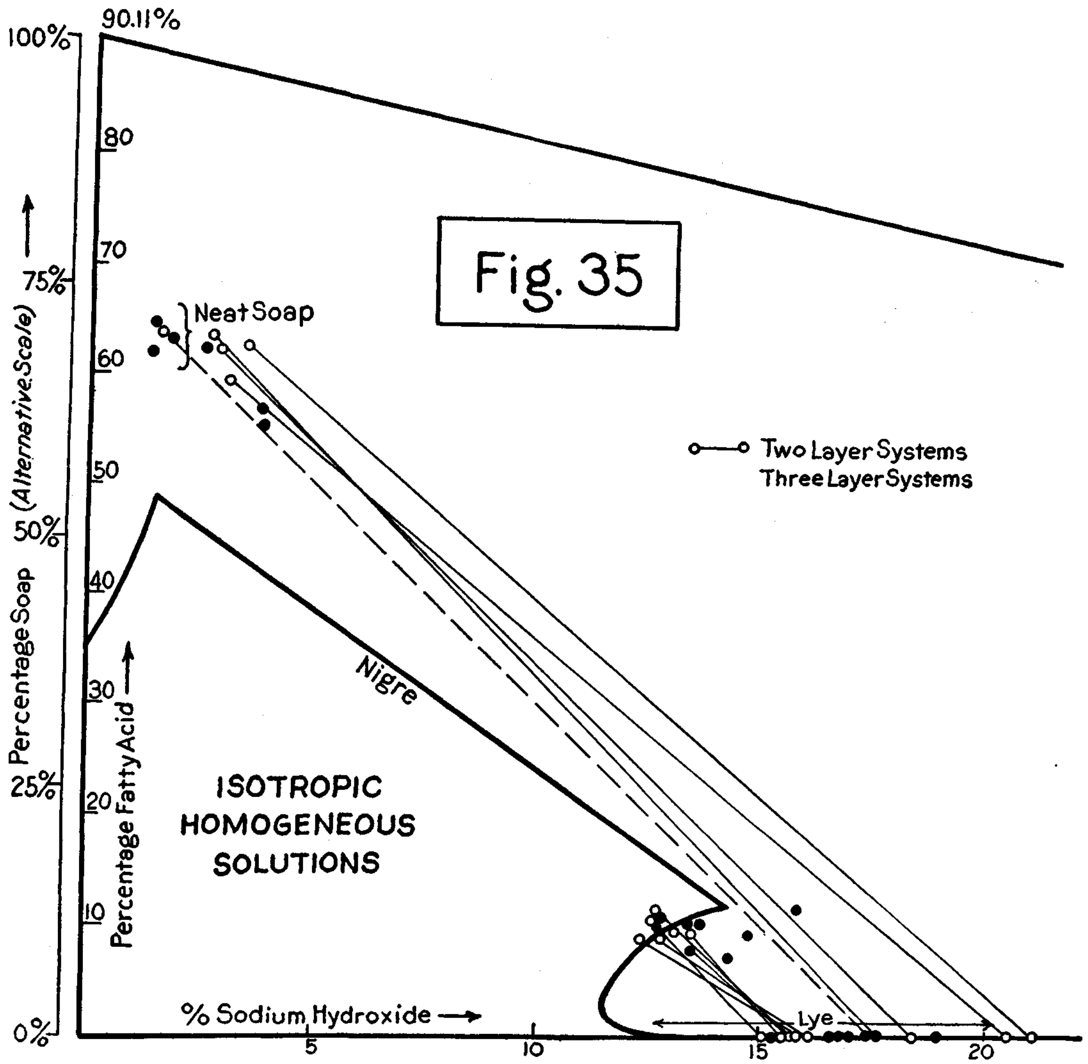


Fig. 34 (72)
$KC_{18}^{=}+KCl+H_2O$ at 20°



Solubility

Any soap, pure or commercial, mixed with water or with water and an electrolyte can be made to exist as either lamellar soap crystals or curd fiber crystals; both are usually hydrated, and more than one hydrate may occur. On raising the temperature the crystals or curd dissolve to form ordinary isotropic solution, middle soap, or neat soap depending upon the concentration. The data usually refer to the form of hydrated crystals most stable under the experimental conditions.

Hydrated Curd Fibers; Temperature of Complete Solution to Form Isotropic Solution of Concentration, N_w

N_w	°C	N_w	°C	N_w	°C	N_w	°C
NaC_{12} (69)		NaC_{16} (78)		$KC_{\overline{18}}$ (10)		KC_{12} (73)	
2.0	45	10.0	(90)	15	55	8.004	39.0
1.0	40	1.009	67	12	26	8.878	56.0
0.2	34	0.504	63	KC_{12} (73)		9.694	60.0
0.1	31	0.01	51	2.508	15	10.98	90.0
$NaC_{\overline{18}}$ (53)		$KC_{\overline{18}}$ (72)		3.222	17.5	11.52	100
0.6	25	50	150	4.004	20.0	12.96	100
0.4	23	40	132	5.373	25.5	16.14	130
0.2	21	30	118	5.653	26.0	19.36	152
0.1	18	25	98	7.226	32.0	43.32	200

Figs. 35 and 36 (1).—A reinterpretation (by J. W. McBain) of M. Thörl's laboratory experiments with sodium hydroxide on the salting out of soap prepared from coconut oil at 100°C showing how they accord with phase-rule diagrams for the pure soaps.*

* The boundary line of the isotropic solutions is sketched in an identical position in diagrams 35, 36 and 37 and takes account of results of Perkowski quoted by Richert. Results of Thörl, Bätz, Richert and Perkowski are not true per cent but grams per 100 cm³ of solution measured at 100°C. The data of Penny and Elford are grams per 100 grams of total system.

Solubility of Hydrated Curd Fibers in Terms of N_w of Mother Liquor in Curd after Solidification ($=N_w$ in Table)

Soap	Orig. N_w	N'_w	t, °C	Lit.
NaC_{10}	2	1	15	(12)
NaC_{16}	0.1914	0.01778	30	(53)
	0.25	0.00819	25	
NaC_{16}*	0.25	0.03	17–25	(6)
	1.0	0.1	17–25	
NaC_{16}	0.005–0.0004	0.0003	17	(112)
$NaC_{\overline{18}}$	0.6	0.39	18	(53)
		0.26	10	
		0.114	0	
	0.1905	0.0998	18	

* NaC_{16} dissolved in 0.6 N_w aqueous glycerol.

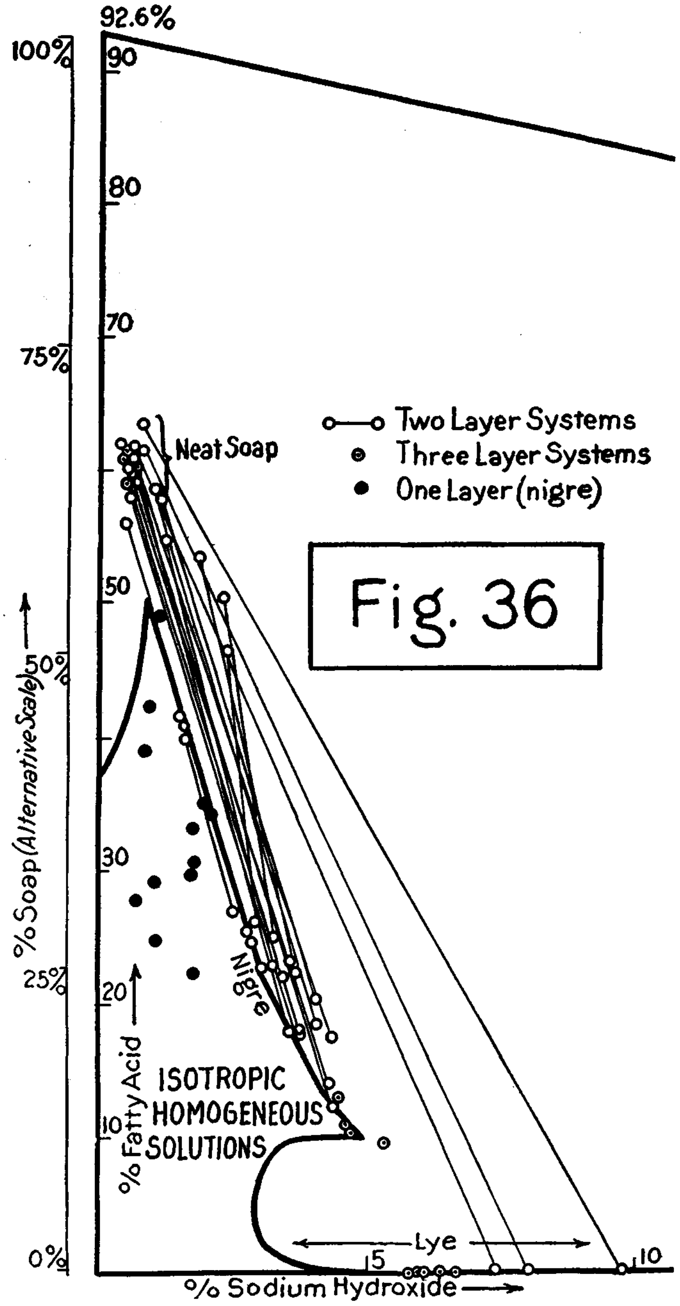


Fig. 36

Solubility of Curd Fibers as Determined from Fatty Radical from Curd

Soap	N_w		t, °C	Lit.
	Curd	Ultrafiltrate		
NaC_{16}..........	0.04–0.009	0.0003	18	(55)
	0.003–0.006	0.00023	18	
KC_{16}...........	0.034	0.0002	22	(50)
NaC_{18}..........	0.065	0.0004–0.0006	14–18	(50)
	0.03	0.0001*	18–22	
	0.03	0.0004–0.0005	14–18	
	0.0013	0.0001	14–18	

* Assumed by Kratz to be correct solubility.

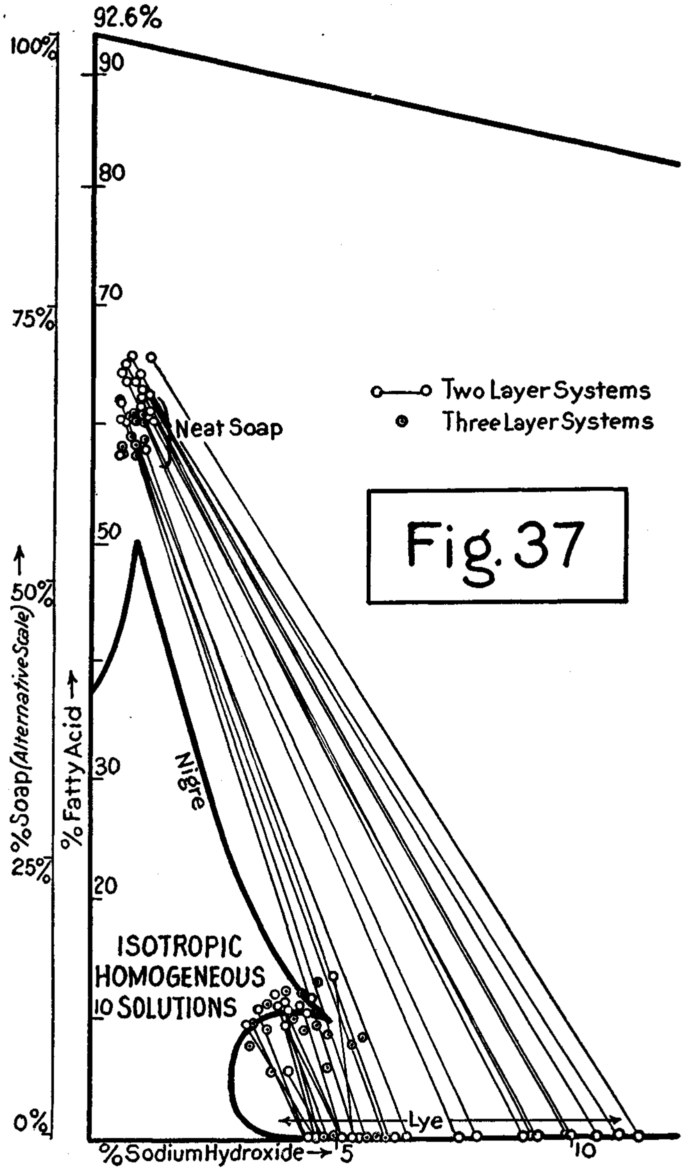


Fig. 37

Temperature of Spontaneous Separation of Na Soap (Curd Fibers) from Aqueous Solution on Cooling, °C (47)

Soap, g per 100 g H_2O	C_{18}	C_{16}	C_{14}	C_{12}	$C_{\bar{18}}$	Elaidate	$C_{\bar{22}}$	Brassidate
1	60°	45°	32°	11°	0°	35°	27°	42°
20	69°	62°	53°	(36°)	*ca.* 13°	45°	35°	56°

(12)	3	2	1.5	1	$0.75N_v$
NaC_9..........	13–14°	10–11°	−1°	<0°	
NaC_{10}..........		16°	3–4°	2.3°	≯0°

Also (108); 6% NaC_{12} at 26°, 1% NaC_{16} at 43°, 6% NaC_{16} at 52°, 1% NaC_{16} + 6% NaC_{12} at 8°, 1% NaC_{16} + 1% NaC_{12} at 29°; (3) NaC_{16}, 0.1 N_w at 58°, 0.5 N_v at 65°; KC_{16}, 0.5 N_v at 38°C; (12) 62.5 g anhyd. NaC_{12} in 100 g H_2O at 12–18°.

Solubility.—(*Continued*)

TEMPERATURE OF COMPLETE SOLUTION OF HYDRATED CRYSTALLINE CURD FIBERS IN AQUEOUS NaCl SOLUTIONS

NaC_{12} (69)			KC_{12} (73)		NaC_{16} (78)		
N_w soap	N_w NaCl	°C	N_w soap	°C	N_w soap	N_w NaCl	°C
2.0	0.534	57	N_w KCl = 0.5		3.02	0.293	(77)
	0.62	56	6.01	(21.0)	1.01	.680	76
	1.02	60	6.99	29.0	0.504	.794	74
	1.02	63.5	7.46	35	.504	.55	72
	1.92	68	8.76	50	.504	.642	76
1.0	0.49	48	9.77	65	.503	.738	75.5
	1.59	60	11.2	90	.399	.906	76
	1.66	65	12.6	100	.351	.835	75
	1.71	62	20.0	115	.206	.836	74
	1.86	63	N_w KCl = 1.0		.135	.819	72.5
	2.10	66	6.01	24.5	.0610	.807	72.5
0.20	1.21	55	7.91	50.5	.058	.908	(75)
	1.56	60	8.93	79.0	NaC_{22} (52)		
	2.05	61	9.8	90.0	0.05	0.42	100
0.10	1.97	60	15.0	98.0	0.05	0.59	100
	2.08	61	N_w KCl = 2.0				
	2.19	62	5.02	33.5			
			5.97	35.2			
			7.70	41.5			

GRAMS OF SOAP IN 100 GRAMS OF WATER AT VARIOUS TEMPERATURES

	15°	25°	50°	100°C	Lit.
LiC_{12}		0.180	0.280		(39)
LiC_{14}		0.036	0.060		(39)
LiC_{16}		0.015			(39)
LiC_{18}		0.010			(39)
SrC_6* + $3H_2O$		8.89 (at 24°)			(45)
MgC_{12}	0.009	0.009	0.026		(39)
MgC_{14}	0.006	0.006	0.014		(39)
MgC_{16}	0.005	0.005	0.009		(39)
MgC_{18}	0.003	0.004	0.008		(39)
$MgC_{18}^{=}$	0.022	0.024	0.03		(92)
Mg erucate		0.006			(123.5)
BaC_6	8	7	8		(29, 60, 116)
BaC_7	1.6	1.6	1.6		(60)
BaC_{12}	0.008	0.009	0.011		(39)
BaC_{14}	0.007	0.008	0.010		(39)
BaC_{16}	0.004	0.005	0.007		(39)
BaC_{18}	0.004	0.005	0.006		(39)
CaC_6	2.4	2.3	2.3	2.57	(29, 60, 61, 116)
CaC_7†	0.84	0.81	0.80	1.24	(60, 116)
CaC_8	0.31	0.29	0.26	0.50	(116)
$CaC_{18}^{=}$	0.04	0.04	0.03		(92)
$ZnC_6 + H_2O$		1.03 (at 24.5°)			(45)
$CdC_6 + 2H_2O$		0.96 (at 23.5°)			(45)
PbC_{12}			0.007		(39)
PbC_{14}			0.006		(39)
PbC_{16}			0.007		(39)
PbC_{18}			0.006		(39)
AgC_6	0.09	0.12	0.20		(60, 116)
AgC_7	0.09	0.11	0.17		(60, 116)
AgC_{14}			0.007		(39)
AgC_{16}			0.006		(39)
AgC_{18}			0.004		(39)

* Caproic acid from fermentation butyric acid.

† *See also* Landau, 1893, and Altschul, 1896 (116).

ADDITIONAL DATA

Fahrion (21) 1 l water at 15° dissolved 90 mg of $CaC_{18}^{=}$ and 224 mg $MgC_{18}^{=}$. Blumercron (12) curding of solutions of NaC_6, NaC_7, NaC_8, NaC_9, NaC_{10}, at 20° on addition of NaCl and NaOH. Partheil and Ferié (107), LiC_{12}, LiC_{14}, LiC_{16}, $LiC_{18}^{=}$ at 18° and 25°. Oudemans ((59) p. 159) Mg, Ca, Sr, Ba, Zn, Pb, Mn, Co, Ni, Cu, Ag salts of C_{12} at 15° and at boiling point. Lewkowitsch ((59) p. 143, 157) CaC_6, CaC_8, CaC_{10}, CaC_{12} at 20° or 100°. Jensen (41) AgC_8, AgC_{10} at 20° in water and $\frac{1}{20}N$ $AgNO_3$ solution. Altschul ((116) p. 614) AgC_7, 0–80°. Lieben and Janecek (61) CaC_6, BaC_6 at 10–12°. Zsigmondy and Bachman (130) NaC_{16} in water. McBain, Cornish and Bowden (70) NaC_{14} in water. Kottal (45) CaC_6, BaC_6.

Freezing-Point Lowering

Values of k_F, $= \Delta t_F/N_w$, where Δt_F is the freezing-point lowering in °C at the concentration N_w moles per kg H_2O (52).

Soap	N_w	Δt_F	Soap	N_w	Δt_F
KC_{12}	0.05	0.177	KC_8	3.0	4.71
	.1	.212	$NaC_{18}^{=}$	0.4	0.146
$KC_{18}^{=}$	.6	.348		.2	.095
	.4	.215	NaC_{22}	.05	.036
NaC_8	1.0	2.445			

See further, Fig. 38.

Boiling-Point Elevation

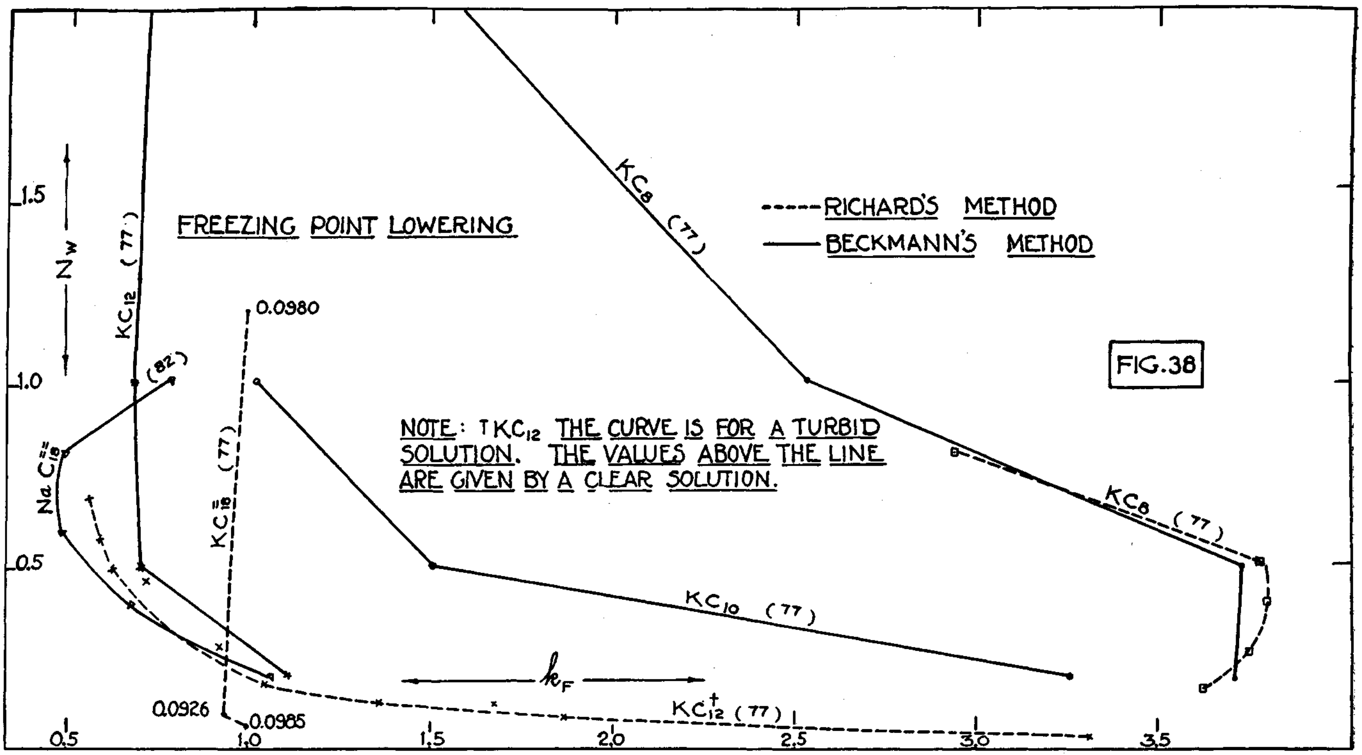
Values of $k_B = \Delta t_B/N_w$, where $\Delta t_B = t_s - t_w$, t_s being the temperature at which the partial vapor pressure of water from the solution is equal to the vapor pressure of pure water at t_w, °C. The data for the higher temperatures ($t_w = 90 - 100$°C) are shown graphically in Fig. 39. Some values at lower temperatures are given in the following table:

Soap*	t_w, °C	N_w	k_B	Lit.
KC_8	20	3.0	0.23	(77)
NaC_{12}	43	1.5	.20	(86)
NaC_{12}	40	1.5	.20	(86)
KC_{12}	20	0.2	.20	(77)
NH_4C_{12}	20	1.0	.17	(77)
NH_4C_{12}	20	0.5	.16	(77)
NaC_{16}	67	1.0	.26	(86)
NaC_{16}	70	1.0	.26	(86)
KC_{16}	33	0.5	.34	(86)
NH_4C_{16}	20	1.0	.06	(77)
NH_4C_{16}	70	1.0	.23	(85)
NaC_{18}	18	0.6	.10	(53)
$NaC_{18}^{=}$	18	0.4	.10	(53)
$KC_{18}^{=}$	20	0.6	.12	(77)
K elaidate	20	0.75	.24	(68)
K elaidate	20	0.5	.26	(68)
K elaidate	20	0.2	0.6–0.8	(68)
$NaC_{18}^{=}OH$	20	1.0	0.21	(68)
$NaC_{18}^{=}OH$	20	0.75	.25	(68)
$NaC_{18}^{=}OH$	20	0.5	.34	(68)
$NaC_{18}^{=}OH$	20	0.2	.35	(68)
$NaC_{18}^{===}$	20	0.5	.20	(68)
$NaC_{18}^{===}$	20	0.2	.075	(68)

* For solutions of soap with various added constituents, *v.* (46, 77, 85, 89, 109).

Refractive Index (62)

The specific refraction, $R = (n - 1)/d$ or $R' = (n^2 - 1)/d \times (n^2 + 2)$ for soap in soap solutions at 70° is for any one soap independent of concentration (and also of solvent), the molecular refraction for the soap in solution being equal to that calculated for the pure anhydrous liquid soap. Concentrations between 2.4 and 17.8 g/100 cm³ aqueous solution.



NOTE: †KC12 THE CURVE IS FOR A TURBID SOLUTION. THE VALUES ABOVE THE LINE ARE GIVEN BY A CLEAR SOLUTION.

FIG. 38

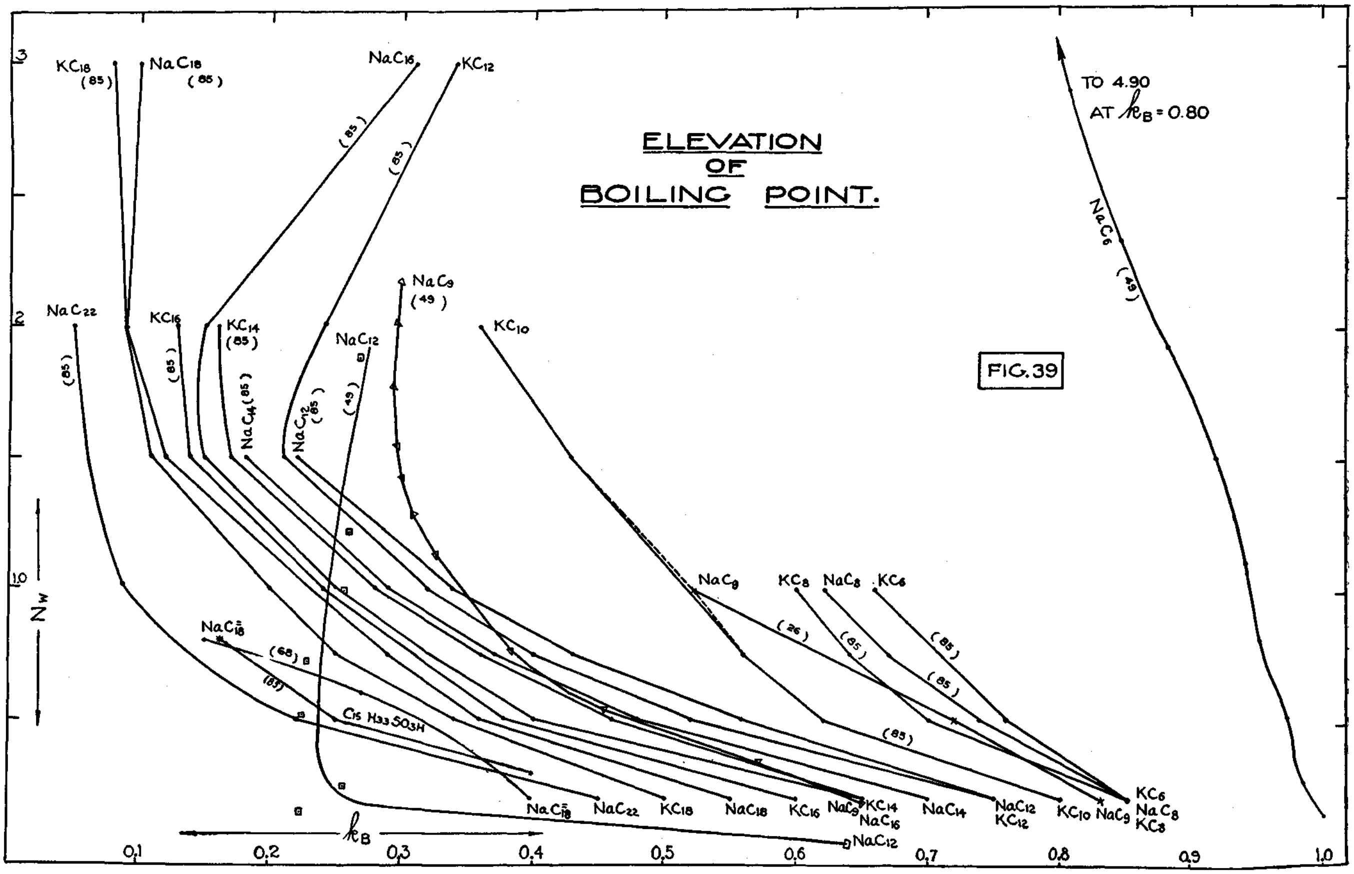


FIG. 39

Refractive Index.—(*Continued*)

Soap	R_C	R_D	R_F	R'_C	R'_D	R'_F
NaC_{16}		0.480			0.289	
NaC_{16}	0.467	0.471	0.476	0.283	0.284	0.286
KC_{16}		0.471			0.284	
NaC_{18}		0.475			0.287	
NaC_{18}^{-}	0.475	0.480	0.484	0.286	0.288	0.290

Electrical Conductivity of Aqueous Solutions

The values given are $\Lambda = 10^3\kappa/N_v$ where κ is the specific conductance of the solution in mhos

Na Soaps at 90°C

N_w =	1.5	1.0	0.75	0.5	0.2	0.1	0.05	0.01	Lit.
NaC_9		106.9		(127.5)	150.44	166.42	196.0	199.8	(26)
NaC_{12}	96.2	104.2		109.5	113.4	125.5	157.0	193.9	(70)
NaC_{14}	84.76	94.93	97.57	99.15	95.23	96.51	110.4	191.7	(70)
NaC_{16}	84.5*	83.6	85.8	87.4	79.4	75.5	76.4	101.7	(80)
NaC_{18}	81.5	88.3		76.1	77.4	76.0	78.0	125.9	(14, 70)
NaC_{22}				80.96	61.99	67.09	78.58	141.7	(26)

* From (87).

NaC_{14} (70)						NaC_{16} (3)		
N_w	80°	70°	60°	50°	40°C	°C	N_v	
							0.01	0.1
1.5	75.1	65.4	55.2	44.8		85	114.7	73.1
1.0	84.3	73.6	62.2	51.5		75	99.9	64.3
0.5	87.5	74.6	62.3	52.1		65	85.1	55.4
0.2	84.0	71.5	59.8	50.0	40.0	55	72.6	46.8
0.1	85.1	72.6	60.6	50.7	40.5	45	66.3	
0.05	97.3	83.1	69.4	58.0	46.5			
0.01	169.0	144.3	120.5	100.6	80.3			

$NaC_{16}SO_3$ (112)

N_v	65°	60°	55°	50°	45°	40°C
0.0666	45	41.5	38.6	35.6	32.3	29.5
0.0333	46	42.1	39.1	35.5	32.6	29.4
0.01665	51.6	47.2	42.7	39.1	34.9	31.4

NaC_{18}^{-} at 25° (55)

$1/N_v$	5	10	30.25	60.50	121	242	484	968
Δ	22.09	20.1	20.9	25.95	34.1	47.1	57.6	61.6

NaC_{18}^{-} at 18° (112)

10^3N_v	66.70	33.35	16.67	8.34	4.17	2.08	1.04	0.52
Δ	19.27	20.67	23.58	28.08	38.40	49.44	54.72	61.44

NaC_{18}^{-} (Identical for Sol and Jelly) (53)

°C	5.0	10.0	15.0	18.0	22.0	25.0
$0.4N_w$	13.94	16.22	19.13	20.95	22.62	25.84
$0.6N_w$	15.10	16.95	20.35	21.65	22.64	25.97

Na Soaps at 18°

N_w	1.0	0.6	0.4	0.2	0.1	0.05	0.01	Lit.
C_{18}^{-}		21.67	20.80	19.77	20.46	20.59	30.09	(77)
C_{18}^{--}*	26	30.1	29.6	28.9	29.0	30.5	49.60	(66)
C_{18}^{---}			29.6	28.70	29.13			(84)
$C_{18}^{-}OH$†	27.7	32.1	34.0	35.8	37.8	40.7		(71)

* At 24°C. † $1.5N_w$ 23.1, and 24° (79); $1.0N_w$ 35.5; $0.5N_w$ 43.8.

K Soaps at 90° (16)

N_w =	1.0	0.75	0.5	0.2	0.1	0.05	0.02	0.01
C_6	149.5		177.7	201.2	216.5	227.7	(241.2)	245.9
C_8*	148.7		168.5	191.0	205.2	219.2	(234.5)	239.5
C_{10}	145.9		156.3	180.9	200.6	211.9	(227.0)	232.4
C_{12}†	143.2	142.6	146.0	144.2	159.7	195.9	(223.5)	233.0
C_{12}‡	136.2	144	147	136.6	162	191		
C_{14}	136.2		135.4	130.8	121.8	136.6	181.6	224.3
C_{14}‡	138	132	127	120	117	117		
C_{16}	124.2	127.9	127.0	111.0	107.0	110.8	133.2	171.6
C_{18}	113.4	112.6	113.9	100.0	96.0	101.7	124.9	147.7
C_{18}‡			126	117	114.5	113		

* 107.3 at $3.063N_w$. † 123.5 at $2.028N_w$. ‡ Concentration N_v (51).

K Soaps (51)

°C	N_v at 90° =	0.05	0.1	0.2	0.375	0.4	0.6	0.8	1.0
60	C_{12}	123.6	105	93.9	102.8	103	106	104.5	99.6
	C_{14}	77.1*	77.4	77.6	88.5	90.1	95	92.9	89
	C_{18}^{-}	80.3†	81.5	77.0	86.3	87.5	88.6		
45	C_{12}	95.4	83.0	74.3	82.3	81.8	88.5	83.6	79.5
	C_{14}	57.9*	58.7	60.9	69.5	70.7	75	74.2	72.0
	C_{18}^{-}	61.0†	60.7	60.4	67.7	68.8	70.7		
30	C_{14}	47.7*	47.2	46.2	51.6	52.5	55.9	56.0	54.9
20	C_{12}	59.1	50.0	44.8	50.6	50.8	53.7	52.0	52.1
	C_{14}	35.7*	39.5	33.0	35.5	36.0	38.4	41.4	45
	C_{18}^{-}	37.1†	36.9	35.5	39.9	40.5	42.6		

* N_v = 0.054. † N_v = 0.0518.

KC_{16}; Effect of Time (3); *see further* (53)

°C	85	75	65	55	45	35	25
$0.01N_v$	136.4* 140.8†	118.8	100.5	86.7	79.6 →	87.6 →	92.8‡
$0.1N_v$	88.9	78.7	68.4	58.8	49.1	41.0	35.8

* 10 min. † 60 min. ‡ All at 45°, 0 min, 20 min and 24 hr resp.

K Soaps at 18°

N_w	2.0	1.0	0.75	0.5	0.2	0.1	0.05	0.01	Lit.
C_8	42.24	48.60	49.75	53.00	63.05	69.50			(77)
C_{12}	43.14	47.09	47.21	45.44	41.77	44.03	54.89	75.4	(77)
C_{18}^{-}				37.0	33.30	29.74	29.57	51.95	(77)
Elaidate			38.01	35.83	34.04	35.05	47.35		(90)

$C_{16}SO_3H$ at 90° (100); *cf.* (112)

N_w	0.75	0.5	0.2	0.1	0.05	0.02	0.01
Δ	237	232.0	203.9	188.1	185.5	195.0	208.0

K and NH_4 Salts of Fatty Acids from Palm-Kernel Oil (28, 51)

Molten K and Na Soaps (9)

Mixtures: Solutions of Soaps with Additions of Salts, Acids and Bases (3, 24, 27, 28, 51, 70, 89, 109)

Gold Numbers and Detergent Action, *v.* (37, 38, 50, 57, 74, 104, 105, 106, 108, 114, 117, 119, 120, 121, 122)

Hydration

H_2O = moles H_2O per mole soap

Negative sorption from lyes which salt out curd fibers from aqueous solutions of soap, yield the following values expressed as the retention of the solvent assuming that none of the salts are sorbed. The conditions and methods of experiment are described in the reference cited. For negative sorption by NaC_{16} from salt mixtures, *v.* (81).

t, °C	Soap	Orig. N_w	Salt	N_w	H_2O	Lit.
90	NaC_{18}	0.5	NaOH	1.5	4.3	(88)
90	NaC_{16}	1.0	NaOH	3.0	3.4	(88)
		1.0	NaOH	2.0	5.2	
		0.5	NaOH	1.5	6.5	
		1.0	NaOH	0.5	4.4	
			NaCl	2.0		

Hydration.—*(Continued)*

t, °C	Soap	Orig. N_w	Salt	N_w	H_2O	Lit.
17–25	NaC_{16}..........	1.0	Glycerol	0.6	4.3	(6)
		0.25	Glycerol	0.6	10	
90	NaC_{12}..........	1.0	NaCl	Satd.	1.8	(86)
12–18	KC_{12}...........	1.1	KCl	0.6	11.8	(9)
20	KC_{12}...........	1.1	KCl	0.9	11.3	(64)
		1.6	KCl	0.8	10.1	
		2.6	KCl	0.67	9.4	
20	KC_{12}...........	1.0	KCl	1.0	11.0	(23)
		1.5	KCl	0.86	10.8	
		2.9	KCl	0.65	8.6	
		1.0	KCl	0.1	24	
12–18	$NaC_{\overline{18}}$..........	0.25	NaCl	0.1	9.2	(76)

Hydration of soap in solutions of $1.0N_w$ KC_{12} containing known amounts of KCl at 18° by comparison of conductivity, migration, and vapor pressure (109).

KCl added (N_w)......	0.5	0.7	1.0	1.5	2.0	2.5	3.0	3.5
H_2O................	11 (±1.1)	12.2	12.8	10	9.6	5.2	6.3	6.9

For vapor pressures during hydration and dehydration of solid NaC_{18}, *v.* (50).

Hydrolysis

The values given are % hydrolysis according to the equation:

$$\% \text{ hydrolysis} = \frac{(N_w \text{ of } OH^-) \times 100}{\text{Total } N_w \text{ of soap}}$$

1. Hydrolysis by hydrogen electrode, neglecting diffusion potential (results too high in concentrated soaps) (80).

Soap............	t, °C	$N_w = 1.0$	0.75	0.5	0.2	0.1	0.05	0.01	0.001
NaC_{16}..........	90°	0.2	0.27	0.38	0.55	1.3	5.5	6.6	
KC_{16}...........	90°	0.08	0.27	0.6	0.65	1.3	5.0	6.8	
$NaC_{\overline{18}}$..........	25°	(55)				0.1(?)		0.6 (?)	4(?)

Hydrolysis.—*(Continued)*

$0.5N_w$ Soap at 90°

Soap..............	KC_{16}	KC_{14}	KC_{12}	KC_{10}	KC_8
% Hydrolysis.....	0.64	0.54	0.36	0.076	0.072

2. Hydrolysis by catalysis of nitrosotriacetonamine; values of 10^5N_v of OH^-. Results in concentrated soap probably low owing to sorption of amine.

NaC_{16} (65)							
	N_w = ...	0.042	0.5	0.8	1.0	0.46	0.1
	t, °C..............	90	90	90	90	70	70
	$10^5N_vOH^-$	91	20	25	27	44	56

KC_{16} (65)									
	N_w..........	90°	0.019	0.042	0.1	0.3	0.85		
	$10^5N_vOH^-$...		76	93	93	58	11		
	N_w..........	70°	0.05	0.1	0.85	40°	0.051	30°	0.05
	$10^5N_vOH^-$...		55	61	6		39		97

$NaC_{\overline{18}}$, 90° (5)						
	N_w..................	0.002	0.01	0.02	0.05	0.1
	$10^5N_vOH^-$...........	55	66	74	98	79

Various Good Commercial Soaps at 90°; Values of 10^5N_v of OH^- (5)

x* =	1	0.5	0.1	x* =	0.5
Coconut oil..........	31	21	5	Washer............	77
Olive oil............	73	60	18	Tallow rosin........	79
Toilet soap..........	76	60	24	Coal tar............	82
Cold process.........	108	80	30	Shaving............	94

* Grams soap in 100 cm³ solution at room temperature.

3. Hydrolysis by indicator method. Comparison of the color given an indicator in a pure soap solution with that of standard buffer solutions. Buffers were Sörensen and Palitzsch's glycine/NaOH and borax/boric acid. Indicators were Alizarin yellow G for 0.003 to $0.0005N_w$ OH^-; phenolphthalein for 0.0008 to $0.0001N_w$ OH^-, and for extremely dilute soap, phenol red. The myristic acid used was impure. Indicator was added in amount to produce the maximum color (75).

Soap	t, °C	Values of N_w of Soap										
		0.5	0.2	0.1	0.05	0.02	0.01	0.005	0.002	0.001	0.0_35	0.0_31
NaC_{12}............	90	0.6	1.0	1.4	1.8	2.4	2.1	1.6				
	20	0.2	0.6	0.9	1.4	1.4	1.7	1.4				
KC_{12}.............	90	0.7	1.2	1.6	2.2	1.6	2.4	Also 0.35 at N_w = 0.86				
	20	0.17	0.50	0.70	1.4	1.2	1.9	Also 0.12 at N_w = 0.86				
NaC_{14}............	90		0.56	1.11	2.2	3.85	4.3	Also 0.23 at N_w = 0.4				5.0
KC_{14}.............	90		0.56	1.1	1.6	1.75	2.9	1.8 Also 0.3 at N_w = 0.4				
KC_{16}.............	90	0.20	(1.0)	1.6	3.1	4.8	6.7	9.7		12.4	19.1	
	20						14				51	
NaC_{16}............	90	0.2	(1.1)	1.6	1.6	4.1	7.0	8.0	15.5	15.8	18	
	20								35	27	68	
NaC_{18}............	90	0.2	0.5	0.9	3.0	(6.0)	12		35			
	20							13.2				
KC_{18}.............	90		0.76	1.55	3.3	(8.6)	(15)	(20)	(50)	67	68	
	20										60	
$NaC_{\overline{18}}$............	90		0.41	0.85	2.0	5.0	8.5	(10.1)	(21)	24	16	
	20			0.24	1.6	2.7	4.5	6.3	16.1	24	28	
$KC_{\overline{18}}$.............	90	(0.2)	0.7	1.5	2.9	5.9	6.9	9.2		18	16	
	20	(0.01)	0.08	0.2	1.4	3.8	2.0	5.9		23	28	
NaC_{22}............	90		3.4	6.8	13.6	32.5	27					
			Jelly		Viscous liq.		Clear					
	20		45 (Viscous liq.)				68 (milky liq.)					

NaC_{16} and $KC_{\overline{18}}$ with excess of fatty acid, *v.* (75). Other determinations with various soaps and with added material, *v.* (50, 52, 55, 65, 67, 75, 76, 80, 112).

LITERATURE

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INTERNATIONAL CRITICAL TABLES

X-RAY DATA

J-PHENOMENON IN X-RAYS

C. G. Barkla

As the wave-length (λ) of the homogeneous (unifrequent) beam of X-rays incident upon a thin sheet of absorbing substance is varied, the absorption by the sheet varies discontinuously at certain values of λ. These absorption edges (or occasionally lines) are sharply defined, and correspond to the frequency required to excite the characteristic radiation (*K*, *L*, *M*, etc.) of the absorber.

When the incident beam is heterogeneous (multifrequent) and its "effective" λ is varied, similar sharp discontinuities in the absorption may occur. The "effective" λ is here defined as the λ of that unifrequent radiation for which the ionization produced in a short air-electroscope is reduced to one-half its value by such a thickness of Al as will produce the same reduction in the ionization of the incident multifrequent beam. It may be specified either in Ångstrom units, or by the "effective" mass-absorption-coefficient (μ/ρ) for the incident beam, as determined by the equation $e^{-\mu x} = 0.5$, where x is the thickness of Al required to reduce the ionization to 0.5 its value; ρ = density of Al. It must be emphasized that a discontinuity is not associated with either the minimum λ or the λ of maximum intensity of the incident beam, but with some kind of average for the whole beam—possibly analogous to temperature. Also neither the "effective" $(\mu/\rho)_{Al}$, nor "effective" λ, is an absolute constant in a given substance; it varies somewhat with other factors for the radiation, which are not yet measurable. The critical "effective" $(\mu/\rho)_{Al}$ and "effective" λ are thus approximate only. They are only tentative and cannot precisely express the complex quantity involved.

What appear to be distinct series (J_1, J_2 . . .) of discontinuities have been observed. Later work has shown that under certain conditions, intermediate discontinuities occur (4). It is *possible* that a true measure of the fundamental factor involved will show the critical values for one series to be identical in various substances.

Only tentatively then is the following table given.

J-Absorption Edges (1, 2, 3, 4)

$(\mu/\rho)_{0.5}$ = "effective" mass absorption coefficient in Al for the multifrequent radiation corresponding to the edge; λ_e = wavelength of unifrequent radiation for which mass absorption coefficient of Al = $(\mu/\rho)_{0.5}$. "Effective" coefficient is computed from thickness required to reduce ionization by 50 %. Unit of $(\mu/\rho)_{0.5}$ = 1 cm²/g; of λ = 1 Ångstrom.

Absorber	$(\mu/\rho)_{0.5}$				λ_e			
	J_1	J_2	J_3	$J_{4,5}$*	J_1	J_2	J_3	$J_{4,5}$*
C6			1.05				0.39	
N7		2.5				0.55		
O8	>4	2.2	0.83	0.47	>0.66	0.5	0.355	0.28
Al13	3.8	1.9	0.7	0.34	0.63	0.49	0.335	0.23
Si14		1.85				0.493		
S16		1.7				0.48		
Cu29	3.5	1.46	0.6		0.61	0.45	0.315	
Ag47	2.0	1.4			0.5	0.45		
Pt78			0.57				0.305	
Au79			0.54				0.30	

* J_4, J_5, or J_4 and J_5.

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(For a key to the periodicals see end of volume)

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POLARIZATION OF X-RAYS

C. G. Barkla

The polarization of primary X-rays was discovered by Barkla in 1904 (1, 2), and in 1906 (3) he found that certain scattered X-rays are almost completely polarized: the ionization method of intensity measurement was used. By photographic methods it has been shown that heterogeneous primary radiation from a carbon target (9), and heterogeneous scattered radiation (8) are polarized, that the homogeneous characteristic radiation after reflection in a direction at 90° to the incident radiation is fairly completely polarized (11), and that characteristic radiation excited by homogeneous radiation is unpolarized (11). In order to determine the amount of polarization, the beam is intercepted by a suitable scattering substance, and the variation in the intensity of the rays that are scattered in directions perpendicular to the incident beam is determined. With a variation of 360° in the direction of scattering, this intensity passes through 2 maxima and 2 minima; the difference in azimuth from a maximum (M) to a minimum (m) is 90°. If the incident beam is compounded of unpolarized radiation of intensity R, and of plane polarized radiation of intensity P, then $M/m = (P + 0.5R)/(0.5R)$. Hence, fraction (p) which is plane polarized is $P/(P + R) = (M - m)/(M + m)$ and the relative component variation (v) is $(M - m)/M = P/(P + 0.5R)$.

Degree of Polarization of X-Rays

$P[R]$ = intensity of plane polarized [unpolarized] constituent; $p = P/(P + R)$; $v = P/(P + 0.5R)$. $H[S]$ indicates that incident radiation is hard [soft]. Except where the contrary is indicated, the rays are heterogeneous. Unit of v and of p = 1 %.

Rays	Source	v		p		Lit.
		H	S	H	S	
Primary........	Gas tube*	6	20	3	11	(2, 4)
Primary........	Gas tube	4	28	2	16	(6)
Primary........	Gas tube	7	21	4	12	(12)
Primary........	Gas tube		43†		27†	(12)
Primary........	Coolidge tube	8	23	4	13	(10)
Primary........	Coolidge tube	16.5‡	2§	9‡	1§	(10)
Scattered‖......	Carbon	$70 + x$		$54 + y$		(3)
Scattered‖......	$\lambda = 0.25$ Å	$95 + x'$		$90 + y'$		(7)
Characteristic...		0		0		(3, 4)

* The constituents of higher frequency are the more completely polarized.

† From Ni target.

‡ $\lambda = 0.3$ Å.

§ $\lambda = 1$ Å.

‖ Data refer to rays scattered in a direction perpendicular to primary radiation. The true polarization is greater than that actually measured; correction factors x and y are necessary owing to obliquity of rays in beams of finite cross-section. Hence polarization of scattered rays in stated direction is approximately complete; *i.e.*, 100 %.

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(For a key to the periodicals see end of volume)

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ELECTRONIC RADIATION EXCITED BY X-RAYS

Maurice de Broglie and Jean Thibaud

For unexplained symbols, *see* Vol. I, p.16

Perrin (53) and, later, Curie and Sagnac (27) observed that all kinds of matter emit electrons (28) when irradiated by X-rays. There are two distinct classes of these electrons: Those of one class have a high velocity when emitted and are often called β-rays, and those of the other have a much lower velocity and are often called δ-rays. The latter are much the more numerous (65); 85% of the electrons emitted by gold leaf irradiated by X-rays from a Coolidge tube with a tungsten target have velocities lower than that corresponding to 2 volt.

Wilson (75) and Auger (3, 4) have shown by the fog method that very often a single atom will emit a group of several electrons. In such cases, the X-ray quantum causes initially the ejection of an electron from (*e.g.*) the K-level. An L-electron replaces it and there results an emission of a $K\alpha$-ray; this detaches an electron from the L-level of the same atom. Two L-rays are thus produced and, in their turn, ionize the more exterior levels. The initial quantum releases 4 photoelectrons. Thus it may be that the energy is not emitted as electromagnetic radiation but within the atom is transformed to the electronic form.

VELOCITY OF THE EMITTED ELECTRONS

High Velocity Electrons.—Among the electrons emitted with high velocity are electrons of all velocities, within a certain range, forming a "continuous spectrum" which corresponds, at least partially, to that of the exciting X-rays. There are also groups of electrons having essentially a common velocity which varies discretely from group to group. The common velocity of each of these groups (*v.* Table 1) has been found (19, 31, 41, 58, 64) to satisfy the generalized Einstein relation (30) $\mathbf{m}_0\mathbf{c}^2\{(1-\beta^2)^{-\frac{1}{2}} - 1\} = \mathbf{h}\nu - w_0$, where $\beta \equiv v/\mathbf{c}$, v = velocity of the electron when emitted, ν = frequency of the exciting X-rays, w_0 = work done by the electron in escaping from the atom. The value of w_0 depends upon the structure of the atom and the energy-level from which the electron is ejected. Values of w_0 may be determined from ionization potentials (V_0) (*q.v.*, p. 69) by the relation $\mathbf{e}V_0 = w_0$, or from critical absorption-limits, or frequency limits of characteristic X-radiation (*v.* Emission of X-rays, p. 23), by the simple Einstein relation $w_0 = \mathbf{h}\nu_0$, where ν_0 = frequency limit. Some authors (6, 7); *cf.* (9, 12, 35, 50, 61, 71, 72) have observed in the emission from Ag and Sn a few electrons for which $w_0 = 0$. For gases, w_0 is in all cases very small, rare gases of high atomic numbers excepted.

If the X-rays are complex, there will be a group velocity corresponding to each wave-length and to each absorption-level of the atom; and superposed upon this emission will be another, arising from the fluorescent (characteristic) X-radiation emitted by the atoms which are ionized by the primary rays. On passing through a magnetic field these groups are spread out into a magnetic spectrum (19).

The Einstein relation, having been established in many cases, may be used for determining, from the observed velocity of the emitted electrons, (1) the energy corresponding to unknown levels (13, 45) and (2) the wave-length of the exciting radiation (31, 69).

Robinson (57) has discovered an interesting relation involving the electronic emission from the various subdivisions of a given level. The greatest number of electrons comes from the subdivision of smallest energy, (*e.g.*, L_{III}), provided that the critical frequency (L) of the element is not too much smaller than the frequency of the incident X-rays. But as the critical frequency is successively reduced by passage from element to element (*i.e.*, as it differs more and more from that of the X-rays), the maximum of intensity of the secondary electrons is displaced towards the subdivision of greatest energy (L_I).

From observations with gases Whiddington (71) found that when an electron has passed a distance x through matter its velocity has been reduced from v_0 to v_x, such that $v_0^4 - v_x^4 = ax$, where a is a constant characteristic of the matter. If the unit of a is 10^{40} cm³/sec⁴, the value of a for air is 2, for Al is 732, and for Au is 2540. If R = range (unit = 1 cm) in air (t = 20°C, p = 1 atm.) of electrons which have a velocity which may be annulled by a potential difference $= V$ (unit = 1 volt), then (Wilson (74, 75)) $V = 21\,000\sqrt{R}$ if $0.1 < R < 1.5$; this agrees well with Whiddington's expression.

TABLE 1.—ENERGY (E) OF ELECTRONS EMITTED BY ELEMENTARY SUBSTANCES UNDER THE ACTION OF X-RAYS

Observed energy: $E = \mathbf{e}V$; calculated energy: $\mathbf{e}V' = \mathbf{h}\nu - w_0$; Rad. = exciting radiation; Lev. = energy-level from which electron is ejected. X-rays are generated in a Coolidge tube with target of the material indicated. Estimated precision and observer: Cu target (56), 0.5%; Rh target (19), 2%; Rh target (73), 1.5%; W target (19), 2%. Unit of V and V' = 1 volt.

V	Rad.	Lev.	V'
	Ag; Z = 47; target = Cu		
4 237	$K\alpha_1$ Cu	L_1	
3 152	$K\alpha_1$ Cu	L_2	
4 695	$K\alpha_1$ Cu	L_3	
7 382	$K\alpha_1$ Cu	$M_{1,2}$	
7 498	$K\alpha_1$ Cu	M_3	
7 708	$K\alpha_1$ Cu	$M_4 - M_5$	
8 006	$K\alpha_1$ Cu	N	
	Ag; Z = 47; target = W		
17 940	$K\alpha$ Ag	L	18 020
20 900	$K\beta$ Ag	L	20 860
32 760	$K\alpha$ W	K	32 880
40 990	$K\beta$ W	K	41 520
55 140	$K\alpha$ W	L	54 730
	Al; Z = 13; target = Rh (73)		
18 440	$K\alpha$ Rh	K	18 600
20 660	$K\beta$ Rh	K	21 110
	As; Z = 33; target = Rh (73)		
9 135	$K\alpha$ As	L	9 094
10 330	$K\beta$ As	L	10 290
11 110	$K\beta$ As		11 730
18 190	$K\alpha$ Rh	L	18 720
20 860	$K\beta$ Rh	L	21 230
23 170	$K\beta$ Rh		22 670
	Au; Z = 79; target = Cu		
4 595	$K\alpha_1$ Cu	M_1	
4 875	$K\alpha_1$ Cu	M_2	
5 291	$K\alpha_1$ Cu	M_3	
5 756	$K\alpha_1$ Cu	M_4	
5 843	$K\alpha_1$ Cu	M_5	
7 296	$K\alpha_1$ Cu	$N_1 - N_3$	
7 508	$K\alpha_1$ Cu		
7 724	$K\alpha_1$ Cu	$N_{4,5}$	
8 006	$K\alpha_1$ Cu	$N_{6,7}$, O	
	Ba; Z = 56; target = Cu		
2 025	$K\alpha_1$ Cu	L_1	
2 421	$K\alpha_1$ Cu	L_2	
2 801	$K\alpha_1$ Cu	L_3	
3 613	$K\alpha_1$ Cu	*	
4 331	$K\alpha_1$ Cu	*	
6 733	$K\alpha_1$ Cu	M_1	
6 880	$K\alpha_1$ Cu	M_2	
6 960	$K\alpha_1$ Cu	M_3	
7 239	$K\alpha_1$ Cu	$M_{4,5}$	
7 464	$K\alpha_1$ Cu	(?)KO†	

* Fluorescence, $L - M$. † KO = K-radiation of oxygen.

TABLE 1.—(*Continued*)

V	Rad.	Lev.	V'
Ba; Z = 56; target = Cu.—(*Continued*)			
7 584	$K\alpha_1$ Cu	(?)KC‡	
7 842	$K\alpha_1$ Cu	$N_1 - N_3$	
8 036	$K\alpha_1$ Cu	$N_4 - O$	
Ba; Z = 56; target = W			
26 090	$K\alpha$ Ba	L	25 600
30 290	$K\beta$ Ba	L	30 000
53 500	$K\alpha$ W	L	52 430
Bi; Z = 83; target = Cu			
4 014	$K\alpha_1$ Cu	M_1	
4 339	$K\alpha_1$ Cu	M_2	
4 844	$K\alpha_1$ Cu	M_3	
5 317	$K\alpha_1$ Cu	M_4	
5 435	$K\alpha_1$ Cu	M_5	
7 065	$K\alpha_1$ Cu	N_1	
7 204	$K\alpha_1$ Cu	N_2	
7 340	$K\alpha_1$ Cu	N_3	
7 513	$K\alpha_1$ Cu	N_4	
7 579	$K\alpha_1$ Cu	N_5	
7 911	$K\alpha_1$ Cu	$N_{6,7}$, O	
Bi; Z = 83; target = Rh (73)			
8 518	$L\alpha$ Bi	M	8 395
10 700	$L\beta$ Bi	M	10 700
12 340	$L\gamma$ Bi	M	13 000
15 140	$L\gamma$ Bi		15 310
19 710	$K\alpha$ Rh	N	19 920
22 140	$K\beta$ Rh	N	22 430
Cu; Z = 29; target = Cu			
6 920	$K\alpha_1$ Cu	L_1	
7 086	$K\alpha_1$ Cu	$L_2 - L_3$	
7 943	$K\alpha_1$ Cu	M	
Cu; Z = 29; target = Rh (73)			
7 078	$K\alpha$ Cu	L	7 119
7 942	$K\beta$ Cu	L	7 983
8 929	$K\beta$ Cu		8 888
11 110	$K\alpha$ Rh	K	11 230
12 880	$K\beta$ Rh	(?)K	13 740
18 970	$K\alpha$ Rh	L	19 260
20 660	$K\beta$ Rh	L	21 770
22 720	$K\beta$ Rh		22 670
Cu; Z = 29; target = Rh (19)			
11 360	$K\alpha_1$ Rh	K	11 230
13 660	$K\beta_1$ Rh	K	13 740
19 260	$K\alpha_1$ Rh	L	19 180
21 650	$K\beta_1$ Rh	L	21 690
I; Z = 53; target = Cu			
2 841	$K\alpha_1$ Cu	L_1	
3 200	$K\alpha_1$ Cu	L_2	
3 463	$K\alpha_1$ Cu	L_3	
6 947	$K\alpha_1$ Cu	M_1	
7 130	$K\alpha_1$ Cu	$M_2 - M_3$	
7 399	$K\alpha_1$ Cu	$M_4 - M_5$	
7 906	$K\alpha_1$ Cu	N, O	
I; Z = 53; target = W			
23 130	$K\alpha$ I	L	22 920
27 320	$K\beta$ I	L	26 460
54 650	$K\alpha$ W	L	53 080
Mo; Z = 42; target = Cu			
5 157	$K\alpha_1$ Cu	L_1	
5 411	$K\alpha_1$ Cu	L_2	
5 509	$K\alpha_1$ Cu	L_3	
7 646	$K\alpha_1$ Cu	(?)M_3	
7 783	$K\alpha_1$ Cu	(?)M_5	
7 989	$K\alpha_1$ Cu	(?)N	

V	Rad.	Lev.	V'
Mo; Z = 42; target = Rh (73)			
14 860	$K\alpha$ Mo	L	14 980
20 210	$K\beta$ Mo	L	17 120
19 550	$K\beta$ Mo		19 590
Mo; Z = 42; target = W			
14 070	$K\alpha$ Mo	L	14 690
16 630	$K\beta$ Mo	L	16 910
38 680	$K\alpha$ W	K	38 350
Pb; Z = 82; target = Cu			
4 179	$K\alpha_1$ Cu	M_1	
4 468	$K\alpha_1$ Cu	M_2	
4 954	$K\alpha_1$ Cu	M_3	
5 442	$K\alpha_1$ Cu	M_4	
5 557	$K\alpha_1$ Cu	M_5	
7 367	$K\alpha_1$ Cu	$N_{1,3}$	
7 605	$K\alpha_1$ Cu	$N_{4,5}$	
7 919	$K\alpha_1$ Cu	$N_{6,7}$, O	
Rh; Z = 45; target = W			
16 790	$K\alpha$ Rh	L	16 870
19 420	$K\beta$ Rh	L	19 510
35 800	$K\alpha$ W	K	35 180
Sb; Z = 51; target = W			
21 890	$K\alpha$ Sb	L	21 930
25 270	$K\beta$ Sb	L	25 350
28 810	$K\beta$ Sb	M	28 850
Se; Z = 34; target = Rh (19)			
8 148	$K\alpha_1$ Rh	K	7 777
9 053	$K\alpha_1$ Se	L	9 547
10 290	$K\beta$ Rh	K	10 370
	$K\beta$ Se	L	10 780
17 780	$K\alpha_1$ Rh	L	18 560
20 660	$K\beta$ Rh	L	21 070
Sn; Z = 50; target = Cu			
3 563	$K\alpha_1$ Cu	L_1	
3 861	$K\alpha_1$ Cu	L_2	
4 092	$K\alpha_1$ Cu	L_3	
7 146	$K\alpha_1$ Cu	M_1	
7 317	$K\alpha_1$ Cu	$M_{2,3}$	
7 550	$K\alpha_1$ Cu	$M_4 - M_5$	
7 928	$K\alpha_1$ Cu	N	
Sn; Z = 50; target = W			
20 580	$K\alpha$ Sn	L	20 820
23 700	$K\beta$ Sn	L	24 110
29 220	$K\alpha$ W	K	28 810
36 640	$K\beta$ W	K	37 410
53 170	$K\alpha$ W	L	53 990
Sr; Z = 38; target = Cu			
5 793	$K\alpha_1$ Cu	L_1	
6 001	$K\alpha_1$ Cu	L_2	
6 055	$K\alpha_1$ Cu	L_3	
7 473	$K\alpha_1$ Cu	(?)KO*	
7 703	$K\alpha_1$ Cu	(?)M	
8 026	$K\alpha_1$ Cu	(?)N	
Sr; Z = 38; target = Rh (73)			
12 020	$K\alpha$ Sr	L	12 180
13 740	$K\beta$ Sr	L	13 870
15 230	$K\beta$ Sr		15 840
17 530	$K\alpha$ Rh	L	18 190
16 950	$K\beta$ Rh	L	20 700
22 390	$K\beta$ Rh		22 670
Sr; Z = 38; target = W			
11 520	$K\alpha$ Sr	L	12 020
13 500	$K\beta$ Sr	L	13 790

‡ KC = K-radiation of carbon.

* KO = K-radiation of oxygen.

Table 1.—(*Continued*)

V	Rad.	Lev.	V'
W; $Z = 74$; target = Cu			
5 206	$K\alpha_1$ Cu	M_1	
5 465	$K\alpha_1$ Cu	M_2	
5 761	$K\alpha_1$ Cu	M_3	
6 148	$K\alpha_1$ Cu	M_4	
6 226	$K\alpha_1$ Cu	M_5	
7 605	$K\alpha_1$ Cu	$N_1 - N_3$	
7 798	$K\alpha_1$ Cu	$N_4 - N_5$	
8 037	$K\alpha_1$ Cu	$N_6 - N_7 - O$	
W; $Z = 74$; target = Rh (73)			
6 749	$L\alpha$ W	M	6 666
8 353	$L\beta$ W	M	8 312
9 917	$L\gamma$ W	M	9 958
11 400	$L\gamma$ W		11 600
18 310	$K\alpha$ Rh	M	18 520
20 330	$K\alpha$ Rh		20 160
22 390	$K\beta$ Rh		22 670
Yb; $Z = 70$; target = W			
41 640	$K\alpha$ Yb	L	42 840
48 560	$K\beta$ Yb	L	49 870
Zn; $Z = 30$; target = Rh (73)			
7 777	$K\alpha$ Zn	L	7 613
8 847	$K\beta$ Zn	L	8 559
9 629	$K\beta$ Zn		9 547
10 700	$K\alpha$ Rh	K	10 990
13 090	$K\beta$ Rh	(?)K	13 500
18 760	$K\alpha$ Rh	L	19 180
Zn; $Z = 30$; target = W			
7 407	$K\alpha$ Zn	L	7 366
8 395	$K\beta$ Zn	L	8 312

Low Velocity Electrons.—The velocity with which the slow electrons are emitted is independent of the nature of the radiator (63). Shearer (63) attributes these electrons to a secondary effect of the rapid electrons and Simons (65, 66) to the recoil of the atoms from which the rapid electrons are ejected; the latter notes a relation between the distribution of the velocities of these electrons (corresponding to $T = 11\,000$°K) and that of thermions in a hot body. Their origin may be associated with the diffusion of the incident X-rays, as Compton (24) has shown that the weakly bound electrons can be expelled by a quantum of radiation.

NUMBER OF ELECTRONS EMITTED

The total number (n_e) of electrons emitted per second is intimately related to the absorption of the X-rays by the substance. The law of fluorescent absorption deduced by Bragg and Peirce, $\tau A/\rho = CZ^4\lambda^3$, where τ = coefficient of fluorescent absorption (coefficient of absorption after correction for scattering), ρ = density, λ = wave-length, A = atomic weight, C = constant of proportionality, and Z = atomic number of radiator = number of electrons per atom, has also been deduced from thermodynamics and the quantum theory (20) and by means of the principle of correspondence (43). It indicates (21) that the probability of emission of an electron from an atom of atomic number Z under action of radiation of intensity (I) and frequency (ν) is proportional to $Z^4\nu^{-4}I$. Jauncey (38) has recently announced the same result in a somewhat different form. Throughout this report I is defined as proportional to the total number of ions produced, per second and per unit of solid angle, by complete absorption of the radiation in air. The experimental results are discordant, as follows:

Variation with Emitting Substance.—The value of n_c increases with Z (Laub (44)), is proportional to Z^4 (Moore (49)), is proportional to Z (Whiddington (73)). Shearer (63) states that for Al, Fe, Ni, Cu, Ag, Sn, Au, Pb and Bi, the number (N_e) of electrons excited in an atom is $N_e = K(Z - 10)$, and consequently n_e is proportional to the number of electrons contained in an atom. Actually, we observe only those which escape from the body and the law of variation of the absorption (of the electrons) with the velocity is uncertain. This may explain the discordances.

For salts and gases, n_e increases with the molecular weight; for CH_3I, it is 100 times as great as for air.

Variation with the Radiation.—For a given I, n_e decreases as penetration increases, $n_e \propto V^{-1/2}$ (Shearer (63)), where V = tube voltage. Hoepner (34) found n_e decreased more rapidly than I; Herweg and Mie (33) found $n_e \propto I$ even when I was very small. To obtain concordant results, the number of electrons belonging to each group of uniform velocity should be measured individually, and also the number composing the adjacent portion of the continuous spectrum, and these should be correlated with the distribution of I in the spectrum of the exciting radiation. This has not been done.

DIRECTION OF EMISSION

Solids.—For solids, the number of electrons emitted in the direction of propagation of the X-rays exceeds that emitted in the opposite direction (10, 18, 25, 42, 47, 54, 62, 68). This dissymmetry is independent of Z and of the physical state of the radiator (51); from his experiments with Cu, Wilson (74, 75) concludes that it arises from a curvature in the trajectories of the electrons, rather than a dissymmetry in emission.

Gases.—*Long Range Electrons.*—A polarization of the X-rays leads to a marked lateral concentration of the long range emitted electrons, in the direction of the electric vector of the X-rays (22, 74, 75). The emitted electrons are also concentrated longitudinally in a privileged direction making an acute angle with the direction of propagation of the X-rays. In air, Wilson (74, 75) found the privileged direction was 45° to the X-rays, 20% of the electrons were ejected at 90° (result of polarization) and a few had a backward component. Using polarized X-rays, Bubb (22) found ½ had a forward component, ⅙ had a backward component, and ⅓ were almost at 90°. In H, Auger (1) found privileged direction at 80° and the number of electrons with a forward component was about twice as great as that of those with a backward one. For halogens, the longitudinal dissymmetry increases in the order I, Br, Cl, F, and possibly decreases as the tube-voltage decreases (16).

Recent experiments (2, 5, 17, 22) by the fog method show that the most probable direction of ejection of a photoelectron is nearly that of the electric vector of the incident wave but there is an additional component in the direction of propagation of the wave. This component increases when either the potential difference applied to the tube or the frequency of the X-rays is increased (4). When the X-rays are polarized there is a very great preponderance in the number of photoelectrons in the plane containing the electric vector of the incident rays (22). Many attempts to account theoretically for this distribution have been made. Those of Bubb (23); *cf.* (17) and of Auger and Perrin (5) agree qualitatively with the observations, but neither completely agrees quantitatively.

The origin of the path of a swift electron is marked by a cloud of ions due to the simultaneous emission of a slow electron (1). The initial portion of the path of a swift electron is straight, but deviations of the following 3 kinds become more and more frequent as the velocity decreases: (*a*) A sudden deflection through a large angle, frequently 180°, due to the electron's passing very near an atomic nucleus. (*b*) A sudden deflection, which may attain 45°, due to a collision in such a manner with another electron that the latter is ejected, generally at 90° to the path of the primary electron, with sufficient velocity to give rise to a bifurcated or "branch track" of ions. (*c*) A progressively curved path due to an accumulation of small deflections of type (*b*) or, according to some authors, to a gyroscopic action of the electron. The end of the path is marked by a small cloud of ions. Wilson (74, 75) thinks he has shown that, when a tertiary path is grafted upon the main trajectory the two emissions, at the point where the deflection occurs, occur at appreciably different times (0.001 sec). (This conclusion is similar to Bearden's (8) that the emission of fluorescent X-rays occurs 10^{-5} sec after the arrival of the exciting radiation.) Along the entire path there are groups of one or several pairs of ions, apparently due to short and ramified paths of type (*b*).

Short Range Electrons.—Under action of X-rays of sufficiently high frequency a secondary emission of electrons of very short range ("fish-tracks" of 1 to 2 mm, "sphere-tracks" of a few tenths of a mm), which form a distinct class and do not satisfy the quantum relation, has been observed (15, 74, 75) in air, H and He. They are ejected nearly in the direction of propagation of the X-rays. At a tube voltage of 20 kv, there are no fish-tracks in air, and sphere-tracks are rare, but as the voltage increases both increase rapidly, sphere-tracks become fish-tracks and these increase in range (67), and presently short range electrons are more numerous than long range ones. The origin of these electrons is explained by the quantum theory of diffusion of radiation as developed by Compton and Debye; *see also* (24, 39).

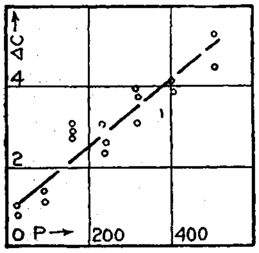

FIG. 1.

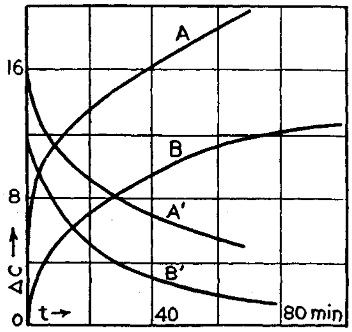

FIG. 2.

FIG. 1.—Effect of pressure (P) upon increase (ΔC) in conductance of a crystal of Se when irradiated by X-rays (48).

Unit of $\Delta C = 10^{-8}$ ohm^{-1}, of $P = 1$ g on area of 0.064 mm^2.

FIG. 2.—Progressive increase (ΔC) in conductance of a crystal of Se during irradiation by X-rays, and its recovery after cessation of irradiation (48).

Pressure = 320 g on area of 0.064 mm^2; initial conductance = 48×10^{-8} ohm^{-1}. Unit of $\Delta C = 10^{-8}$ ohm^{-1}, of time (t) = 1 minute. A = change during irradiation, A' = recovery; B and B' are similar to A and A' but apply to the crystal after it had been fatigued by exposure to γ-rays and had a conductance of 46×10^{-8} ohm^{-1}.

CONDUCTIVITY OF SOLIDS AND LIQUIDS EXPOSED TO X-RAYS

On exposure to X-rays, the conductivity of solids and liquids, especially of dielectrics, is temporarily increased (11, 14, 26, 36, 40, 70). The increases in the conduction of a crystal of Se after an exposure of 1 min to light ($\lambda = 7000$ Å), to X-rays ($\lambda = 1.5$ Å) and to γ-rays ($\lambda = 0.03$ to 0.4 Å) were 33.2, 58.5, and 108.9 ohm^{-1} per joule absorbed, respectively (48, 52). For variation with time and pressure, *see* Figs. 1 and 2. The conductivity of a plate of NaCl increases during exposure to X-rays, and gradually decreases after the X-rays are withdrawn; the exposure "activates" the plate for future action of ordinary light (59). The conductivity of S increases considerably under action of X-rays; the increase is proportional to intensity of the radiation and varies with the nature of the rays in same manner as the ionization of air; in the range of potential difference investigated (69 to 204 volt) the conduction satisfies Ohm's law; the conductivity conferred by irradiation is 3 times as great for monoclinic as for rhombohedral sulfur (32). The conductivity of crystals of calcite ($CaCO_3$), of fluorite (CaF_2), and of feldspar is increased by radiation (46), and the property of luminescence, previously reduced by heating, is restored. The apparent charges of a permanently polarized dielectric are temporarily destroyed by exposure to X-rays (29).

Under action of X-rays, insulating liquids acquire a conductivity which satisfies Ohm's law if the potential gradient does not exceed about 700 volt per cm; the value of this conductivity for a certain unstated radiation is given in Table 2. There is no appreciable dissociation of the molecules, *cf.* (37). Recently, del Regno (55) has studied the variation in the electrical resistance of a selenium cell subjected to the radiations from mesothorium, and Ross (60) has studied the increase in the conductivity of solid dielectrics (sulfur, paraffin, ebonite, amber) subjected to X-rays. For action of γ-rays, *see* (36).

TABLE 2.—CONDUCTIVITY (C) OF INSULATING LIQUIDS WHEN EXPOSED TO X-RAYS (26, 36)

Quality and intensity of X-rays are not stated, unit of $C = 10^{-4}$ ohm^{-1} cm^{-1}

Formula	Name	C
CCl_4	Carbon tetrachloride	8
CS_2	Carbon disulfide	20
C_5H_{10}	Amylene	14
C_6H_6	Benzene	4
	Liquid air	1.3
	Petroleum ether	15
	Vaseline oil	1.6

LITERATURE

(For a key to the periodicals see end of volume)

(1) Auger, *34*, **177**: 169; 23. **178**: 929; 24. (2) Auger, *34*, **178**: 1535; 24. (3) Auger, *34*, **180**: 65; 25. (4) Auger, *51*, **6**: 205; 25. (5) Auger and Perrin, *34*, **180**: 1742; 25. (6) Barkla and Dallas, *3*, **47**: 1; 24. (7) Barkla and Shearer, *3*, **30**: 745; 15. (8) Bearden, *58*, **113**: 857; 24. (9) Beatty, *3*, **20**: 320; 10.

(10) Beatty, *201*, **15**: 492; 10. (11) Becker, *8*, **12**: 124; 03. (12) Becker, *2*, **22**: 524; 23. (13) Becker, *2*, **24**: 478; 24. (14) Becquerel, *34*, **136**: 1173; 03. (15) Bothe, *96*, **20**: 34, 237; 23. (16) Bothe, *96*, **26**: 59; 24. (17) Bothe, *96*, **26**: 74; 24. (18) Bragg and Porter, *5*, **85**: 349; 11. (19) de Broglie, *34*, **172**: 274, 527, 746, 806; 21. **173**: 1157; 21. *51*, **2**: 265; 21.

(20) de Broglie, *51*, **3**: 33; 22. (21) de Broglie and de Broglie, *34*, **173**: 527; 21. (22) Bubb, *2*, **23**: 137; 24. (23) Bubb, *3*, **49**: 824; 25. (24) Compton and Hubbard, *2*, **23**: 429; 24. (25) Cooksey, *58*, **77**: 509; 08. *3*, **24**: 37; 12. (26) Curie, *34*, **134**: 420; 02. (27) Curie and Sagnac, *51*, **1**: 13; 02. (28) Dorn, *18*, **5**: 595; 00. (29) Eguchi, *219*, **2**: 45; 20.

(30) Einstein, *8*, **17**: 132; 05. (31) Ellis, *5*, **99**: 261; 21. (32) Grebe, *96*, **17**: 295; 23. (33) Herweg and Mie, *8*, **68**: 120; 22. (34) Hoepner, *8*, **46**: 577; 15. (35) Innes, *5*, **79**: 442; 07. (36) Jaffé, *8*, **25**: 257; 08. (37) Janitzky. *96*, **20**: 280; 23. (38) Jauncey, *3*, **48**: 81; 24. (39) Jauncey, *2*, **23**: 580; 24,

(40) Joffé, *8*, **20**: 919; 06. (41) Kang-Fuh Hu, *2*, **11**: 505; 18. (42) Kleemann, *58*, **83**: 339; 10. *5*, **83**: 530; 10. (43) Kramers, *3*, **46**: 836; 23. (44) Laub, *8*, **26**: 712; 08. (45) Ledrus, *34*, **176**: 383; 23. (46) MacKay, *69*, **15**: 3, 95; 21. (47) MacKenzie, *3*, **14**: 176; 07. (48) MacMahon, *2*, **16**: 558; 20. (49) Moore, *5*, **91**: 337; 15.

(50) Moseley, *3*, **27**: 703; 14. (51) Owen, *67*, **30**: 133; 18. (52) Perreau, *34*, **129**: 956; 99. (53) Perrin, *6*, **11**: 496; 97. (54) Philpot, *67*, **26**: 131; 14. (55) del Regno, *22*, **3**: 201; 26. (56) Robinson, *5*, **104**: 455; 23. (57) Robinson, *3*, **50**: 241; 25. (58) Robinson and Rawlinson, *3*, **28**: 277; 14. (59) Röntgen, *8*, **64**: 1; 21.

(60) Ross, *96*, **36**: 18; 26. (61) Sadler, *3*, **19**: 337; 10. (62) Seitz, *8*, **73**: 183; 24. (63) Shearer, *3*, **44**: 793; 22. (64) Simons, *3*, **41**: 120; 21. (65) Simons, *3*, **46**: 473; 23. (66) Simons, *3*, **48**: 250; 24. (67) Skobelzyn, *96*, **24**: 393; 24. **28**: 278; 24. (68) Stuhlman, *3*, **22**: 854; 11. (69) Thibaud, *34*, **178**: 1706; 24. **179**: 165, 815; 24.

(70) Thomson and McClelland, *201*, **9**: 126; 98. (71) Whiddington, *5*, **86**: 360; 12. (72) Whiddington, *5*, **86**: 370; 12. (73) Whiddington, *3*, **43**: 1116; 22. (74) Wilson, *5*, **104**: 1; 23. (75) Wilson, *5*, **104**: 192; 23.

CRYSTAL GRATINGS FOR X-RAY SPECTROSCOPY

BERGEN DAVIS

The wave-length of X-rays is usually determined either by means of the ionization spectrometer or by a photographic method. With suitable crystals, the former is probably the more accurate, but it requires uniform reflecting planes sufficiently large to reflect a considerable amount of energy. The photographic method may be used with small irregular crystals and is particularly useful with powdered crystals.

Grating Constant.—The grating constant of a crystal is usually measured in terms of that of either calcite ($CaCO_3$) or rock salt (NaCl), the constant of the standard being calculated from crystal data and other physical constants. Even the best specimens of rock salt are imperfect crystals, the reflecting planes being not uniformly parallel planes throughout any considerable volume of the crystal; also the rocking curves obtained by means of the double X-ray spectrometer are wide (11.1), indicating that the crystal elements are quite imperfect. Calcite (Iceland spar) is much more nearly perfect; for it, the rocking curves are very smooth and narrow (less then $\frac{1}{60}$ of the width of the rock salt curves).

On account of the perfection of its crystal structure, it is recommended that calcite (Iceland spar) be selected as the primary standard in all measurements of the wave-lengths of X-rays; and that the value $d_{100} = (3.029 \pm 0.001) \times 10^{-8}$ cm (at 20°C) be used. This value of d_{100} for calcite is as probable as any other value yet deduced; it is equivalent (27) to $d_{100} = 2.814 \times 10^{-8}$ cm (at 20°C) for rock salt. A large number of measurements have already been made in terms of one or other of these equivalent values.

If a_0 = length of edge of unit crystal form, the observed grating space for the planes (h, k, l) of a face-centered cubic crystal, like rock salt, is $d_{hkl} = a_0/\sqrt{h^2 + k^2 + l^2}$ if h, k, and l are *all odd*, and in all other cases $d_{hkl} = 0.5a_0/\sqrt{h^2 + k^2 + l^2}$. For face-centered rhombohedral crystals $a_0\sqrt{1 + 2\cos^3\beta - 3\cos^2\beta}/\sqrt{(h^2 + k^2 + l^2)\sin^2\beta + 2(hk + hl + kl)(\cos^2\beta - \cos\beta)}$, where β = angle between edges of unit rhombohedron, replaces $a_0/\sqrt{h^2 + k^2 + l^2}$ of the preceding cubic expressions. In cubic crystals $a_0 = (nV_m)^{1/3}$, where n = number of molecules in the elementary crystal unit and $V_m(= M/\rho N_0)$ is the molecular volume, M = molecular weight, ρ = density, N_0 = Avogadro's number = number of molecules per mole. The value of n depends upon the crystal structure. For both rock salt (NaCl) and calcite ($CaCO_3$), $n = 4$. The main sources of error lie in the determination of ρ and N_0.

For calcite, $2d_{100} = [4V_m/\varphi(\beta)]^{1/3}$, where $\varphi(\beta)$ = volume of the calcite rhombohedron which has unit distance between the (100) planes $= (1 + \cos\beta)^2/(\sin\beta)(1 + 2\cos\beta) = 1.0962$, as $\beta = 101°\ 55'$. Compton (6) found $\rho = 2.7116$, corrected to 2.7102 g/cm³, at 20°C, and Compton, Beets, and Defoe (8) also found 2.7102 at 20°C. This value of ρ together with the I. C. T. values for M and N_0 (Vol. I, p. 18 and 43) lead to $d_{100} = (3.029 \pm 0.001) \times 10^{-8}$ cm at 20°C. Other values for ρ are 2.716 (9) and 2.715 (3); the average of these and the preceding two is 2.713 which gives $d_{100} = (3.028 \pm 0.002) \times 10^{-8}$ cm at 20°C.

Some of the better determinations of ρ for rock salt are 2.167 at 17°C (24, 25), 2.15 (9), 2.170 (15), 2.167 (22), 2.174 (19), 2.161 (1) and 2.1632 (13). The mean of these (2.166) gives $d_{100} = (2.814 \pm 0.002) \times 10^{-8}$ cm at 20°C. A more recent determination (14) gives $d_{100} = 2.814[1 + 0.00004(t - 18)] \times 10^{-8}$ cm at t,°C.

GRATING SPACES OF SELECTED CRYSTALS

(*c*) = measured in terms of calcite, $d_{100} = 3.029$; (*r*) = measured in terms of rock-salt, $d_{100} = 2.814$. a_0 = length of edge of the unit crystal form; d = grating space, temperature = 20°C. For other data, *see* (2, 20, 23, 26, 29, 30). Unit of a_0 and of d = 1 Å = 10^{-8} cm.

Symbol	Crystal	System	Plane	a_0	d	Lit.
$CaCO_3$.......	Calcite	Rhomb.*	100	6.9347	3.029 ± 0.001	(Calc.)
NaCl........	Rock salt	Cubic	100	5.628	2.814	(3)
FeS_2.........	Pyrite	Cubic	100 (2)	5.4056	2.703 (*c*)	(10, 11)
KCl.........	Sylvite	Cubic	100	6.272	3.136 (*r*)	(31)
KI..........	K iodide	Cubic	100	7.064	3.533 (*c*)	(5)
$CaSO_4.2H_2O$.	Gypsum	Monoc.*	010		7.584 (*r*)	(28)
	Mica	Monoc.*	001		10.1 (*r*)	(4)
$C_{12}H_{22}O_{11}$....	Cane sugar	Monoc.*	100		10.570 (*r*)	(28)

* Rhomb. = rhombohedral; Monoc. = monoclinic.

Refraction.—If the surface of the crystal is parallel to the reflecting planes in the crystal, if n is the order of the spectrum, and θ is the glancing angle of reflection corresponding to the maximum intensity of radiation of wave-length λ, then $n\lambda = 2d \sin\theta(1 - \delta \cot^2\theta)$, where $1 - \delta$ is the index of refraction of the crystal for radiation of wave-length λ. Measurements of δ for calcite (16) and for pyrites (10, 11) show (10, 11) that $\delta = \frac{\mathrm{e}^2}{2\pi\mathrm{m}} \times \left[\frac{n_1}{\nu^2 - \nu_1^2} + \frac{n_2}{\nu^2 - \nu_2^2} + \ .\ .\ .\ \right]$, where ν = frequency of incident radiation and $n_1, n_2, \ldots$ are the numbers of electrons per unit volume having the critical absorption (resonance) frequencies $\nu_1, \nu_2, \ldots$ As $\nu_1, \nu_2, \ldots$ are generally small as compared with ν, a first approximation is $\delta = \frac{\mathrm{e}^2}{2\pi\mathrm{m}}\left[\frac{n_1 + n_2 + \ .\ .\ .}{\nu^2}\right]$. For refraction of X-rays, *see* p. 49, and also (7, 12, 17, 18, 21).

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TABLE 4.—REFLECTIVITY OF X-RAYS: EFFECT OF POLISH

Double spectrograph and successive reflections from two crystals. $r = 100\ I_2/I_1$, where $I_1[I_2]$ = intensity of beam incident upon [reflected by] the second crystal when so placed that the reflection is a maximum. First order reflection from planes 100 (*cf.* Fig. 3). $r_p[r_u]$ = value of r when crystals are polished [unpolished]. Unit of λ = 1 Å.

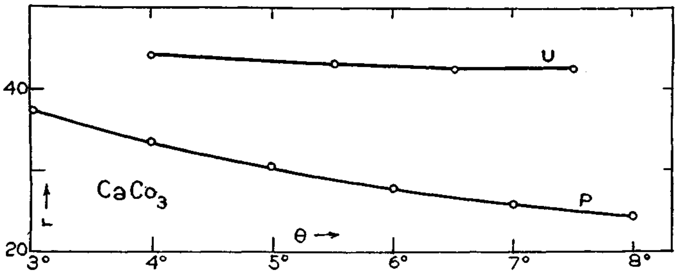

FIG. 3.—Effect of polishing: Calcite (9).
r = % reflected at glancing angle θ; P = polished; U = unpolished. λ = 0.317 to 0.842 Å, Pl = 100. (*Cf.* Table 4.)

TABLE 4.—(*Continued*)

λ	r_u	r_p	Lit.
	$CaCO_3$, Calcite		
0.369		35.4	(9)
0.422	44.4		(9)
0.580	43.1	29.2	(9)
0.685	42.8		(12)
0.790		25.3	(12)
	NaCl, Rock salt		
0.294	24.8	22.1	(10)
0.491	15.3	15.1	(10)
0.686	13.0	11.5	(12)

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ELECTRONICS AND GAS CONDUCTION

ELECTRIC ARCS

C. D. CHILD

CONTENTS

SYMBOLS

D	Diameter of electrodes.
E	Strength of electric field.
I	Electric current.
l	Length of arc.
R	True resistance of arc: R = limiting values of dV/dI as dI approaches zero.
T	Absolute temperature.
vp	Vapor pressure.
V	Voltage difference of electrodes.

Electrical Data.—The residual emf between cored carbon electrodes, after removal of impressed emf, is $\geqq$ 0.64 volt at 0.4 sec and 0.05 volt at 7 sec (3). Duddell defines the counter emf as $V - RI$; for carbon arcs, he finds it varies from 11.2 to 18.5 volt, depending upon the current and the nature of the electrode (5, 10). Others have defined the term in various ways; hence the recorded values vary greatly (5).

Voltage Difference: Effect of Length and Current

. $V = a + bl + cI^{-1} + dlI^{-1}$. Carbon (C) electrodes are solid unless the contrary is indicated. For metallic electrodes, I small, *see* (8). Unit of V = 1 volt, of I = 1 ampere, of l = 1 mm.

Electrodes	Gas	a	b	c	d	I	Lit.
Carbon*.....	Air	38.88	2.07	11.66	10.54	3 to 16	(2)
Carbon†.....	Air	0.0	0.99	0.0	0.0	120 to 700	(33)
Carbon‡.....	Air	62	11.4	0.0	3.26	3	(12)
Carbon......	CO_2	80	1.17	90	7.3	3	(12)
Carbon......	H_2	0.0	29	180	22.2	3	(12)
Carbon......	H_2O	200	1.0	0.0	18.5	3	(12)
Carbon A. C.§		20.4	1.81	0.0	0.0	6.5	(15)
Magnetite....	Air	35.8	0.89	−7	5.81	3	(12)
Copper‖......		18	17.5	52.1	3.43		(28)

* D = 11 mm; l measured from tip of cathode to plane through edges of crater; for long arcs, V is less than value given by these constants (10). For flaming arcs (6) and for cored carbons (20, 21), V is less than for solid carbons; no simple equation can be given for cored carbons (32).

† l measured from tip of cathode to bottom of crater.

‡ $l \geqslant 50$ cm.

§ Cored electrodes; A. C. = alternating current arc. *See also* note.*

‖ For metal electrodes, V varies greatly (6).

Distribution of Voltage

Determined by use of exploring electrodes. For small currents between metallic electrodes, *see* (8). $V_a[V_c]$ = drop of potential at anode [cathode]; anode = electrode of higher potential. Unit of V_a, V_c = 1 volt; of E = 1 volt/cm; of I = 1 ampere.

Electrode	Gas	V_a	V_c	E	I	Lit.
C, Carbon*......	Air	33.7	8.96		10	(2)
Hg..............	Vacuum	4.08†	5.27 (27)	0.68‡	4.3	
Na-K...........	Vacuum	2.5	3.8	0.8	1.5	(23)

* Solid electrodes; l = 5 mm.

† vp = 0.45 mm Hg; value of V_a varies from 4.8 to 18, depending upon vp, I, and the shape of tube and electrodes (13); as vp and I are increased indefinitely V_a approaches 3.72 as limiting value (12, 24).

‡ vp = 2 mm Hg, T = 1000°K (2).

Mechanical Data.—Area of crater = 1.34 mm² per ampere for solid carbons (1); =(3.83 + 1.52I) mm² for positive carbon cored, negative solid, and l = 4 mm, unit of I = 1 ampere (2).

Area of cathode spot = 0.0253 mm² per ampere for Hg-arcs (14); = 0.213 mm² per ampere for C-arcs of such lengths that anode does not affect the area and for I = 1.5 to 10 ampere (14).

Consumption of electrodes (unit of l = 1 mm). Solid carbons, open arcs, D = 1 cm, anode consumption if $l \geqq 20$ mm is $(2.4 + 1.3l + 0.0044l^2)$ g per hr if I = 4 ampere, and $(1.73 + 0.086l + 0.003l^2)$ g per hr if I = 8 ampere; cathode consumption if $l \geqq 12$ mm, I = 6 ampere, is $(0.72 + 0.022l - 0.0115l^2)$ g per hr (11).

Solid carbons, enclosed arcs, D = 11 mm, I = 5 ampere, consumption of positive electrode = 1.65 mm per hr, of negative electrode = 0.319 mm per hr (21).

Flaming arc, carbon electrodes, anode D = 8 mm, cathode D = 7 mm, each electrode consumption = 30 mm per hr (26).

Magnetite arc, cathode consumption = 1.5 mm per hr (16), I = 6.6 ampere, value of D is not stated.

Temperature of the Arc.—The temperature of the cathode is usually several hundred degrees lower than that of the crater; that of the gases between the terminals is higher than that of the crater; the exact value is not known. The temperature of the crater of the carbon arc in air is between 3900 and 4000°K for graphite terminals (30); 4200°K at 1 atm., decreasing to 3940°K at 0.1 atm. for solid carbons (18, 19); 4200°K at 1 atm, increasing to 5890°K at 22 atm. for impregnated (cored) carbons (18, 19).

Photometric Data for Arcs

The luminous efficiency of the radiation (= ratio of energy of luminous radiation to that of total radiation) varies with l and I from 0.043 to 0.083 for direct current enclosed arcs between solid carbons, and from 0.115 to 0.225 for yellow flaming arcs, direct and alternating current (17).

V_t = voltage difference of lamp terminal; W = power expended in lamp; scp = mean spherical candlepower, lcp = mean lower hemispherical candle-power. Unit of I = 1 ampere; of V_t = 1 volt; of W = 1 watt; of scp, lcp = 1 candle.

Type	I	V_t	W	scp	W/scp	lcp	W/lcp	Lit.
Direct current arcs								
Carbon, open....	9.6	50	480	540	0.89	813	0.59	(25)
Carbon, enclosed	6.6	70 to 75	480	310	1.55	505	0.95	(25)
Flaming........	8	44.2*	354	919	0.385	1670	0.21	(26)
Magnetite†.....	5	77.5	388	426	0.91			(9)
Alternating current arcs								
Carbon, enclosed	6.6	70	455	314	1.44			(22)
Flaming (Blondel)......	10	35*	255	1890	0.135			(4)

* Voltage difference of electrodes.

† With clear globe and small internal reflector.

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THERMAL EMISSION OF ELECTRONS

SAUL DUSHMAN

The relation connecting the absolute temperature (T) and the rate of electron emission is generally expressed in terms of I, the electric current per unit area of surface, by one or other of the equations $I = A_1T^{0.5}e^{-b_1/T}$ and $I = A_2T^2e^{-b_2/T}$, which are experimentally indistinguishable within the temperature range covered in the past. In this range, $\frac{b_1 - b_2}{2.303} = \frac{3 \log_{10}(T_1/T_2)}{2(T_2^{-1} - T_1^{-1})}$ or approximately, $b_2 = b_1 - 1.5\frac{(T_1 + T_2)}{2}$, and $\log_{10}(A_1/A_2) = 1.5 \log_{10} T + (b_1 - b_2)/2.303T$ or approximately, $A_2 = 0.223A_1 \times T^{-1.5}$. In general, data obtained before 1913–1914 are quite unreliable and even data obtained more recently are, in many cases, equally unreliable either because insufficient precautions were taken to secure a good vacuum or because a very inaccurate temperature scale was used. In a few cases in which very good data are available weighted average values are given in the following tables; these, and the individual values which are especially good, are each indicated by an asterisk (*). If W is the amount of work required to remove an electron from the surface, the "work function," $\phi = W/e$, is the potential difference required to confer upon an electron an amount of energy equal to W; $\phi = k_0b/e = 8.62 \times 10^{-5}b$ volt. Unless the contrary is indicated the values of ϕ given in the following tables are derived from b_2, and will be denoted by ϕ_2. The relation between Richardson's ϕ_0 (28) and b_2 is $b_2 = 11\,600\phi_0$. Papers (12, 15, 32) should be read.

TABLE 1.—ELECTRON EMISSION AND THERMIONIC WORK FUNCTION: ELEMENTARY SUBSTANCES AND OXIDES

At temperature T, the current leaving the surface per cm² is $I_T = A_1T^{0.5}e^{-b_1/T} = A_2T^2e^{-b_2/T}$; work function is ϕ. $A_1 = a_1 \times 10^n$, $A_2 = a_2 \times 10^n$, $b_1 \doteq \beta_1 \times 10^4$, $b_2 = \beta_2 \times 10^4$, $I_T = i_T \times 10^n$. Unit of I = 1 ampere/cm² = 3×10^9 es/(sec cm²) = 0.1 em/(sec cm²) = 6.28×10^{18} electron/(sec cm²). Unit of ϕ = 1 volt = 10^8 cgsm unit of potential = 0.003335 cgse unit of potential = 1.591×10^{-12} erg per electron.

Symbol	a_1	n	β_1	a_2	n	β_2	ϕ_2	i_T	n	T, °K	Lit.
Elementary substances											
C............................				6.02	1	4.65	4.00	2	− 2	2000	*
	7.45	6	5.49	1.86	1	5.19	4.48				(6, 28)
	2.37	6	4.87	5.93	0	4.57	3.93	2.84	− 3	2000	(20, 28)
			4.80			4.50	3.88				(22)
Ca............................	1.74	4	3.65	1.2	−1	3.50	3.02				(13, 28)
				6.02	1	2.60	2.24	4	− 3	1100	(7)
Ce on W†.....................				8.0	0	3.15	2.72	5.8	− 2	1600	(8)
Cs............................				1.62	2	2.10	1.81	2.5	−11	500	(17)
Cs on W‡.....................								1	− 4	700	(16, 23)
Cs on O on W†...............				<3.0	−3	0.830	0.72	3.5	− 1	1000	(16, 23)
Hf............................				4.75	4	5.91	5.09	2.6	− 2	2000	(43)
La on W†.....................				8.0	0	3.15	2.72	5.8	− 2	1600	(8)
Mo; *see also* Table 2.............			5.26	6.02	1	5.15	4.44	1.59	− 3	2000	(10*)
			5.35	6.02	1	5.09	4.38	2.34	− 3	2000	(43*)
	2.1	7	5.00	6.1	1	4.74	4.08	1.3	− 2	2000	(19)
	1.1	8	5.36	3.23	2	5.10	4.39	1.12	− 2	2000	(28, 34)
Ni............................	4.61	6	3.40	2.68	1	3.21	2.77				(28, 30)
O on W†......................				5	11	10.70					(16, 23)
Pt (for effect of H, *see* (23)).......				6.02	1	5.90	5.08	1.6	− 8	1600	*
	1.195	7	4.93	5.38	1	4.73	4.08	2.2	− 4	1600	(26, 28)
	1.1	8	6.55	4.93	2	6.35	5.46	8	− 9	1600	(28, 39)
	1.86	8	7.25	8.40	2	7.05	6.05	1.8	−10	1600	(28, 39)
	7.96	9	6.78	3.56	4	6.58	5.68	1	− 7	1600	(27, 28)
	2.55	6	6.10	1.15	1	5.90	5.08	3	− 9	1600	(13, 28)
	4.87	6	6.10	2.19	1	5.90	5.08	6	− 9	1600	(6, 28)
	3.22	12	8.00	1.45	7	7.80	6.71	2.4	− 8	1600	(19, 28)
	1.15	7	5.11	5.16	1	4.91	4.23	5.6	− 6	1600	(28, 30)

Table 1.—(*Continued*)

Symbol	a_1	n	β_1	a_2	n	β_2	ϕ_2	i_T	n	T, °K	Lit.
Elementary substances.—(*Continued*)											
Pt.—(*Continued*)	3.02	3	4.60	1.36	−2	4.40	3.87	4.5	− 8	1600	(25)
	9.90	3	5.20	4.46	−2	5.00	4.31	2.9	− 9	1600	(25)
				3.01	1	4.85	4.18				(29, 35)
	9.3	6	6.32	2.88	1	6.06	5.22	3	− 9		(33)
	7.59	8	5.79	Not gas-free§			4.99				(35)
	1.21	7	5.31	Less gas§			4.57				(35)
	9.7	8	5.84	In hydrocarbon vapors							(25)
Ta; *see also* Table 2	‖		4.98	6.02	1	4.72	4.07	1.38	− 2		(10)
	4.3	2	4.42	1.31	−3	4.17	3.58	4	− 6	2000	(6, 28)
	1.12	7	5.00	3.40	1	4.70	4.04	8.9	− 3		(19, 28)
	8.32	6	5.08	2.95	1	4.85	4.18	3.2	− 3		(33)
	1.19	5	3.64	Not gas-free§			3.14				(35)
	3.61	4	3.64	Less gas§			3.14				(35)
Th		‖		6.02	1	3.89	3.35	4.3	− 3	1600	(43)
Th on W†; *see also* Tables 2 and 4		‖		3.0	0	3.05	2.63	4.0	− 2	1600	(9*)
		‖		7.0	0	3.12	2.69				(16, 23)
U on W†				3.2	0	3.30	2.84	9.1	− 3	1600	(8)
W; *see also* Tables 2, 3, and 4				6.02	1	5.240	4.52	1.00	− 3	2000	*
			5.51	6.02	1	5.236	4.52	1.00	− 3	2000	(4)
	1.05	7	5.30	4.36	1	5.100	4.40	1.45	− 3	2000	(33)
			5.53	6.02	1	5.250	4.53	9.1	− 4	2000	(10)
			5.77	6.02	1	5.225	4.50	1.12	− 3	2000	(42, 43)
Yt on W†				7.0	0	3.13	2.70	5.8	− 2	1600	(8)
Zr				3.00	3	5.22	4.50	5.50	− 2	2000	(43)
Zr on W†				5.00	0	3.65	3.15	1.59	− 3	1600	(7)
Oxides on Pt											
Al_2O_3	6.61	6	4.85	1.62	1	4.63	3.90	5.9	− 2	2200	(33*)
	6.40	0	3.73	2.09	−5	3.48	3.00	6.2	− 7	1873	(14)
B_2O_3	5.37	6	5.45	1.32	1	5.23	4.51	3.1	− 3	2200	(33*)
BaO	6.6	5	2.15	2.88	0	1.95	1.68	3.55	− 1	1200	(33*)
	7.16	7	4.3			4.12					(37)
	4.70	7	4.16	2.72	2	3.99	3.44	2.78	− 6	1223	(14)
	8	4	1.94			1.76	1.51	2.7	− 1		
BaO + SrO	to		to			to	to	to		1200	(1*)
	2.4	5	2.38			2.20	1.89	2.03	− 3		
				1.07	−3	1.21		6.45	− 2	1200	(18)
	In O_2, $P = 0.005$ mm			4.27	3	3.59					(18)
BeO	8.3	7	4.77	3.60	2	4.57	3.94	1.78	− 1	2000	(33*)
	1.03	0	2.39	4.56	−6	2.19	1.88	1.03	− 6	1373	(14)
CaO	2.05	7	3.12	1.29	2	2.92	2.52	2.19	− 1	1400	(33*)
	1.11	8	4.5			4.33					(37)
	6.36	11	4.8			4.62					(13)
	1.75	7	4.3			4.12					(6)
	4.30	7	4.03	2.49	2	3.86	3.33	1.83	− 6	1173	(14)
CdO	3.7	−1	3.02	1.65	−6	2.82	2.43	2.2	− 7	1673	(14)
CeO_2	1.95	3	3.71	8.62	−2	3.51	3.02	2.01	− 6	1523	(14)
Co_2O_3	6.67	3	4.97	2.17	−2	4.72	4.06	6.5	− 7	1723	(14)
CuO	3.5	−3	2.25	1.55	−8	2.05	1.76	2.2	− 7	1673	(14)
Fe_2O_3	3.57	3	4.69	1.16	−2	4.44	3.82	2.3	− 7	1723	(14)
La_2O_3	6.9	2	3.79	3.03	−3	3.59	3.10	2.01	− 6	1623	(14)
MgO	2.34	8	4.04	1.02	+3	3.84	3.31	1.02	− 1	1600	(33*)
	3.37	0	3.95	1.10	−5	3.70	3.19	1.0	− 7	1873	(14)
NiO	2.79	4	5.12	9.1	−2	4.87	4.19	1.5	− 7	1723	(14)
Sc_2O_3	5.50	6	4.31	1.35	1	4.09	3.52	7.2	− 2	2000	(33*)
SiO_2	3.80	6	5.74	1.23	1	5.50	4.75	8.5	− 4	2200	(33*)
SrO	9.3	5	2.36	4.07	0	2.16	1.86	8.5	− 2	1200	(33*)
	5.07	7	4.49	2.58	2	4.30	3.71	8.7	− 7	1273	(14)
	7.5	2	1.41	Anode potential = 200 volt							(11)
	2.4	3	1.44	Anode potential = 300 volt							(11)
ThO_2	1.78	5	3.93	5.7	−1	3.69	3.18	2.3	− 2	2000	(33*)
	3.5	1	3.56	1.54	−4	3.36	2.89	2.1	− 7	1573	(14)
TiO_2	6.31	5	5.16	2.04	0	4.92	4.24	1.2	− 3	2200	(33*)

TABLE 1.—(*Continued*)

Symbol	a_1	n	β_1	a_2	n	β_2	ϕ_2	i_T	n	T,°K	Lit.
Oxides on Pt.—(*Continued*)											
Yt_2O_3	6.03	6	3.82	1.48	1	3.60	3.10	1.00	− 1	1800	(33*)
	1.86	4	3.63	8.22	−2	3.43	2.95	2.36	− 6	1373	(14)
ZnO	3.1	−1	3.51	1.0	−6	3.26	2.81	2.6	− 7	1973	(14)
ZrO_2	1.17	6	4.65	3.80	0	4.41	3.80	4.2	− 3	2000	(33*)
	6.57	3	3.66	2.90	−2	3.46	2.98	1.71	− 6	1423	(14)

Oxides on 95% Pt + 5% Ni (3)

Electrical resistivity of core $= 2.2(10)^{-5}(1 + 0.00208t - 4.6(10)^{-7}t^2)$ ohm cm, t is centigrade temperature, °C. The coating is a mixture of the oxides of Ba and Sr plus a small admixture of Ni (and Pt) which is transferred from core to coating during preparation and activation of the filament. Thermal emissivity (ratio to black-body) $= 0.4 + 2.5(10)^{-4}T$ if $800°\text{K} < T < 1200°\text{K}$. Electron emission in zero field is given by $I_T = (10)^{-2}T^2e^{-11\ 600/T}$ ampere/cm². For anode potential = 150 volt and space-charge limited current = 0.010 ampere/cm², the average life is $1.5(10)^{-5}e^{22\ 000/T}$ hr. The following values are those most probable when anode potential = 150 volt and electric field is zero:

T	900	950	1000	1050	1100	°K
I_T	20	45	90	170	310	10^{-3} ampere/cm²
p_r¶	2.3	3.0	3.7	4.6	5.6	watt/cm²
p_e¶	0.02	0.045	0.09	0.17	0.31	watt/cm²
Life	730**	170**	55	20	7.4	10³ hr

* This value is especially good. † Monatomic layer.

‡ Emission is a function of bulb temperature; bulb at 30°C.

§ These data are not very reliable.

‖ Values on this line should not be used if $T > 1600$°K.

¶ p_r = power thermally radiated; p_e = power absorbed by electron emission.

** Computed.

TABLE 2.—ELECTRON EMISSION FROM MO, TA, TH ON W, AND W: VARIATION WITH TEMPERATURE

Electric field is assumed zero; if, at cathode, $dV/dr > 0$, a correction must be applied, *see* (31); correction must be applied for losses in the leads, *see* (41). $I = i \times 10^n$ = current per unit area $= A_2T^2e^{-b_2/T}$ ampere/cm².

T, °K	Mo		Ta		Th on W		W	
	i	n	i	n	i	n	i	n
1 000	3.24	−15	1.95	−13	1.73	−7	1.07	−15
1 100	4.09	−13	1.71	−11	3.31	−6	1.52	−13
1 200	2.33	−11	7.21	−10	3.95	−5	9.73	−12
1 300	7.36	−10	1.73	− 8	3.27	−4	3.21	−10
1 400	1.41	− 8	1.23	− 7	2.03	−3	6.62	− 9
1 500	1.91	− 7	2.89	− 6	1.00	−2	9.14	− 8
1 600	1.89	− 6	2.44	− 5	4.06	−2	9.27	− 7
1 700	1.38	− 5	1.51	− 4	1.40	−1	7.08	− 6
1 800	8.32	− 5	7.94	− 4	4.28	−1	4.47	− 5
1 900	4.14	− 4	3.61	− 3	1.164	0	2.28	− 4
2 000	1.74	− 3	1.38	− 2	2.864	0	1.00	− 3
2 100	6.61	− 3	4.62	− 2			3.93	− 3
2 200	2.14	− 2	1.41	− 1			1.33	− 2
2 300	6.58	− 2	3.92	− 1			4.07	− 2
2 400	1.81	− 1	1.00	0			1.16	− 1
2 500	4.62	− 1	2.38	0			2.98	− 1
	$A_2 = 60.2$		$A_2 = 60.2$		$A_2 = 3.0$*		$A_2 = 60.2$	
	$b_2 = 51\ 300$		$b_2 = 47\ 200$		$b_2 = 30\ 500$*		$b_2 = 52\ 400$	

* These values should not be used for computing the emission of Th on W at $T > 1600$°K, approx.; *see* Table 4.

TABLE 3.—ELECTRON EMISSION BY W: EFFECT OF GASES (19, 28)

For effect of gas on other substances, *see* Table 1; $I = A_1T^{1/2}e^{b_1/T}$ ampere/cm²; $A_1 = a_1 \times 10^n$, $b_1 = \beta_1 \times 10^4$; P mm of Hg = pressure of the gas.

Gas	P	a_1	n	β_1
Vacuum	0.00007	1.62	−2	5.55
H_2	0.012	2.58	+2	8.25
	0.007	3.63	9	11.5
	0.0017	3.67	7	10.5
	0.0005	2.05	3	8.5

TABLE 2.—(*Continued*)

Gas	P	a_1	n	β_1
O_2		3.25	4	9.43
N_2*	0.002	1.05	1	7.32
		7.95	−1	6.82

* Effect for N_2 varies with anode voltage.

TABLE 4.—EMISSION OF ELECTRONS BY THORIATED W (9)

When W containing Th is heated, there is evaporation of Th from the surface and a diffusion of Th from the interior to the surface (*see* Table 5); the equilibrium condition is determined by the balancing of these two effects. If we write $\theta = (b_\theta - b_W)/(b_{Th} - b_W)$, where b_{Th} is the maximum value of b_2 for thoriated W, and b_W and b_θ are, respectively, the values of b_2 for W and for the thoriated W under study, then θ is, effectively, the fraction of the surface which is completely covered with Th. At temperatures above *ca.* 1600°K, the equilibrium value of θ is <1, and decreases as T increases (21). Kingdon (16, 23) states $b_\theta = 31\ 200\theta + 52\ 200(1 - \theta)$ and $A_2 = [7^\theta + 60^{(1-\theta)} - 1]$ ampere/(cm² deg²). $I_T = A_2T^2e^{-b_2/T}$ ampere/cm² $= i \times 10^n$; $b_2 = \beta_2 \times 10^4$.

θ	$\log_{10} A_2$	β_2	$\log_{10} I$*	i*	n
1	0.455	3.040	0.066	1.16	0
0.924	0.397	3.213	$\bar{1}.613$	4.19	−1
0.830	0.318	3.415	$\bar{1}.072$	1.18	−1
0.723	0.573	3.657	$\bar{2}.775$	5.96	−2
0.565	0.890	4.007	$\bar{2}.292$	1.96	−2
0.440	1.036	4.284	$\bar{3}.804$	6.37	−3
0.250	1.199	4.705	$\bar{3}.037$	1.09	−3

* For T = 1900°K.

TABLE 5.—DIFFUSION AND EVAPORATION OF ELEMENTS CONTAINED IN W AS OXIDES (8)

D cm²/sec = diffusivity; E atoms/(cm² sec) = rate of normal evaporation of the element from the surface of the W; H_d g-cal = heat of diffusion = quantity of heat required to produce the diffusion of 1 g-atom of the diffusing material through the metal (here W) in which it is contained. $D = d \times 10^{-11}$; $E = e \times 10^9$; $H_d = h \times 10^3$; T = 2000°K.

TABLE 5.—(*Continued*)

	d	e	h
Ce	95	1450	83
Th*	5.9	1.53	94
U	1.3	>Th	100
Yt	1820		62
Zr	324	68	78

* Langmuir (21) finds for Th, $\log_{10} D = 0.044 - 20\,540/T$; $\log_{10} E = 31.434 - 44\,500/T$.

TABLE 6.—THERMIONIC WORK FUNCTION (ϕ): CALORIMETRIC DETERMINATION

ϕ_c = value by calorimeter, ϕ_b = value computed from b_2 (from b_1, in case of (40)); same material for each. Unit of ϕ = 1 volt = 1.591×10^{-12} erg per electron.

Elementary substances				Oxides on Pt					
Material	ϕ_c	ϕ_b	Lit.	Oxides			ϕ_c	ϕ_b	Lit.
				Ba	Ca	Sr			
C	4.55		(24)						
Mo*	4.59		(24)	50	25	25	2.39 2.54	2.34 2.59	(40)
Os	4.7		(2)						
Pt	5.9		(38)	50	0	50	1.97 2.28	2.02 2.16	(40)
Ta	4.51		(24)						
W	4.52	4.52	(4)	(?)	0	(?)	1.61	1.65	(5)
	4.48		(24)	0	100	0	3.22	3.28	(40)

* Effect of gas, Mo at 200°C (36): A, $\phi_c = 4.76$; H_2 + A, ϕ_c = 4.04 to 4.35; N_2, ϕ_c = 4.77 to 5.01.

Electron emission data for fused gold, silver and copper above and below the melting point have been measured by Goetz (12). Values of A and b vary with the temperature. For a comprehensive discussion of theory and data, *see* W. Schottky and H. Rothe, *Physik der Glühelektroden, Handbuch der Experimentalphysik*, **13 II**, Leipzig, 1928.

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CONTACT POTENTIALS

SAUL DUSHMAN

If the heat absorbed when one unit of electricity passes (1) from the free surface of conductor A to the free surface of conductor B, in contact with A, is P'_{AB}; (2) across the junction from A to $B = P_{AB}$; (3) from surface of A [B] to infinity $= P_{AS}$ [P_{BS}]; then $P'_{AB} = P_{AB} - P_{BS} + P_{AS}$. Let $K_{AB} = V_A - V_B$ = contact potential of A with reference to B; V_A, V_B are the simultaneous potentials of A, B when in contact (2, 5). From thermodynamics, it follows that $\mathrm{d}K_{AB}/\mathrm{d}T = -P'_{AB}/T$; for Fe and Ni this amounts to 0.000032 volt/degree at 50°C, while the experimental value for the range 20 to 60°C is 0.0016 volt/degree (5). The discrepancy is ascribed to the formation of a thin surface layer of oxide.

The value of K_{AB} may be deduced from data pertaining to the thermo- and photo-emission of electrons. If I = current per unit area carried by the thermoelectrons, $K_{AB} = \frac{k_0T}{\mathbf{e}} \log_e \frac{I_A}{I_B}$, and if $I = AT^n e^{-\phi\mathbf{e}/k_0T}$ (*cf.* p. 53), $K_{AB} = \phi_B - \phi_A + \frac{k_0T}{\mathbf{e}} \log_e \frac{A_A}{A_B}$. If A is a universal constant (18), $K_{AB} = \phi_B - \phi_A$.

If ν_0 = threshold frequency for emission of photoelectrons, V_{rAa} = retarding voltage = potential to which A must be raised above the anode in order to prevent the emission of photoelectrons under action of radiation of frequency ν, and K_{Aa} = contact potential of A with reference to anode, then (12, 15) $(V_{rAa} + K_{Aa})\mathbf{e} = \mathbf{h}(\nu - \nu_{0A})$ and $K_{AB} = V_{rBa} - V_{rAa} + (\nu_{0B} - \nu_{0A})\mathbf{h}/\mathbf{e} = V_{rBa} - V_{rAa} + (\phi_B - \phi_A)$; this equation is confirmed by experiments (9, 15). Millikan (15) calls $(V_{rBa} - V_{rAa})$ the "spurious" and $(\nu_{0B} - \nu_{0A})\mathbf{h}/\mathbf{e}$ the "intrinsic" contact potential. For clean metals $V_{rBa} = V_{rAa}$; for others the equality may fail (15). Comparing this expression for K_{AB} with that derived from thermoelectronic data, it is obvious that $V_{rBa} - V_{rAa} = \frac{k_0T}{\mathbf{e}} \log_e \left(\frac{A_A}{B_B}\right)$, if ϕ denotes the same quantity in each case (18).

Many of the following data are not very reliable, but those obtained under similar conditions probably indicate the correct order of the conductors in a Volta series.

TABLE 1.—VALUES OF THE WORK FUNCTION (ϕ) AS DERIVED FROM THE WAVE-LENGTH LIMIT (λ_0) OF THE PHOTOELECTRIC EFFECT: ILLUSTRATIVE DATA

Values for other substances may be derived from the photoelectric data on pages 67–69.

$\phi = \frac{hc}{e\lambda_0}$; $K_{AB} = V_{rBa} - V_{rAa} + \phi_B - \phi_A = \frac{k_0T}{e}\log_e\frac{A_A}{A_B} + \phi_B - \phi_A$ where A_A and A_B have the values derived from thermal electron emission data, p. 53. For clean surfaces, $K_{AB} = \phi_B - \phi_A$. $\phi/\nu_0 = 4.117 \times 10^{-15}$ (volt sec); $\phi\lambda_0 = 12\,344$ (volt Ångstrom). Unit of $\lambda_0 = 1$ Å $= 10^{-8}$ cm $= 10^{-4}\mu$; of $\phi = 1$ volt $= 10^8$ cgsm unit $= 3.33 \times 10^{-3}$ cgse unit.

Conductor	λ_0	Lit.	ϕ	Conductor	λ_0	Lit.	ϕ
Li	5263	(14)	2.35	Pt	2570	(11)	4.80
Na	5770	(6)	2.14		2910	(19)	4.24
	to		to		2960	(21)	4.17
	5830		2.12	Ta	3283	(21)	3.76
	6800	(13)	1.82	W	2200	(7)	5.61
	4860	(21)	2.54		3062	(21)	4.03
				BaO, SrO*	2860†	(11)	4.31
					3800‡	(11)	3.24

* On Pt. †At 20°C. ‡ At 420°C.

TABLE 2.—CONTACT POTENTIAL DEDUCED FROM THERMAL EMISSION OF ELECTRONS

Data for other pairs of conductors may be computed from the data on pages 55–56, by the relation $K_{AB} = \phi_B - \phi_A + \frac{k_0T}{e}\log_e\frac{A_A}{A_B}$. All data from (22) refer to metals in vacuum. $K_{AB} = V_A - V_B$. Unit of K_{AB} = 1 volt.

A	B	K_{AB}	Lit.
Al	C	+0.87	(22)
C	C-black*	−0.24	(22)
C	Fe	−0.02	(22)
C-black*	W	+0.36	(22)
Fe	W	0.00	(22)
W	Zn	−0.51	(22)
W_{hot}	Cu_{cold}	†	(20)
Pt_{hot}	Pt_{cold}	+0.16‡	(20)
Th W_{hot}§	W_{cold}	+0.71	(20)

* Lampblack.
† Presence of H_2 makes W more positive; Hg vapor has no effect.
‡ In H_2, pressure = 0.112 mm of Hg; temp. of Pt_{hot} = 1460°K.
§ Th W = Thoriated W.

TABLE 3.—CONTACT POTENTIAL OF METALS WITH BRASS: CONDENSER METHOD; ROOM TEMPERATURE

Values tabulated are the differences $V_{metal} - V_{brass}$ columns (1), (2), (3); metal in vacuum; (1) surface freshly scraped; (2) four days after scraping; (3) before scraping. Column (4) metal in air at atmospheric pressure; (5) in air at pressure of 0.0001 mm; (6) highest value obtained after heating to high temperature in vacuum; (7) in air at atmospheric pressure; (8) in air at room temperature and atmospheric pressure. Unit of potential = 1 volt = 10^8 cgsm unit = 3.33×10^{-3} cgse unit.

Metal	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ag	+0.05	0	−0.097				−0.35	−0.286
Al	+1.04	+0.874	+0.293	+0.19*	+0.20*	+0.90*		+0.670
Au				−0.23	−0.22	+0.02	−0.33	−0.269
Bi							+0.07	
Cu	+0.10	−0.110	−0.106	−0.04*	−0.04*	+0.44*	−0.15	−0.154
Fe	+0.24	+0.192	+0.053				0.00†	+0.040
Mg	+1.47	+0.713	+0.825					
Ni				+0.16	+0.18	+0.47	+0.09	
Pb							+0.41	+0.396
Pt				−0.30*	−0.28*	−0.23*	−0.32	−0.354
Sb							+0.15	
Sn	+0.32	+0.317	+0.216					+0.318
Zn	+0.64	+0.496	+0.193	−0.596‡			+0.43*	+0.608
Brass	+0.26	+0.228	−0.123					
Lit.	(8)	(8)	(8)	(26)	(26)	(26)	(16)	(1)

* Mean of observations on 2 different specimens. † Same for steel.
‡ One hr after polishing; 1 week after polishing found −0.543; both surfaces polished (23).

TABLE 4.—CONTACT POTENTIAL (K) OF METALS WITH PLATINUM (19)

$K = V_{metal} - V_{Pt}$; unit = 1 volt = 10^8 cgsm unit = 3.33×10^{-3} cgse unit

Metal	Al	Bi	Cu	Mg	Na	Sn	Zn
K	1.20	0.35	0.13	1.05	2.40	0.62	0.90

TABLE 5.—CONTACT POTENTIALS OF MISCELLANEOUS PAIRS OF CONDUCTORS: CONDENSER METHOD; ROOM TEMPERATURE

For metals with brass, *see* Table 3; $K_{AB} = V_A - V_B$

A	B	K_{AB}	Lit.	A	B	K_{AB}	Lit.
Al*	Fe	+0.87	(4)	Pt	Zn‖	‖	(10)
Al*	Zn	+0.29	(4)	K	Pt	+2.8	(25)
Fe*	Zn	−0.60	(4)	C + NH_3¶	Cu	+0.079	(24)
CuO*	Li	−1.52†	(14)	C + H_2¶	Cu	+0.096	(24)
		−1.11‡	(14)	C + N_2¶	Cu	+0.129	(24)
CuO*	Na	−2.52	(14)	C + CO_2¶	Cu	+0.130	(24)
Cd§	Hg	−0.22	(17)	C + NO¶	Cu	+0.136	(24)
Hg§	Sb	−0.26	(17)	C + O_2¶	Cu	+0.142	(24)
Hg§	Zn	+0.17	(17)	C + O_3¶	Cu	+0.155	(24)
Bi‖	Pt	‖	(10)				

* In vacuum. † Fresh surface. ‡ Old surface.
§ Initial value in dry air, pressure = 0.05 mm Hg. K_{AB} varies with the time. Author also gives data for moist air, H_2 and CO_2.
‖ Distilled in vacuum; initially K_{AB} is low, traces of air cause the Bi and Zn to become more positive; after passing a maximum, an equilibrium value is approached. ¶ Coconut charcoal saturated with the gas indicated.

TABLE 6.—SIGNS OF CHARGES ACQUIRED BY DIELECTRICS IN CONTACT WITH HG AND WITH AMALGAMS (3)

Surfaces in high vacuum

Dielectric	Hg	Ag-Hg	Na-Hg	Zn-Hg
Amber	−	−	+	+
Diamond, C	−	−	−	−
Ebonite	−	−	+	+
K-glass	−	−	+	−
Na-glass	−	−	+	+
Sealing wax	−	−	+	+
Quartz, SiO_2	−	−	+	+

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CURRENT FLOW IN VACUUM TUBES WITH HOT CATHODES

Albert W. Hull

CONTENTS

In what follows it is assumed that the emission of electrons (or ions) from the cathode (*see* p. 53) is so ample that the current through the tube is not limited by it.

Diodes.—If the carriers are emitted with velocity = 0, then in all cases $i = KGV_a^{1.5}$, where the value of KG depends only upon the construction of the tube and upon the system of units employed. K depends upon e/m and G upon certain ratios determined by the geometrical configuration of the conductors in the tube; G is dimensionless. Except in certain ideal cases, KG is treated as a single quantity and is denoted by k (*see* Table 3).

Triodes (10, 22).—If the carriers are emitted with velocity = 0, and if there is no magnetic field, $i(= i_p + i_g) = k(E_p + \mu E_g)^{1.5}$, approximately, *see* (20); k has the same value as for the corresponding diode; μ depends solely upon the geometrical configuration of the conductors in the tube (1, 4, 17, 20), but by varying the size of the grid mesh, it can be given any desired value. The mutual conductance (g_m) is a function of i_p, but for a given value of i_p, it is nearly independent of size of grid mesh. It is roughly proportional to length of cathode filament and inversely proportional to distance between grid and filament (*see* Table 4).

Tubes with Four Electrodes.—Space-charge grid tubes have the second grid next to the filament; the presence of this grid multiplies g_m by approximately 4, but the other constants remain the same as for the corresponding triode (21). Screen-grid tubes have the second grid between grid and plate. If screening is perfect, i_p is a function of E_g only, and the value of g_m is only about ¾ as great as in the corresponding triode (7, 21).

SYMBOLS

A	Area of one side of a plate electrode
c	Velocity of light *in vacuo*.
cgse	Cgs electrostatic system of units.
cgsm	Cgs electromagnetic system of units.
csva	Cm-sec-volt-ampere system of units, absolute volt and ampere.*
csVA	Cm-sec-volt-ampere system of units, international volt and ampere.*
E_p, E_g	Potential of plate, grid, above that of cathode.
e	Negative electronic charge.
e	Negative charge of the carrier of electricity (electron or ion).
G	Geometrical factor of k.
g_m	Mutual conductance of plate and grid, $g_m = -\partial i_p/\partial E_g$, E_p being constant.
H	Strength of magnetic field externally applied parallel to axis of cylindrical electrodes.
I	Current flowing through the inner cylindrical electrode parallel to its axis.
i, i_p, i_g	Current to cathode: Total, from plate, from grid; $i = i_p + i_g$.
K	Physical factor of k.
k_0	Boltzmann gas constant.
k	Space charge constant characteristic of the tube; $k = KG$.
l	Length of cylindrical electrode.
M	Molecular weight of the carrier ions.
m	Mass of the carrier of electricity (electron or ion).
$\mathbf{m}_0$	Mass of negative electron at low velocity.
r_a, r_c	Radius of anode, cathode.
r_o, r_i	Radius of outer, inner, of two coaxial cylinders, or of two concentric spheres.
R_p	Plate resistance; $R_p = 1/(\partial i_p/\partial E_p)$, E_g being constant.
T	Absolute temperature of the carriers of electricity, °K. For thermionic carriers, T = temperature of cathode (3); for electrons from low pressure arcs, T is nearly independent of current density, but depends upon the nature and pressure of the gas, and ranges from 10 000 to 50 000°K (16).
V	Excess of potential above that of cathode.
V_m	Minimum value of V in space between anode and cathode.
V_a	Potential of anode above that of cathode.
v	Velocity of carrier.
v_i	Initial velocity of carrier.
x	Distance from cathode in direction of anode.
x_m	Value of x corresponding to V_m.
x_a	Distance between anode and cathode.
α^2, β^2	Functions of r_o/r_i.
ϵ	Dielectric constant of a vacuum. In cgse system, $\epsilon = 1$; in cgsm, $\epsilon = \mathrm{c}^{-2}$; in csva, $\epsilon = (10)^9\mathrm{c}^{-2}$; in csVA, $\epsilon = 1.00052(10)^9\mathrm{c}^{-2}$.
μ	Amplification factor; $\mu = -\mathrm{d}E_p/\mathrm{d}E_g$, i_p being constant.

Table 1.—Ideal Diodes

K_e = value of K if carriers are electrons; $K = K_e\sqrt{e\mathbf{m}_0/\mathbf{e}m} = K_e\sqrt{e/(1847M\mathbf{e})}$. ‖ Plates, Coax. Cyl., Con. Sph. = parallel plates, coaxial cylinders, concentric spheres. General formulae are valid for any consistent system of units; a numerical value is valid only for the indicated system of units.

Electrodes	G	Formula, K	cgse		csVA		Lit.
			k_e	n	k_e	n	
Magnetic field = 0, $v_i = 0$; $i = KGV_a^{1.5}$; $K_e \equiv k_e \times 10^n$							
‖ Plates....	$\frac{A}{x_a^2}$	$\frac{\sqrt{2}}{9\pi}\epsilon\sqrt{\frac{e}{m}}$	3.643	+7	2.341	−6	(2, 8, 11)
Coax. cyl..	$\frac{l^*}{r_a\beta^2}$	$\frac{2\sqrt{2}}{9}\epsilon\sqrt{\frac{e}{m}}$	22.89	+7	14.71	−6	(13, 15)
Con. sph...	$\frac{1^*}{\alpha^2}$	$\frac{4\sqrt{2}}{9}\epsilon\sqrt{\frac{e}{m}}$	45.78	+7	29.42	−6	(14)
Magnetic field = 0, v_i has a Maxwellian distribution (12)							
‖ Plates....	$i = GK(V_a - V_m)^{1.5}\left(1 + C\sqrt{\frac{T}{V_a}}\right)$, where K has same value as for $v_i = 0$, $G = A/(x_a - x_m)^2$, and $C = 2.66\sqrt{\frac{k_0}{e}}$. If $e = \mathbf{e}$, then $C = 0.001426$ cgse = 0.0247 csVA.						
Magnetic field ≠ 0, $v_i = 0$							
Coax. cyl..	$i = GKV_a^{1.5}$ if $V_a > V'$; $i = 0$, if $V_a < V'$. G and K have same values as for field = 0; $V' = \frac{e}{m}\times\left[\frac{H^2r_o^2}{8} + 2I^2\left(\log_e\frac{r_o}{r_i}\right)^2\right]$. In the csVA system, $V' = 0.0221H^2r_o^2 + 0.0188I^2\left(\log_{10}\frac{r_o}{r_i}\right)^2$, if carriers are negative electrons.						

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* In csva system, unit of mass is 10^7 g; required by relation $eV = \frac{1}{2}mv^2$. In csVA system, unit of mass is $\frac{10^7}{1.00032}$ g.

* For values of α^2 and β^2, *see* Table 2.

TABLE 2.—VALUES OF COEFFICIENTS α^2 AND β^2

For coaxial cylinders, $G = l/(r_a\beta^2)$; for concentric spheres, $G = 1/\alpha^2$ (*see* Table 1)

Cathode,	Inside	Outside	Inside	Outside
r_o/r_i	α^2 (14)		β^2 (13)	
1.1	0.0086	0.0096	0.0001	0.01
1.5	0.1302	0.2118	0.1193	0.228
2.0	0.326	0.750	0.2793	0.845
3.0	0.669	2.512	0.5170	2.98
4.0	0.934	4.968	0.6671	6.06
5.0	1.141	7.98	0.7666	9.89
10	1.777	29.2	0.9782	37.0
20	2.378	93.2	1.0715	115.6
50	3.120	395	1.0936	450.2
100	3.652	1 144	1.0782	1 175
200	4.166	3 270	1.0562	2 946
500	4.829	13 015	1.0307	9 502
1 000	5.328		1.0171	
∞			1.0000	

TABLE 3.—CHARACTERISTICS OF TYPICAL COMMERCIAL DIODES (6)

In all cases $i = kV_a^{1.5}$ (9). The tubes are so constructed that, for the size of anode used, k is as great as is now (Jan., 1927) considered practical. The values are for American tubes, but do not differ appreciably from those for similar tubes constructed elsewhere. i_f, E_f = filament current, voltage; E_m = maximum effective A.C. input voltage; i_m = maximum rectified tube current; P_n = nominal power rating; ThW, PW = thoriated tungsten, pure tungsten, filament. Unit of i_f and i_m = 1 ampere; of E_f and E_m = 1 volt; of P_n = 1 kilowatt; of k = 0.0001 ampere/volt$^{1.5}$.

Type	i_f	E_f	E_m	i_m	P_n	k
ThW.......	1.25	7.5	550	0.065	0.0075	1.2
ThW.......	3.25	10	1 500	0.20	0.050	1.7
ThW.......	3.85	11	2 500	0.25	0.250	1.1
PW........	14.7	11	16 000	0.166	1.00	0.5
PW........	24.5	22	17 500	0.833	5.00	1.0
PW........	52	22	18 000	3.0	20.00	1.1
PW........	10	10	20 000	0.10		0.10
PW........	10	10	85 000	0.10		0.11
PW........	32	9	75 000	0.25		0.25
PW........	10	10	150 000	0.100		0.11
PW........	32	12.5	150 000	0.25		0.11

TABLE 4.—CHARACTERISTICS OF TYPICAL COMMERCIAL TRIODES

The following data for American tubes differ but little from those for corresponding tubes manufactured elsewhere. Ox, ThW; PW = oxide coated, thoriated tungsten, pure tungsten filaments; i_f = filament current, E_f filament voltage; E_p = normal plate voltage, L, D = overall length, diameter, of tube; P_a = safe continuous energy dissipation at anode; P_o = rated power output; E_g, i_p = grid voltage, plate current, for normal operation as amplifier. Unit of i_f = 1 ampere; of i_p = 0.001 ampere; of E_f, E_p, E_g = 1 volt; of L, D = 1 cm; of P_a, P_o = 1 kilowatt; of g_m = 0.001 mho = 0.001 ohm^{-1}. μ is dimensionless.

Standard American Triodes (18, 19)

Type	i_f	E_f	L	D	R.C.A. name	E_p	E_g	i_p	g_m	μ	P_a	P_o
Ox...................	0.25	1.1	10	3.0	WD11	90	− 4.5	2.5	0.425	6.6		
Ox...................	0.25	5.0	12	4.6	UX112-A	135	− 9	10.0	1.70	8.0		
ThW................	0.06	3.0	10	3.0	UX199	90	− 4.5	2.5	0.425	6.6		
ThW................	0.125	3.0	10	3.0	UX120	135	− 22.5	6.5	0.500	3.3		
ThW................	0.50	5.0	12	4.6	UX171	180	− 40.5	20	1.500	3.0		
						135	− 27	17	1.360	3.0		
ThW................	0.25	5.0	12	4.6	UX201-A	135	− 9	3.0	0.800	8.0		
						90	− 4.5	2.5	0.725	8.0		
ThW................	0.25	5.0	12	4.6	UX240	135	− 1.5	0.20	0.200	30.0		
ThW................	1.25	7.5	14	5.5	UX210	425	− 35	20	1.500	7.5		
ThW................	3.25	10	20	5.4	UV203-A	1 000	0	120	5	25	0.10	0.075
ThW................	3.85	11	36	10	UV204-A	2 000	0	300	5	25	0.25	0.25
ThW................	15.5	11	45	15	UV851	2 000	− 60	350	15	20	0.750	1
PW..................	14.75	11	40	12.5	UV206	15 000	0	54	1.9	325	0.35	1
PW..................	24.5	22	57	15	UV208	15 000	0	195	3.2	240	1.0	5
PW..................	52	22	48	11	UV207	15 000	−475	400	4.5	20	10	20

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TABLE 3.—(*Continued*)

			V_o	Lit.	V_c	Bands	Lit.
CO........	IC	*a*	5.8	(85)	5.97	Cameron	(53)
					7.27		
	IC	*b*	8.0	(85)	7.99	Fourth positive	(53)
	R, S	*c*	10.15*	(25, 41)	10.34	Third positive (*c-a*)	(53)
	S	*d*	10.7*	(25, 41)	10.72	Ångstrom (*d-a*)	(53)
	S	*e*	11.1	(25)	11.34	(*e-b*)	
	I	*f*	14.2*	(25, 41)			
	S	*g*	16.8*	(25, 41)	16.7	Comet-tail (*g-f*)	(53)
	S	*h*	19.9*	(25, 41)	19.8	First negative (*h-f*)	(53)

Three other spectroscopic levels between *e* and *f*. From vibrational states of normal level (4), $D = 11.2$; from heat of combustion and D for O_2, $D = 10.8$; mean $D = 11.0$. From vibrational states, $D^+ = 9.8$. As $I_A (= I_M + D^+ - D) = 14.2(f) + 9.8 - 11.0 = 13.0$ is, within experimental error, $= I_A$ of O ($= 13.56$, Table 1), the dissociation of CO^+ probably gives C and O^+.

* Mean error = ±0.1.

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DIELECTRIC CONSTANT AND DIELECTRIC STRENGTH

INTRODUCTION

The dielectric constant (ϵ) of a material is a measure of the ratio of the electric displacement (D) to the electric field intensity (E), $D = \epsilon E/4\pi$; for a vacuum, $\epsilon = 1$ cgse unit. The value of ϵ may be determined from the measurements (1) of electrical capacities, (2) of mechanical forces between charged conductors, or (3) of the wave lengths of electrical waves. All three methods yield the same result, except in so far as the value of ϵ varies with the frequency (ν) of E. If electrical waves experience absorption in the substance, the index of the absorption (*v.* Vol. 1, p. 34) being k', then $\epsilon = (1 - k'^2)\lambda_0^2/\lambda^2$, where $\lambda_0[\lambda]$ = wave-length, for frequency ν, in vacuum [in substance]; values of ϵ so obtained are accompanied by the corresponding values of k', if known; when k' is not given, it is believed to be too small to affect the value of ϵ within the stated limits of accuracy.

For variation of ϵ with E, *v.* p. 106; with magnetic field, *v.* p. 105; with illumination, *v.* p. 79.

The dielectric strength (S) of a material is defined as the minimum value, in the material, of the electric field intensity (E) at which a disruptive discharge occurs. In many cases it appears doubtful if S is a constant, characteristic of the material, as it frequently appears to vary with the nature of the electrodes and with the distance between them. As the determination of the actual maximum value of E occurring in the field at the instant of discharge is difficult, the value of S is frequently merely indicated by stating the kind of electrodes, the minimum distance (l) between their surfaces, and the difference in their potentials at the instant of discharge, if the difference is increasing slowly and continuously (D.C.). If the voltage is alternating (A.C.) either the effective (V_e) or the maximum (V_m) value of the alternating potential difference of the electrodes is stated. If the potential difference varies as sin ωt, $V_m = 1.414 V_e$. Electrical oscillations in the circuit may introduce serious errors and injure connected apparatus, and should be prevented from reaching the terminals by the insertion, in series with each terminal, of a non-inductive resistance of at least one ohm per volt. The effect of surrounding objects in modifying the electrical field must be considered, and very definite specifications for the construction of the gap must be followed if accurate values for the potential difference corresponding to a given spark length are desired (*cf.* p. 79, 80).

DIELECTRIC CONSTANT AND DIELECTRIC STRENGTH OF ELEMENTARY SUBSTANCES, PURE INORGANIC COMPOUNDS, AND AIR

H. L. CURTIS AND F. M. DEFANDORF

Symbols.—l = liquid, s = solid, t_R = room temperature, *v.p.* = vapor pressure of the saturated vapor at the temperature indicated. ϵ = dielectric constant, ν = frequency of field used in obtaining ϵ. Such expressions as "(80 p 160)" and "(10° t 100°)" indicate that the accompanying coefficients apply so long as p [t] lies between 80 and 160 [10° and 100°]; "25; 45" in the temperature column indicates that the same value was found at 25° as at 45°. Other symbols unexplained in Vol. I, p. 16, will be defined where used.

No data have been found for the dielectric strength of any solid or liquid included in this section.

TABLE 1.—DIELECTRIC CONSTANT (ϵ) OF PURE INORGANIC GASES

$(\epsilon_t - 1) = (\epsilon_0 - 1)[1 + \alpha t(10)^{-3} + \beta t^2(10)^{-6}]$; $\epsilon - 1 = (\mathrm{a}p + \mathrm{b}p^2)(10)^{-4} = 3\mathrm{c}d_1[1 + \mathrm{c}d_1(10)^{-6}](10)^{-6}$, where d_1 = specific gravity of the gas with reference to itself at 0°C and 1 atmosphere. $\epsilon = 1 + 0.001\Delta$; $\nu = A \times 10^n$. Unit of ϵ = 1 cgse unit; of p = 1 atmosphere; of ν = 1 cycle/sec; of t = 1°C.

	$\Delta_{t,p}$	t	p	A	n	Lit.
A	0.56	0	1	1	6	(15)
Br	12.8	180	1	Radio		(14)
H	0.26	0	1	≤2	6	(5, 12, 49, 75, 96, 151)
	0.92_8	−185	1	Radio		(106)
	c = 90, t = 24 (80 p 160)			0	0	(93)
He	0.074	0	1	0	0	(68)
Hg	0.74	400	1	3	8	(10)
N	0.55_5	0	1	5; 8	5	(5, 49)
	0.60_6	0	1	2	6	(108)
	0.58_1	0	1	Radio		(151)
	0.79	− 75	1	1	6	(153)
	1.90	−189	1	1	6	(153)

TABLE 1.—(*Continued*)

	$\Delta_{t,p}$	t	p	A	n	Lit.
O	0.50_7	0	1	5	5	(5)
	0.51_0	0	1	8	5	(49)
	0.54_7	0	1	2	6	(108)
	0.51_8	0	1	Radio		(151)
	c = 173, t = 13.5 (35 p 110)			0	0	(93)
H_2O	*See* Table 4					
HCl	2.6	100	1	Audio		(5)
	7.6	− 75	1	Radio		(151)
	4.6_0	0	1	Radio		(151)
	2.5_0	100	1	Radio		(151)
	1.6_2	200	1	Radio		(151)
	1.4_0	300	1	Radio		(151)
HBr	3.4_4	− 50	1	Radio		(151)
	3.1_3	0	1	Radio		(151)
	2.6_2	100	1	Radio		(151)
	2.3_0	200	1	Radio		(151)
	2.1_2	300	1	Radio		(151)
HI	2.3_8	− 25	1	Radio		(151)
	2.3_4	0	1	Radio		(151)
	2.2_0	100	1	Radio		(151)
	2.1_5	200	1	Radio		(151)
	2.1_6	300	1	Radio		(151)
	2.1_8	350	1	Radio		(151)
SO_2	9.5	0	1	0	0	(75)
	9.0*	0	1	0	0	(135)
	9.3†	0	1	Audio		(5)
	9.5	0	1	1	6	(153)
	5.3	100	1	1	6	(153)
	3.9	175	1	1	6	(153)

* $\alpha = -4.7$ (10° t 60°) (135).

† $\alpha = -6.3_2$, $\beta = 18.7$ (10° t 100°) audio (5).

TABLE 1.—(*Continued*)

	$\Delta_{t,p}$	t	p	A	n	Lit.
H_2S..........	4.0‡	0	1	1	6	(15)
	ϵ = 2.0§	10	*v.p.*	Audio		(38)
N_2O..........	0.99	0	1	0	0	(12)
	1.16	0	1	0	0	(75)
	1.13	0	1	2	6	(108)
	10	15	10	0	0	(82)
	25	15	20	0	0	(82)
	46	15	30	0	0	(82)
	72	15	40	0	0	(82)
			mm	% NO_2		
$N_2O_4 + NO_2$..	2.3	42.5	747	31		(5)
	2.4	49.7	746	39		(5)
	1.4	63.1	747	55		(5)
	1.4	68.7	741	63		(5)
	1.0	90.5	741	84		(5)
	1.3	92.1	747	85		(5)
			p	A	n	
NH_3..........	8.37¶	0	1	Audio		(5)
	9.2	− 30	1	1	6	(153)
	7.2	0	1	1	6	(153)
	4.0	100	1	1	6	(153)
	2.7	185	1	1	6	(153)
CO..........	0.69_5	0	1	0	0	(12, 15, 75)
	0.70	0	1	5	1	(104)
	2.63	−189	1	Radio		(106)
CO_2..........	0.98**	0	1	≤2	6	(5, 12, 49, 75, 104, 108, 134, 135)
	0.98††	0	1	1	6	(153)
	1.41	− 73	1	Radio		(106)
	5_0	0	*v.p.*	0	0	(135)
	c = 332, t = 13.5 (10 p 50)			0	0	(93)
	8	15	10	0	0	(82)
	19	15	20	0	0	(82)
	37	15	30	0	0	(82)
	62	15	40	0	0	(82)
	See also Fig. 2					
CS_2..........	2.9	0	1	0	0	(75)
	3.2‡‡	0	1	0	0	(5)
Air..........	*See* Table 3					

‡ $\alpha = -5$ (0° t 100°). § *See* Fig. 1.

¶ $\alpha = -7.75$, $\beta = 31$ (18° t 108°) audio (5).

** $\alpha = (3.71 + 0.05p)$ (9° t 66°) (1 p 5) (134, 135).

†† $\alpha = -4.3$, $\beta = 11$ (−75° t 200°) (153).

‡‡ $\alpha = -3$ 7 (85° t 130°) (5).

TABLE 2.—DIELECTRIC CONSTANT (ϵ) OF PURE INORGANIC SOLIDS AND LIQUIDS AND ITS VARIATION WITH TEMPERATURE (t), PRESSURE (p), AND FREQUENCY (ν)

For SiO_2, *v.* p. 341; for single crystals, *v.* p. 98

From certain solids it is difficult, or even impossible, to prepare plates which are sufficiently homogeneous to be used for a direct determination of the dielectric constant (ϵ) of the material. In such case, it is customary to deduce ϵ from the effective dielectric constant (ϵ') of a dry plate formed by compressing the powdered substance, or from the effective constant (ϵ_1) of such a plate when saturated with a liquid (dielectric constant = ϵ'') which does not dissolve the powder. For such deduction, one or another of the following equations is generally used:

(1) $(\epsilon - 1)/d = (\epsilon' - 1)/d'$; (2) $(\epsilon - 1)/d(\epsilon + 2) = (\epsilon' - 1)/d' \times (\epsilon' + 2)$; (3) $(\epsilon - 1)/d(\epsilon + n) = (\epsilon' - 1)/d'(\epsilon' + n)$; (4) $(\epsilon - \epsilon'')/d = (\epsilon_1 - \epsilon'')/d'$. Here d = density of the substance, d' = density of the dry plate, and n is Wiener's number (152).

All liquids are under the pressure of saturated vapor unless contrary is indicated in first column. In column (2), l = liquid, s = solid, ls = intermediate between liquid and solid, P indicates ϵ was deduced from effective constant of a plate of compressed powder, its subscript indicates equation used.

$$\epsilon_t = \epsilon_{t_0} + \alpha(t - t_0)(10)^{-3} + \beta(t - t_0)^2(10)^{-6}; \epsilon_p = \epsilon_0(1 + \mathrm{a}p(10)^{-4} + \mathrm{b}p^2(10)^{-8}); \nu = A \times 10^n$$

Unit of ϵ = 1 cgse unit, of p = 1 atmosphere, of ν = 1 cycle/sec of t = 1°C

Formula	(2)	ϵ_{t_0}	t_0	A	n	Lit.
		A-Table.—The A-Arrangement				
Br..............	l	3.2	23	1	8	(114)
	l	3.1	t_R	1	8	(117)
C (Diamond)....	s	16.5	t_R	Audio		(103)
	s	5.5	t_R	1	8	(117)
Cl..............	l	1.97*	0	0	0	(82)
	l	2.0†	0	Audio		(38)
	l	1.9	14	2	6	(26)
H (p = 1)......	l	1.22‡	−253	1	5	(16)
(p = 1)......	l	1.225§	−253	6	5	(148)
	l	1.253‖	−259	1	5	(145)
	s	1.21¶	−259.9	6	5	(148)
	s	1.21	−259.1	1	5	(145)
He (p = 1).....	l	1.048	−268.9	6	5	(148)
	l	1.058	−270.8	6	5	(146)
	l	1.056	−271.3	6	5	(146)
I..............	s	10	23	1	8	(114)
	s	4	t_R	1	8	(117)
O (p = 1).......	l	1.465	−182	0	0	(63)
(p = 1).......	l	1.493	−182	0	0	(44)
	l	1.46	−182	1	5	(16)
	l	1.51**	−203	1	5	(16, 146)
P (p = 1).......	l	3.85	20; 45	1	8	(115)
	s	4.1	20	1	8	(115)
(Yellow)......	s	3.6	t_R	1	8	(117)
S‖‖ (p = 1).....	l	3.42	400	Audio		(103)
(p = 1)......	ls	3.98	115	Audio		(103)
	s	4.22††	t_R	Audio		(103)
	s	4.0	t_R	0	0	(53)
	s	4.01‡‡	0	0	0	(118)
	s	4.38	t_R	0	0	(130)
	s	4.05††	t_R	5.0	1	(41)
	s	3.80§§	t_R	5.0	1	(41)
	s	4.03	t_R	8.0	1	(130)
	s	4.03	t_R	9.3	1	(42)
	s	4.2	16	1	3	(46)
	P_2	4.7	17	1	6	(74)
	s	3.24¶¶	25	3.8	10	(79)
	s	4.03¶¶	25	5.0	10	(79)
	s	4.00¶¶	25	7.5	10	(79)
Se..............	s	6.13***	20	5.0	1	(138)
	s	7.44	t_R	Audio		(103)
	s	6.14***	20	2.4	7	(138)
	s	6.6	t_R	1	8	(117)

* $\alpha = -3.0$ (−70° t 10°) (82).

† $\alpha = -3.5$ (0° t 140°) (38).

‡ $\alpha = -2.8$ (−259° t t_0) (16).

§ $\alpha = -3.2$ (−259° t t_0) (148).

‖ $\alpha = -3$ (t_0 t − 253°) (145).

¶ $\alpha = 45$ (t_0 t −259.1°) (148).

** $\alpha = -2.2$ (t_0 t − 183°) (16, 146).

†† Freshly crystallized.

‡‡ $\alpha = +1$; (−140° t 80°) (118).

§§ Several months old.

‖‖ Power factor for solid S = 0.03 % at 16°C, $\nu = 10^3$ (46); =0.6 % at t_R, $\nu = 10^6$ (57).

¶¶ From deviation of waves by a prism.

*** Vitreous; in dark.

TABLE 2.—(*Continued*)

Formula	(2)	ϵ_{t_0}	t_0	A	n	Lit.
𝔅-Table.—Standard Arrangement; *v.* Vol. III, p. viii						
H_2O	*See* Table 4					
HCl	*l*	4.60	27.7	4	8	(113)
	l	8.85	− 90	4	8	(113)
HBr	*l*	3.82	24.7	4	8	(113)
	l	6.29	− 80	4	8	(113)
HI	*l*	2.9	21.7	4	8	(113)
	l	2.88	− 50	4	8	(113)
	s	3.95	− 70	4	8	(110)
SO_2	*l*	15.6*	0	Audio		(37)
$(p = 1)$	*l*	13.8	15	2	8	(87)
	l	12.4	22	1	8	(114)
SO_3	*l*	3.56	21	1	8	(114)
	s	3.64	19	1	8	(114)
H_2S†	*l*	5.75‡	10	Audio		(38)
H_2SO_4 $(p = 1)$	*l*	>84§	20	1	8	(140)
	s	3.8‖	−180	1.2	2	(28)
S_2Cl_2	*l*	4.8	22	1	8	(114)
$SOCl_2$	*l*	9.05	22	1	8	(114)
SO_2Cl_2	*l*	9.15	22	1	8	(114)
$(p = 1)$	*l*	8.5	22	1	8	(140)
N_2O	*l*	1.607¶	0	0	0	(82)
$(p = 1)$	*l*	1.933	− 90			(63)
N_2O_4	*l*	2.56	15	1	8	(115)
	s	2.6	− 40	1	8	(115)
NH_3	*l*	14.9	24.5	4	8	(96)
	l	15.5	20.5	4	8	(96)
	l	16.2	14	2	6	(26)
$(p = 1)$	*l*	22	− 34	4	8	(52)
	l	25.4	− 77	4	8	(96)
	s	4.01	− 90	4	8	(96)
HNO_3	*s*	2.4	**	1.2	2	(28)
NH_4Cl	P_2	7.0	t_R	1	6	(72)
NH_4Br	P_2	7.1	t_R	1	6	(72)
$(NH_4)_2SO_4$	P_2	3.3	17	1	6	(74)
PH_3	*l*	2.71	− 25	4	8	(96)
	l	2.55	− 60	4	8	(96)
PCl_3	*l*	3.72	18	1	8	(115)
	l	3.4	22	1	8	(114)
$POCl_3$	*l*	14	22	1	8	(114)
PBr_3	*l*	3.88	18	1	8	(115)
PI_3	*l*	4.12	65	1	8	(115)
	s	3.66	20	1	8	(115)
AsH_3	*l*	2.05	15	4	8	(116)
	l	2.74	− 50	4	8	(116)
$AsCl_3$	*l*	12.35	21	1	8	(114)
$(p = 1)$	*l*	12.8	20	1	8	(140)
	l	12.6	17	1	8	(115)
	s	3.6	− 50	1	8	(115)
$AsBr_3$	*l*	8.83	35	1	8	(115)
$(p = 1)$	*l*	9.3	35	1	8	(140)
	s	3.33	20	1	8	(115)
	s	3.4	20	1	8	(140)
AsI_3	*l*	7.0	150	1	8	(115)
	s	5.4	18	1	8	(115)
SbH	*l*	2.58	− 50	4	8	(96)
	l	2.93	− 80	4	8	(96)
$SbCl_3$	*l*	33.2	75	1	8	(114)
	s	5.34	18	1	8	(114)

---

* $\alpha = -78$ (0° t 150°) (37).

† *See* Fig. 1.

‡ $\alpha = -23$, $\beta = -25$ (t_0 t 80°) (38).

§ $d = 1.85$ g/cm³.

¶ $\alpha = -6.1$ (−6° t 14°) (82).

‖ $\alpha = +9$ (−185° t −120°).

** −185° to −110°.

TABLE 2.—(*Continued*)

Formula	(2)	ϵ_{t_0}	t_0	A	n	Lit.
$SbCl_5$	*l*	3.78	21.5	1	8	(114)
$SbBr_3$	*l*	20.9	100	1	8	(115)
	s	5.05	20	1	8	(115)
SbI_3	*l*	13.9	175	1	8	(115)
	s	9.1	20	1	8	(115)
CO_2*	*l*	1.585†	0	0	0	(82, 135)
CS_2 $(p = 1)$	*l*	2.58	46	Audio		(54)
$(p = 1)$	*l*	2.6	25	Audio		(54)
$(p = 1)$	*l*	2.64	20	1.2	2	(27, 45)
$(p = 1)$	*l*	2.647‡	20	8.5	5	(78)
$(p = 1)$	*l*	2.638§	19	Audio		(95)
$(p = 1)$	*l*	2.64	17	4	8	(31)
$(p = 1)$	*l*	2.61	15	1.5	8	(59)
$(p = 1)$	*l*	2.644‖	13	7	2	(139)
$(p = 1)$	*l*	2.676¶	0	Audio		(125)
$(p = 1)$	*l*	2.68**	0	5	5	(71)
$(p = 1)$	*l*	2.638††	0	Radio		(105)
$(p = 1)$	*l*	2.631‡‡	10	Radio		(55)
$(p = 1)$	*l*	2.64	− 75	1.2	2	(27, 45)
$(p = 1)$	*ls*	2.93	− 95	5	5	(71)
$(p = 1)$	*ls*	2.87	−100	5	5	(71)
$(p = 1)$	*ls*	2.83	−105	5	5	(71)
$(p = 1)$	*ls*	2.81	−110	5	5	(71)
	s	2.78§§	−180	5	5	(71)
	s	2.24	−185	1.2	2	(27, 45)
SiO_2	*See* p. 341					
$SiCl_4$	*l*	2.4	16	1	8	(115)
$SnCl_4$	*l*	3.2	22	1	8	(114)
PbO	P_4	25.9	15	1	8	(131)
PbF_2	P_1	3.6	t_R	1	6	(81)
$PbCl_2$	P_1	4.2	t_R	1	6	(81)
	P_2	6.0	17	1	6	(74)
$PbBr_2$	P_1	4.9	t_R	1	6	(81)
PbI_2	P_1	2.4	t_R	1	6	(81)
PbS	P_4	17.9	15	1	8	(131)
$PbSO_4$	P_2	14.3	17	1	6	(74)
$Pb(NO_3)_2$	P_3	37.7	18	6.3	7	(7, 67)
$Pb(CHO_2)_2$	P_2	2.6	17	1	6	(74)
$PbCO_3$	P_4	18.6	15	1	8	(131)
$TlCl$	P_2	46.9	t_R	1	6	(72)
$TlBr$	P_2	53.8	t_R	1	6	(72)
Hg_2Cl_2	*s*	9.4	t_R	1	6	(72)
$HgCl_2$	P_2	3.2	17	1	6	(74)
$Hg(CN)_2$	P_2	4.8	17	1	6	(74)
CuO	P_4	18.1	15	1	8	(131)
$CuCl_2.2H_2O$	P_3	7.6	20	6.3	7	(7, 67)
$CuSO_4$	P_3	10.3	18	6.3	7	(7, 67)
$CuSO_4.5H_2O$	P_3	7.8	18	6.3	7	(7, 67)
	P_4	5.5	15	1	8	(131)
$AgCl$	*s*	11.2	t_R	1	6	(72)
$AgBr$	*s*	12.2	t_R	1	6	(72)
$AgCN$	P_2	5.6	t_R	1	6	(72)
FeO	P_4	14.2	15	1	8	(131)
$FeF_3.3H_2O$	P_3	7.3	20	6.3	7	(7, 67)
$CrF_3.4H_2O$	P_3	6.8	21	6.3	7	(7, 67)

---

* *See* Fig. 2.

† $\alpha = -3.9$ (−7.5° t 17.5°) (82); $\alpha = -2.7$, $\beta = -110$ (−5° t 30°) (135).

‡ a = 0.723, b = − 0.722 (1 p 3000) (78).

§ a = 0.726, b = − 1.33 (1 p 500) (95).

‖ a = 0.757, b = − 3.71 (1 p 130) (139).

¶ $\alpha = -2.61$, $\beta = -1.24$ (20° t 180°) (125).

** $\alpha = -2.8$ (−90° t 200°) (71).

†† $\alpha = -2.6$ (−5° t 37°) (105).

‡‡ $\alpha = -1.9$ (10° t 40°) (55).

§§ $\alpha = +0.3$ (−186° t −110°) (71).

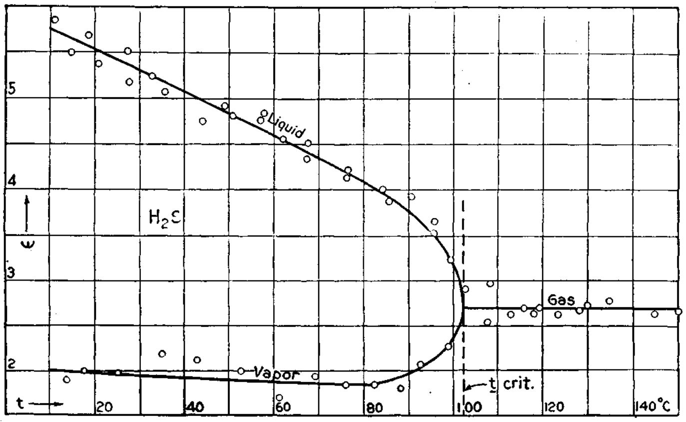

FIG. 1.—Dielectric constant (ε) of H_2S (38) at audio frequency. Below the critical temperature, pressure (p) is that of the saturated vapor; above the critical temperature, p = critical pressure.

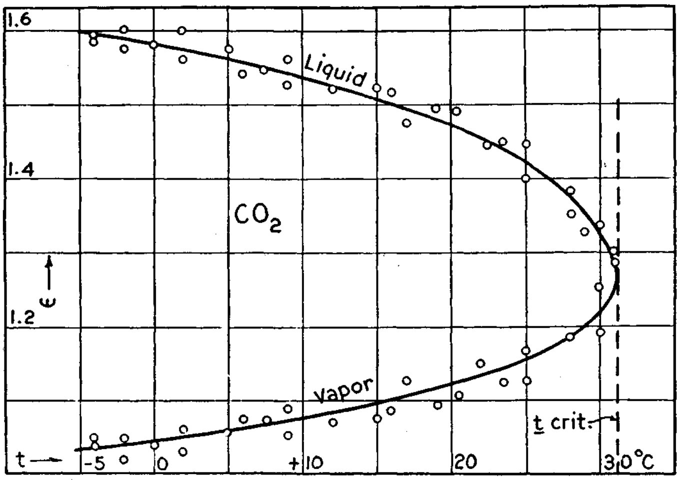

FIG. 2.—Dielectric constant (ε) of CO_2 (135). Below the critical temperature, pressure (p) is that of the saturated vapor; above the critical temperature, p = critical pressure; $\nu = 4 \times 10^6$ cycle/sec.

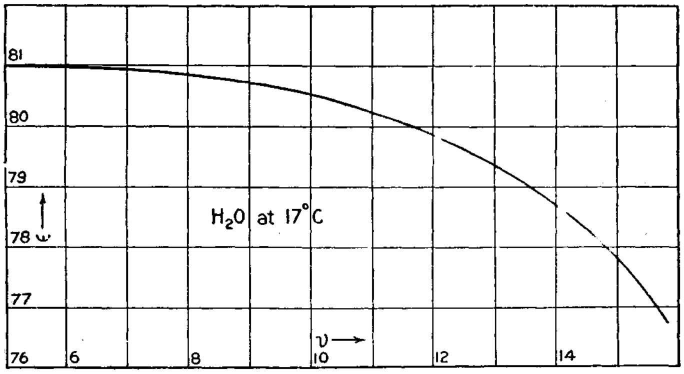

FIG. 3.—Dielectric constant (ε) of liquid H_2O at 17°C: Variation with frequency (ν) (25, 26).

Unit of ν = 10^8 cycle/sec; of ε = 1 cgse.

TABLE 2.—(*Continued*)

Formula	(2)	ϵ_{t_0}	t_0	A	n	Lit.
$CrO_2.Cl_2$ ($p = 1$)	l	2.6	20	1	8	(140)
VCl_4	l	3.05	25	4	8	(84)
$VOCl_3$	l	3.4*	0	4	8	(84)
$VOBr_3$	l	3.85†	0	4	8	(84)
CaF_2	s	7.36	t_R	Audio		(103)
$CaSO_4.2H_2O$	s	5.61	15	1	6	(131)
$CaSO_4.2H_2O$	s	5.66	t_R	Audio		(103)
$CaCO_3$	s	6.14	t_R	1	6	(131)
BaF_2	P	2.3‡	18	6.3	7	(7)
$BaCl_2$	P_3	11.4	19	6.3	7	(7, 67)
$BaCl_2.2H_2O$	P_3	9.4	19	6.3	7	(7, 67)
$BaBr_2.2H_2O$	P_3	10.9	19	6.3	7	(7, 67)
$Ba(BrO_3)_2.H_2O$	P_3	8.0	20	6.3	7	(7, 67)
$Ba(IO_3)_2.H_2O$	P_3	12.9	18	6.3	7	(7, 67)
$BaSO_4$	P_4	11.4	15	1	8	(131)
	P	3.3§	18	6.3	7	(7)
$Ba(NO_3)_2$	P_3	5.9	18	6.3	7	(7, 67)
	P_4	9.15	15	1	8	(131)
$Ba(CNS)_2.3H_2O$	P_3	12.8		6.3	7	(7, 67)
$BaCrO_4$	P	4.25‖	18	6.3	7	(7)
NaF	P_3	3.9	19	6.3	7	(7, 67)
NaCl	s	6.12	t_R	Audio		(103)
	s	5.81	t_R	1	6	(131)
	s	9.3	t_R	4	9	(80)
	P_3	6.3	19	6.3	7	(7, 67)
$NaClO_4$	P_3	5.4	19	6.3	7	(7, 67)
$NaBrO_3$	P_3	7.7	19	6.3	7	(7, 67)
$NaNO_3$	s	5.2	t_R	0	0	(4)
Na_2CO_3	P_3	8.4	20	6.3	7	(7, 67)
$Na_2CO_3.10H_2O$	P_3	5.3	20	6.3	7	(7, 67)
$KF.2H_2O$	P_3	5.9	20	6.3	7	(7, 67)
KCl	s	5.03	t_R	Audio		(103)
	P_3	4.9	19	6.3	7	(7, 67)
	P_2	2.4	17	1	6	(74)
$KClO_3$	P_3	5.1	18	6.3	7	(7, 67)
	P_4	6.2	15	1	8	(131)
KBr	s	4.6	t_R	1	6	(72)
	P_3	4.7	18	6.3	7	(7, 67)
KI	P_3	5.6	18	6.3	7	(7, 67)
	P_2	5.2	t_R	1	6	(72)
K_2SO_4	P_3	5.9	19	6.3	7	(7, 67)
	P_4	6.4	15	1	8	(131)
KNO_3	s	2.7	t_R	0	0	(4)
	P_3	5.0	19	6.3	7	(7, 67)
K_2CO_3	P_4	5.6	15	1	8	(131)
$K_2CO_3.2H_2O$	P_3	6.6	20	6.3	7	(7, 67)
K_2CrO_4	P_3	7.3	19	6.3	7	(7, 67)
$K_2Al_2(SO_4)_4.24H_2O$	P_2	3.8	17	1	6	(74)

* $\alpha = -0.4$ ($-70°$ t $26°$) (84).

† $\alpha = -8$ ($-70°$ t $30°$) (84).

‡ For plate, $d' = 1.6$ g/cm³, value not reduced.

§ For plate, $d' = 1.9$ g/cm³, value not reduced.

‖ For plate, $d' = 1.85$ g/cm³, value not reduced.

TABLE 3.—DIELECTRIC CONSTANT OF AIR

For gaseous air, $\epsilon = \dfrac{1 + 2c_1d_1}{1 - c_1d_1} = 1 + 3c_1d_1 + 3c_1^2d_1^2 + \ . \ . \ . = 1 + 3c_1d_1(1 + c_1d_1) + \ . \ . \ . \ ; d_1 = p/(1 + 0.003665t)$ if unit of $p = 1$ atmosphere, of $t = 1°C$. ε is independent of the frequency. If we write $c_1 = c \times 10^{-6}$, $c = 195$; tested and found

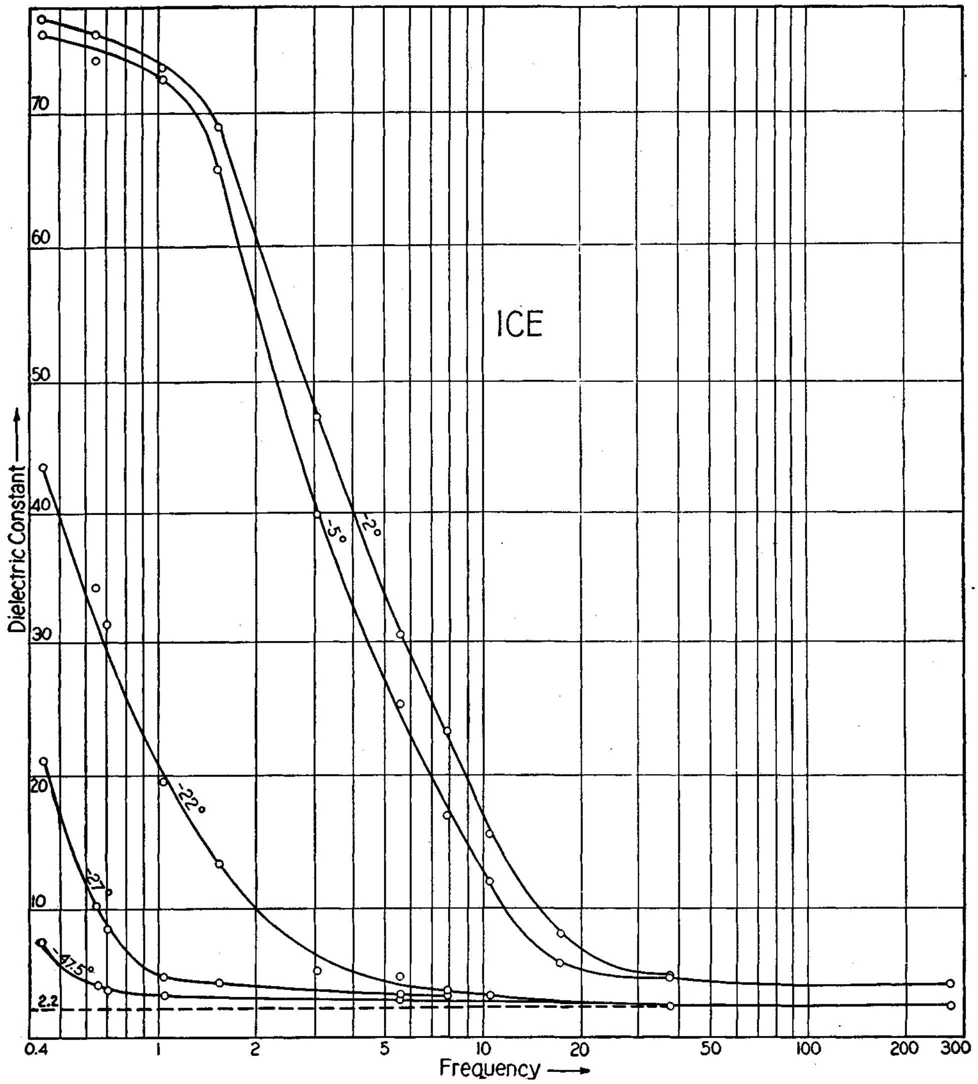

FIG. 4.—Dielectric constant (ϵ) of ice: Variation with frequency (ν) and temperature (t) (36). Unit of ν = 1 kilocycle/sec; of ϵ = 1 cgse; t = °C.

constant for (0 p 175); (0° t 70°) (9, 19, 49, 51, 75, 92, 94, 104, 126, 127, 135, 139); at very low temperatures, c is a few per cent greater than 195; at −185.5°C, $\epsilon - 1 = 0.001890/p$. ν = frequency, cycle/sec. Unit of ϵ = 1 cgse; of p = 1 atm.; of t = 1°C.

Gaseous, $p = 1$			Liquid, $p = 1$			
t	ϵ	Lit.	t	ϵ	ν	Lit.
0	1.000585		−185	1.432	(?)	(103)
−185.5	1.00189	(106)	−185	2.28	7.5×10^9	(88)

TABLE 4.—DIELECTRIC CONSTANT (ϵ) OF H_2O; STEAM, WATER, AND ICE

Unit of ϵ = 1 cgse unit, of p = 1 atmosphere, of ν = 1 cycle/sec; of t = 1°C.

Steam, $p = 1$, (140° t 150°): $\epsilon = 1.00785 - 0.00016\ (t - 140°)$ (5). If (0 p' 40) (40° t 165°), $\epsilon = 1 + [9.3 - 0.026(t - 40)]p' \times 10^{-6}$, where unit of p' = 1 mm of Hg (152).

Water, $p = 1$, (0° t 100°) (0 ν 10^8): $\epsilon = 80 - 0.4\ (t - 20°)$, (18, 23, 24, 28, 50, 65, 69, 73, 74, 86, 90, 91, 105, 107, 109, 110, 121, 122, 128, 131, 133, 150). For $\nu > 10^8$, the value of ϵ is uncertain; two observers (25, 111), using standing waves along wires, find ϵ decreases as ν increases (*see* Fig. 3); another (79), from measurements of refraction, concludes that the reverse is true.

At 16.3°C, $\nu = 6 \times 10^7$ (7 p 200), $\epsilon = 81.5 + 0.0046p$ (39).

Ice, at −5°C (10^7 ν 10^9), $\epsilon = -0.08 + 0.34 \log_{10} \nu$ (58). For variation with ν and t, *see* Fig. 4. Other determinations are tabulated below.

t	$\epsilon_{t,\nu}$	t	$\epsilon_{t,\nu}$	t	$\epsilon_{t,\nu}$
$\nu = 50$ (129)		$\nu = 120$* (27, 45)		$\nu = 320$ (28)	
− 2	94	− 80	31.5	− 7	51
− 10	95.2	− 90	20.2	− 47	3.6
− 18	96.5	−100	14.5	Audio (1)	
−182	3	−110	8.6	− 80	3.8
$\nu = 120$* (27, 45)		−120	6.1	$\nu = 5 \times 10^6$ (2)	
− 20	59.5	−130	4.7	0 to −24	3.8
− 30	59.0	−140	3.5	$\nu = 10^7$ (131)	
− 40	58.5	−150	2.7	− 2	3.4
− 50	56.0	−165	2.43	− 5	2.3†
− 60	49.5	−185	2.43	− 5	2.8
− 70	41.5	−185	2.83	$\nu = 10^8$ (11)	
				−190	1.8

* Condenser charged and discharged by commutator, 120 charges per sec; *see also* Fig. 5. † From (58).

Table 5.—Effect of Illumination upon Dielectric Constant (56)

For a phosphorescent ZnS containing a trace of Cu, $\epsilon_l - \epsilon_d = B\epsilon_d(1 - e^{-aJ})$, where ϵ_l, ϵ_d = dielectric constant in the light, in the dark, and J = irradiation of the material. B and a vary with the wave-length (λ) of the light. For room temperature and $\nu = 3 \times 10^6$ cycle/sec, the following values were found. Unit of λ = 1mμ = 10 Å; of $J = 10^{-12}$ watt cm^{-2}.

λ	313	365	405	435
B	0.006	0.035	0.042	0.033
a	13.2	9.1	5.0	12.4

Table 6.—Relative Dielectric Strengths of Pure Inorganic Gases at 25°C and 1 Atmosphere (6, 13, 64, 70, 76, 85, 97, 120, 132, 147, 149)

For other pressures, *v.* (61, 62, 97, 141, 147) or use Paschen's law (*v.* Table 7). Values are not affected by the electrode material except in the case of gases of low ionization potential at low pressure, but are affected by the condition of the electrode surface (32, 154). For a mixture of two gases which do not react chemically (64, 70) $(p_1 + p_2)V = p_1V_1 + p_2V_2$ where p_1 and p_2 are the partial pressures of the two constituents of the mixture, and V_1 and V_2 are the sparking potentials for the pure constituents at 25°C and 1 atmosphere.

The presence of an ionizing radiation does not appreciably lower the electric strength of a gas, but makes the individual observations more concordant by eliminating the variable, temporary excess in voltage, which otherwise occurs (64, 89, 141, 158). For bibliography and discussion of data pertaining to the electrical breakdown of gases, *see* (120, 156).

V/V_a = potential difference at which spark passes in gas *divided by* potential difference at which spark passes in air, the temperature (25°C), pressure (= 1 atm), terminals, and gap-length being the same for each. Accuracy, *ca.* 10%.

Gas	Cl	H	N	O	SO_2	H_2S	NH_3	CO_2
V/V_a	0.85	0.65	1.15	0.85	0.30	0.90	1.00	0.95

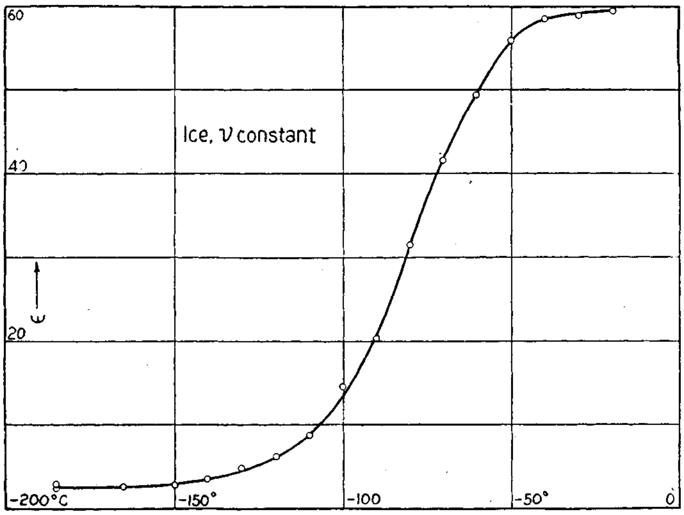

FIG. 5.—Dielectric constant (ϵ) of ice: Variation with temperature, ν is constant at 120 charges (and discharges) per second (27, 45).

Table 7.—Dielectric Strength of Air: Spherical Electrodes, 25°C and 1 Atmosphere

The tabulated data apply to gaps having the following characteristics: The electrodes are two spheres of the same diameter; variations in diameter should not exceed 0.1% and the curvature should nowhere differ from that of a true sphere by more than 1%. The spheres must be highly polished if the frequency of the emf is very high (*e.g.*, 40 000 cycle per sec); at commercial frequencies and for D.C. potential the degree of polish is much less important. Considerable deviation in successive breakdown values may occur if the sparking surfaces are not properly cleaned (154, 158). The diameter of the shanks supporting the spheres should not exceed 0.2 the diameter of the spheres, and if they pass through metal collars, the collars should be small and not closer to the gap than the length (l) of the latter. Each sphere should be at least $2l$ distant from all surrounding materials other than air.

For other temperatures and pressures, multiply the tabular values of V by the factor f (or, less accurately, by c); $c = 298p/(273 + t)A_n$, $f = \sqrt{c}(\sqrt{cr} + \delta)/\sqrt{r + \delta}$, where r = radius of the electrode, δ = 0.54 cm, p = pressure, A_n = pressure of one normal atmosphere. Paschen's law (147), V is a function of (dl), holds throughout the range within which air is essentially an ideal gas (61); *cf.* (20, 21, 35, 60, 64, 141). Values of V are independent of the humidity of the air and of the electrode material (32, 98, 99, 124, 144), d = density, D = diameter of spheres, G = one sphere grounded, connected to earth, I = both spheres insulated from earth, l = shortest distance between surfaces of spheres, u = greatest uncertainty in the data, it is probably several times greater than actual error, V_m = maximum value of A.C. voltage. Unit of D and of l = 1 cm; of V_m = 1 kilovolt = 10^{11} cgsm unit = 3.335 cgse unit.

D	0.25	0.50	1.0	D	2.0	2.5	3.0	4.0
l	V_m			l	V_m			
0.01	1.08	1.01	0.86	0.10	4.62		4.50	
.02	1.59	1.51	1.49	.20	7.84		7.80	8.4
.03	2.06	2.00	1.94	.30	10.9		11.0	11.4
.05	2.92	2.83	2.78	.40	13.9		13.8	14.4
.08	4.00	3.92	3.92	.50	16.9	18.3		17.4
.10	4.73	4.67	4.67	.60	19.7	21.4		20.2
.15	6.60	6.54	6.42	.80	24.9	27.2		25.4
.20	8.34	8.26	8.08	1.0	29.5	32.8		30.0
.30	11.3	11.4	11.3	1.2	33.4	38.3	37.8	34.2
.40	13.7	14.5	14.4	1.4	36.8	43.3	43.5	
.50	15.8	17.3	17.4	1.6	39.7	48.3	49.0	
.60	17.4	19.8	20.4	1.8	41.8	53.1	54.0	
.80	19.2	23.9	25.7	2.0	43.6	57.4	58.8	
1.00	20.5	26.9	29.8	2.5	45.8	66.5	69.3	
1.20	21.7		34.7	3.0	46.5	72.9	78.0	
1.40	22.5		38.3	3.5	48.3	78.0	84.7	
1.60			41.5	4.0	49.2	82.4	90.4	
				4.5	50.0	86.0	92.7	
				5.0	50.5	89.5		
	One sphere grounded in all cases			6.0	51.2	One sphere grounded in all cases		
				8.0	52.4			
u	5 %	5 %	5 %	u	5 %	7 %	7 %	10 %
Lit.	(66, 97)	(66, 97)	(48, 66, 97, 137)	Lit.	(48, 77, 89, 137, 156)	(66, 97)	(6)	(48)

D	5.0		10.0		12.5		15.0	20.0
l	V							
	I	G	I	G	I	G	G	G
0.1			4.46	4.46			4.44	4.39
0.2			7.64	7.64			7.58	7.62
0.3			10.6	10.6	10.8	10.8	10.62	10.52
0.4			13.4	13.4	14.0	14.0	13.44	13.44
0.5	17.1	17.1	16.3	16.3	17.0	17.0	16.30	16.30
0.6	20.2	20.2	19.5	19.1	19.9	19.9	19.07	19.14
0.8	26.3	26.2	25.2	24.6	25.5	25.5	24.5	24.6
1.0	32.0	31.8	30.8	29.8	31.1	31.1	29.9	29.8
1.2	37.6	37.2	36.4	35.1	36.5	36.5	35.1	34.9
1.4	42.8	42.3	41.7	40.2	41.9	41.9	40.1	40.0
1.6	47.9	47.0	47.0	45.3	47.2	47.2	45.0	45.1
1.8	52.8	51.7	52.6	50.2	52.6	52.6	49.9	
2.0	57.4	55.8	57.6		58.0	58.0		
2.5	68.3	65.0	70.0		70.7	70.7		
3.0	77.7	72.0	80.9		83.1	82.8		
3.5	86.1	77.4	93.4		95.2	94.5		
4.0	93.4	81.0	104.5		106.8	105.2		
4.5	100.6	84.2	114.7		117.8	115.6		
5.0	106.0	86.5	125.0		128.5	125.5		
6.0	116.4	88.8	143.5		147.2	143.4		
7.0	126.0	90.0	159.5		167	158		
8.0	134	90.4	173.4		184	171		

TABLE 7.—(*Continued*)

D	5.0		10.0		12.5		15.0	20.0
l	V							
	I	G	I	G	I	G	G	G
9.0	140	90.9	186		200	182		
10.0	145	92	198		213	191		
12.0	155	93	218		238	208		
14.0	162		235		258	220		
16.0	168		248		274	230		
18.0	175		261		288	239		
20.0	180		270		302	246		
25.0	194		288					
30.0	207		294					
35.0	220							
40.0	233							
45.0	248		u = 5 % in all cases					
Lit.	(3, 66, 83, 89, 136, 137, 156)		(77, 136, 156)		(99, 101)		(77, 156)	(77)

D	25		30		50	75	
l	V_m						
	I	G	I	G	G	I	G
0.1			4.36	4.36			
0.2			7.58	7.58			
0.3			10.53	10.53			
0.4			13.44	13.44			
0.5			16.30	16.30			
0.6			19.37	19.08			
0.8			25.1	24.4			
1.0		30.9	30.6	29.6			
1.2			35.9	34.8			
1.4		42.7	40.9	39.8			
1.6			46.1				
1.8			51.1				
2.0		59.6	56.4		56.6		
2.5		73.5	69.2				
3.0		86.7	82.2		84.0		
3.5		99.4	95.2				
4.0	112.0	111.5	108.0		110.8		
4.5	124.1	123.7	120.6				
5.0	136.0	135.0	133.0		137.0		
6.0	160.8	159.6	157.8		162.6		
7.0	181	178	181		188		
8.0	202	198	205		212		
9.0	222	218	227		236		
10.0	241	235	247		259		
12.0	277	268	284		305		
14.0	310	296			347		
16.0	341	320			387		
18.0	369	342			425		
20.0	392	360			456	502	502
25.0	443	392				605	605
30.0	480	417				696	696
35.0	514	441				784	770
40.0	548	460				866	835
45.0						936	887
50.0						1000	940
60.0						1120	1030
70.0						1225	1105
80.0						1303	
90.0	u = 5 % except for D = 75.0, for which 7 %					1376	
Lit.	(22, 99, 101, 156)		(136)		(22, 99, 101, 155)	(102)	

TABLE 8.—DIELECTRIC STRENGTH OF AIR: NEEDLE ELECTRODES, 25°C AND 1 ATMOSPHERE (48, 99, 100, 101, 102, 136, 141, 157)

The tabular data apply to gaps having the following characteristics: The electrodes are new sewing needles, No. 00, supported axially at the ends of linear conductors at least $2l$ long. There must be no other material than air nearer than $2l$ to any portion of the gap. Needles must be replaced after each spark. A needle-gap is not suitable for the measurement of impulsive or high frequency voltage.

For other temperatures and pressures, multiply the tabular values of V by the factor f (or c), *v.* introduction to Table 7. Values of V vary with humidity, and for D.C. differ from V_m of A.C., h = relative humidity, u = greatest uncertainty in the data, it is probably several times greater than actual error, V_e = effective A.C. voltage. Unit of l = 1 cm; of h = 1%; of V, V_e, V_m = 1 kilovolt = 10^{11} cgsm unit = 3.335 cgse unit.

h	0	57	70	75	82.5	l	A.C.	D.C.
l	u = 5%, V_e(60 cycle/sec)						V_m	V
1	8.1	8.1	8.1	8.1	8.1	Humidity is not stated		
2	15.8	15.8	15.8	15.8	15.8			
3	23.1	23.1	23.1	23.1	23.1		(100)	(100)
4	29.5	29.5	29.5	29.5	29.5			
5	34.6	34.6	34.6	34.6	34.6			
6	39.4	39.4	39.4	39.4	39.4	5.1	51.0	52.0
7	43.1	43.2	43.3	43.5	43.7			
8	46.5	46.7	47.3	47.5	47.8	7.6	62.5	63.0
9	49.5	50.1	51.0	51.3	51.6			
10	52.0	53.0	54.3	54.7	55.6			
12	56.9	58.4	61.1	61.6	62.1	10.2	76.5	73.5
14	62.2	64.3	67.0	68.0	69.3	12.7	88.3	82.5
16	67.7	70.6	73.6	74.8	76.5			
18	73.4	75.9	80.1	81.4	83.4	15.3	98.3	90.5
20	79.4	83.4	86.8	88.4	90.7			
25	94.1	99.1	103.3	106.0	108.2	A.C. is 60 cycle/sec		
30	109.4	115.8	121.0	123.6	126.4			
40	140.0	148.6	153.3	157.0	162.1			
50				192				
75				280				
280				1040				

LITERATURE

(For a key to the periodicals see end of volume)

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60, **19**: 734; 15. (85) Macfarlane, *3*, **10**: 389; 80. (86) Mazzotto, *22*, **5 II**: 301; 96. (87) Merczyng, *8*, **34**: 1015; 11. (88) Merczyng, *8*, **37**: 157; 12. (89) Müller, *8*, **28**: 585; 09.

(90) Nernst, *7*, **14**: 622; 94. (91) Niven, *5*, **85**: 139; 11. (92) Occhialini, *59*, **10**: 217; 05. (93) Occhialini, *59*, **7**: 108; 14. (94) Occhialini and Bodareu, *59*, **5**: 15; 13. (95) Ortvay, *8*, **36**: 1; 11. (96) Palmer and Schlundt, *50*, **15**: 381; 11. (97) Paschen, *8*, **37**: 69; 89. (98) Pedersen, *8*, **71**: 317; 23. (99) Peek, *129*, **32**: 812; 13.

(100) Peek, *119*, **35**: 783; 16. (101) Peek, *B7*. (102) Peek, *107*, **78**: 1319; 21. (103) Pirani, *Diss.*, Berlin, 1903. (104) Pohrt, *8*, **42**: 569; 13. (105) Ratz, *7*, **19**: 94; 96. (106) Riegger, *8*, **59**: 753; 19. (107) Röntgen, *8*, **52**: 593; 94. (108) Rohmann, *8*, **34**: 979; 11. (109) Rosa, *3*, **31**: 188; 91.

(110) Rückert, *8*, **55**: 151; 18. (111) Rukop, *8*, **42**: 489; 13. (112) Sauzin, *34*, **171**: 164; 20. (113) Schaefer and Schlundt, *50*, **13**: 669; 09. (114) Schlundt, *50*, **5**: 157, 503; 01. (115) Schlundt, *50*, **8**: 122; 04. (116) Schlundt and Schaefer, *50*, **16**: 253; 12. (117) Schmidt, *8*, **11**: 114; 03. (118) Schmidt, *8*, **44**: 329; 14. (119) Schumann, *125*, **11**: 1; 22.

(120) Schumann, *Elektrische Durchbruchfeldstärke von Gasen.* Berlin, Springer, 1923. (121) Smale, *8*, **57**: 215; 96. (122) Southworth, *2*, **23**: 631; 24. (123) Stoecker, *96*, **2**: 236; 20. (124) Stoekle, *2*, **19**: 258; 22. (125) Tangl, *8*, **10**: 748; 03. (126) Tangl, *8*, **23**: 559; 07. (127) Tangl, *8*, **26**: 59; 08. (128) Terešin, *8*, **36**: 792; 89. (129) Thomas, *2*, **31**: 278; 10.

(130) Thornton, *3*, **19**: 390; 10. (131) Thwing, *7*, **14**: 286; 94. (132) Tits, *327*, **31**: 144; 07. (133) Turner, *7*, **35**: 385; 00. (134) Verain, *34*, **154**: 345; 12. (135) Verain, *16*, **1**: 255; 14. (136) Villard and Abraham, *34*, **153**: 1200; 11. (137) Voigt, *8*, **12**: 385; 03. (138) Vonwiller and Mason, *5*, **79**: 175; 07. (139) Waibel, *8*, **72**: 161; 23.

(140) Walden, *7*, **46**: 182; 03. (141) Watson, *46*, **43**: 113; 09. (142) Watson, *201*, **17**: 90; 13. (143) Weichmann, *8*, **66**: 501; 22. (144) Weicker, *98*, **55**: 554; 11. (145) Werner and Keesom, *64P*, **29**: 34; 26. *168*, **No. 178a.** (146) Werner and Keesom, *64P*, **29**: 306; 26. *168*, **No. 178c.** *168*, **No. 190a.** (147) Wolf, *8*, **37**: 306; 89. (148) Wolfke and Onnes, *64P*, **27**: 621, 627; 24. *168*, **No. 171b, 171c.** (149) Wright, *4*, **111**: 643; 17.

(150) Yule, *8*, **50**: 742; 93. (151) Zahn, *2*, **24**: 400; 24. (152) Zahn, *2*, **27**: 329; 26. (153) Zahn, *2*, **27**: 455; 26. (154) Carroll and Cozzens, *39*, **47**: 892; 28. (155) Dessauer, *101*, **44**: 1087; 23. (156) Edler, *Elektrotechnik und Maschinenbau*, **43**: 809, 829; 25. (157) Müller, *125*, **13**: 478; 24. (158) Reukema, *129*, **47**: 38; 28.

DIELECTRIC CONSTANT AND DIELECTRIC STRENGTH OF SINGLE CRYSTALS, MIXTURES AND SOLUTIONS, PURE ORGANIC COMPOUNDS, AND MISCELLANEOUS MATERIALS*

L. Hartshorn, C. C. Harris, J. A. Hey, T. I. Jones, and A. G. Milligan

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* Industrial materials (Vol. II) are excluded from this section; for CS_2, *v.* p. 75.

* Les matières industrielles (Vol. II) sont exclues de cette section; pour CS_2, *v.* p. 75.

* Technische Materialien (Bd. II) sind in diesem Abschnitt nicht enthalten; für CS_2, *siehe* S. 75.

* I materiali industriali (Vol. II) non sono compresi; per CS_2, *v.* p. 75.

ELECTRICAL CONDUCTIVITY AND RESISTIVITY

PROPERTIES OF CARRIERS OF FREE ELECTRICITY IN GASES*

LEONARD B. LOEB

INTRODUCTION

Types of Ions.—Three types of carriers may be distinguished: Normal ions, slow ions, and free electrons.

Normal ions are the carriers generally found in dry, dust-free gases at approximately atmospheric pressure. As far as is known (**83, 97, 139**), after the first few hundredths of a second they carry a single electronic charge (4.774×10^{-10} es). Their mass is not known, but is of the same order as that of one to several molecules; their exact nature is an object of controversy (**67, 81, 82, 96, 126**) but it is certain that in *some cases* they consist of two or more molecules. Where the mobility of the completely formed positive ion is markedly less than that of the negative ion the mobility of the newly formed positive ion is abnormally great (**33, 35, 36, 37, 38, 39, 41, 79, 136, 149, 152**) and probably equals that of the negative ion (**40, 87**). In these gases the positive carrier seems to be completely formed after 0.03 second, and then its mobility no longer varies with its age. For gases in which the negative ion is the less mobile, no data exist. The mobility of both ions appears to be remarkably independent of the mass of the initially ionized molecule (**10, 38, 40, 41, 42, 49, 61, 67, 82, 100, 125, 153**). In at least one case (**40**) this can be ascribed to a transfer of the charge from an ionized molecule of higher ionizing potential to one of a lower; in other cases, such as with radioactive ions (**36, 39, 42**), this is not so. The nature of the completely formed ion does not depend upon the process by which it was formed (**38, 39, 41, 42, 49, 73**) provided this process does not directly give rise to charged particles of more than molecular mass. It does however very much depend on the electrical and chemical nature of the surrounding gases with which it has had time to come into equilibrium (**41, 81, 82, 96**). In gases with a negative mobility higher than that of the positive, the mobility of the negative ion is independent of its age; abnormalities observed at low pressures are attributed to a delay in the attachment of the electrons to neutral molecules to form negative ions (**50, 55, 56, 68, 69, 77, 97, 134, 155, 156**); in some gases, an electron must make many collisions with molecules before attaching to one to form an ion (*see* Table 12). In certain pure gases [He, A (**43**), N_2, H_2 (**68**), CO (**150**) and probably NH_3] the electron cannot attach itself to a molecule to form an ion. In such cases the negative ions are formed by the attaching of the electrons to impurities which may be present; these negative ions have mobilities which are of the same order of magnitude as those of positive ions.

Slow ions consist of pre-existing nuclei, of more than molecular mass, to which normal ions have become attached (**45, 112**). Their mobilities appear to vary somewhat with age (**8, 9, 18, 19, 20, 21, 22, 23, 45**). Two definite types (**107, 108, 112**) of such

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* Covering data prior to March, 1928. For complete survey of the subject and complete bibliography, *see* (**110**).

* Contient les données antérieures à mars 1928. Pour avoir une vue d'ensemble complète du sujet et pour la bibliographie complète, *voir* (**110**).

* Daten soweit wie sie bis einschliesslich Februar 1928 bekannt geworden sind. Für die vollständige Übersicht dieses Gegenstandes und die gesamte Literatur, *siehe* (**110**).

* Comprende i dati anteriori al marzo 1928. Per una conoscenza completa del soggetto e per una bibliografia completa, *vedi* (**110**).

ions have been found in moist air. *Type I* is characterized by a mobility which decreases as the partial pressure of the water vapor is increased; these are not found when the partial pressure exceeds 17 mm of mercury (108). *Type II* (62, 63, 107), the so-called Langevin ion, is found at all humidities; and its mobility depends, not upon the partial pressure, but upon the relative humidity, decreasing as the latter increases (8, 9, 18, 19, 20, 21, 22, 23, 90, 98, 99, 101, 102, 103, 145). Besides the ions included in these two types, there are other carriers formed by the attachment of normal ions to solid particles of various sizes; the mobilities of these vary with the size of the particles; these will be called *heterogeneous slow ions.*

Electrons.—The velocity (v) of migration of free electrons is not proportional to the intensity of the electric field causing the migration (4, 70, 71, 112, 139, 143, 144). Under the action of an impressed electric field, the velocity of thermal agitation of the electrons exceeds (139, 143, 144) that of the surrounding gas molecules by a factor (c) depending upon both the field strength (F) and the pressure (P) of the gas. Within the limits covered by observations, the values of c and of v at a specified temperature and for a given gas are quite closely determined by the ratio F/P. *See* Table 11. (For theoretical discussions, *see* (25, 26, 51)).

Coefficient of Recombination of Ions.—Our knowledge of the coefficient of recombination of ions in gases is in a highly unsatisfactory state. Beside difficulties due to columnar ionization in the case of ionization by α-particles (131), no matter what the source of ionization, the initial density and distribution of ions are not known, and erroneous assumptions in this regard may lead to values of the coefficient (α) which are seriously in error. Thus, Rümelin (120) and Plimpton (106) have found that, during a short interval immediately following the formation of the ions, α has an apparent value that is five times the corresponding value reported below (Tables 7, 8, 9). This may be due in part to an initial recombination of free electrons with + ions (84). Values obtained by the use of α-particles have been eliminated as far as possible from Tables 7, 8, and 9, later values obtained in other ways being given. Most observers find that at low pressures and room temperatures α increases nearly proportionally to P, but at pressures greater than 1 atm. it approaches a constant value. Data for variation with temperature are discordant; those of Erikson are probably the best, and indicate that α increases with the temperature.

Mobility (k).—The mobility of an ion = velocity of migration per unit electrical field intensity. Over a wide range of densities (d), kd is a constant for a given gas. (*See* Table 4.) Value of k at 0°C and 760 mm of mercury at 0°C, is often called the mobility constant = k_0. Uncertainties in the proper interpretation of the observations and slight variations in the experimental procedure (73, 74, 128, 146), as well as traces of unsuspected active impurities present in any one of a series of gases, may introduce variations of 20 to 30% in the inferred value of k, but relative values obtained under comparable conditions (41, 81, 96, 112, 139, 147) are quite accurate except for the selective action of impurities. For methods of measurement and interpretation of observations, *see* (24, 33, 45, 46, 49, 56, 57, 60, 73, 74, 112, 118, 128, 160). For attempts at establishing theoretical relations between k and other properties of the gas, *see* (45, 61, 67, 76, 82, 94, 112).

Effective Sectional Area of Molecule.—*See* p. 117.

TABLE 1.—MOBILITY CONSTANT OF NORMAL IONS IN GASES

For mixed gases other than air, *see* Table 2

Except as another is indicated, pressure = 760 mm of Hg, temperature = 15°C. Methods: B = air-blast, C = current measurement, F = Franck's, L = Langevin's, R = Rutherford's, T = Tyndall and Grindley's; F, R, and T are alternating current methods. Range in value is indicated by {; el = negative carriers are free electrons; i = gas was slightly impure; p = gas was pure, giving free electrons even at high pressures. Mobility constant is $k_0 = kd/d_0$ where d_0 = density at 0°C and 760 mm of Hg and d = density when k was measured; excepting at the higher temperatures the values of k given below do not differ significantly from k_0. Data marked * have been reduced by dividing the observed values by 1.21 so as to bring them to the same basis as the others which were obtained by methods yielding a doubtful low value (*see* (73, 74, 128, 146)); it is believed that $k = 1.21M$ in all cases; subscripts ($_+$, $_-$) indicate the ion to which M refers. Unit of k = 1 cm sec^{-1} per volt cm^{-1} = 1 cm^2 volt^{-1} sec^{-1}.

Gas	M_+	M_-	Method	Lit.
Air	1.36	1.87	B	(160)
	1.37	1.80	F	(46)
	1.40	1.70	L	(60)
		1.70*	R	(56)
	1.36*	1.82* }	F, p	(128)
	1.57*	2.02* }		
		1.80*	F, R	(73)
		1.78*	T	(146)
A	1.37	1.70	F, i	(43)
	1.37	el	F, p	(43)
Cl_2		0.73	F	(148)
H_2	6.70	7.95	B, i	(160)
	5.33†	el	F, p	(88)
	6.02	7.68	F, i	(46)
	5.52	8.71	F, i	(158)
	5.34*	8.22*	F, i	(88)
	5.11	9.67	F, i	(156)
	4.96*	8.35*	F, i	(96)
He	5.09	6.31	F, i	(46)
	5.09	el	F, p	(45)
N_2	1.27	1.84	F, i	(44)
	1.27	el	F, p	(44)
	1.32	1.79	F, i	(158)
O_2	1.36	1.80	B	(160)
	1.29	1.79	F	(43)
CO		0.99*	R, p	(148)
	1.10	1.14	L	(154)
CO_2		1.02*	R, p	(72)
	0.76	0.81	B	(160)
	0.86	0.90	L	(60)
	0.83	1.02	L	(112†)
	0.73	1.07	F, p	(156)
	0.76	0.99	F	(112†)
CCl_4	0.30	0.31	L	(154)
H_2O	1.1	0.95	B, 100°	(110)
	0.77	0.73	B	(109)
	0.62	0.56	F	(86)
HCl	1.27‡		C	(123)
	0.65*	0.56*	F	(80)
NH_3	0.74	0.80	L	(154)
	0.62*	0.67*	F	(81)
		0.64*	R, p	(148)
N_2O	0.82	0.90	L	(154)
		1.10*	R	(72)
SO_2	0.415	0.414	F	(155)
	0.412	0.414	F	(159)
H_2S	0.59	0.57	F	(88)

Gas	Formula	M_+	M_-	Method	Lit.
Acetylene	C_2H_2		0.95*	R, p	(148)
		0.71*	0.77*	F, p	(87)
Benzene	C_6H_6	0.18	0.21	B	(109)
Ethane	C_2H_6		1.07*	R	(148)
Ethylene	C_2H_4		0.75*	R	(148)

TABLE 1.—(*Continued*)

Gas	Formula	M_+	M_-	Method	Lit.
n-Hexane	C_6H_{14}	0.15	0.16	*B*	(109)
n-Pentane	C_5H_{12}	0.36	0.35	*L*	(154)
		0.385	0.451	*F*	(159)
Chloroform	$CHCl_3$	0.19	0.16	*B*	(109)
Ethyl chloride	C_2H_5Cl	0.304	0.317	*F*	(159)
		0.33	0.31	*L*	(154)
Ethyl iodide	C_2H_5I	0.17	0.16	*L*	(154)
		0.181	0.181	*F*	(159)
Methyl bromide	CH_3Br	0.29	0.28	*L*	(154)
Methyl iodide	CH_3I	0.24	0.233	*F*	(155)
		0.216	0.226	*F*	(159)
Isobutyl alcohol	$C_4H_{10}O$	0.21	0.21	*B*, 105°	(110)
Ethyl alcohol	C_2H_6O	0.39	0.412	*F*	(155)
		0.363	0.373	*F*	(159)
Isoamyl alcohol	$C_5H_{12}O$	0.19	0.23	*B*, 130°	(110)
Methyl alcohol	CH_4O	0.37	0.38	*B*, 66°	(110)
		0.29	0.30	*B*	(109)
n-Propyl alcohol	C_3H_8O	0.22	0.22	*B*, 97°	(110)
Acetaldehyde	C_2H_4O	0.31	0.30	*L*	(154)
		0.307	0.331	*F*	(159)
Acetone	C_3H_6O	0.31	0.29	*L*	(154)
		0.236	0.247	*F*	(159)
Ethyl acetate	$C_4H_8O_2$	0.31	0.28	*L*	(154)
		0.16	0.19	*B*, 77°	(110)
		0.226	0.247	*F*	(159)
		0.19	0.24	*B*, 58°	(110)
Methyl acetate	$C_3H_6O_2$	0.33	0.36	*L*	(154)
n-Propyl acetate	$C_5H_{10}O_2$	0.15	0.17	*B*, 100°	(110)
Ethyl formate	$C_3H_6O_2$	0.30	0.31	*L*	(154)
Ethyl ether	$C_4H_{10}O$	0.29	0.31	*L*	(154)
		0.19	0.22	*F*	(79)
		0.15	0.16	*B*	(109)

* Observer's value is $k = 1.21M$. † Page 324. ‡ Sum of + and − mobilities.

TABLE 2.—MOBILITY (*k*) OF NORMAL IONS IN MIXED GASES

If p_a and p_b = the partial pressures of the constituents *A* and *B* of a binary mixture, $P = p_a + p_b$, $c_a = 100p_a/P$, and $c_b = 100p_b/P$, then c_a and c_b are the per cent concentrations of the two constituents. If k_a, k_b, k_{ab} are the mobilities for the pure gases and for the mixture, all reduced to 760 mm of Hg, then $k_{ab} = 100k_ak_b/(c_ak_b + c_bk_a)$ in the following cases: Both ions in $CO_2 + H_2$, and CO_2 + air (Blanc (10)), in $C_2H_2 + H_2$ (Loeb (87)), and in $O_2 + H_2$ (Mayer (96)); for + ions in $CH_3I + H_2$ (Wellisch (153)); and for − ions in $(C_2H_5)_2O + H_2$ (Loeb (81)). For both ions in NH_3 + air (Loeb (85)) and for + ions in $Cl_2 + H_2$ (Mayer (96)), $k_{ab} = k_ak_b/\sqrt{(c_ak_b^2 + c_bk_a^2)/100}$ fits the observations better. For all other mixtures yet studied, the data depart markedly from these laws if the concentration of the gas of lower mobility is small, but approximate one or other of them as this concentration is increased; *see also* (7, 61, 147). c_v = percentage of vapor. Unit of k = 1 cm²/(volt sec); of c = 1%; of P = 1 mm of Hg.

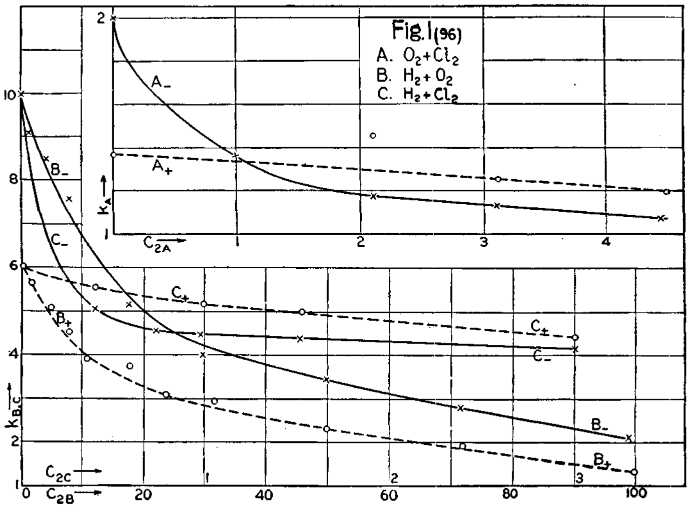
Air + vapor (*see also* Fig. Index)

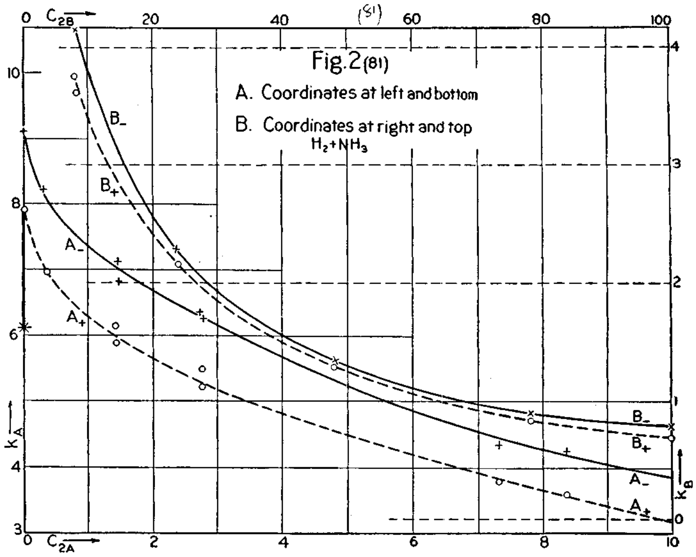
Vapor	c_v	k_+	k_-	P	t, °C	Lit.
None	0	1.37	1.80	737	15	(153)
H_2O*	0.0	1.38	2.11	566	25	(96)
	1.6	1.38	2.00	539	25	(96)
	2.4	1.35	1.85	535	26.5	(96)
	2.5	1.32	1.83	535	23	(96)
	3.0	1.25	1.63	522	23	(96)
CH_3I	0.81	1.37	1.80	737	15	(153)
C_2H_5Br	0.81	1.32	1.80	737	15	(153)
C_2H_5OH	1.32	0.91	1.10	755	15	(153)
C_3H_6O	1.19	1.15	1.37	755	15	(153)

* For H_2O, k has been reduced to basis of P = 760 mm.

Figure Index

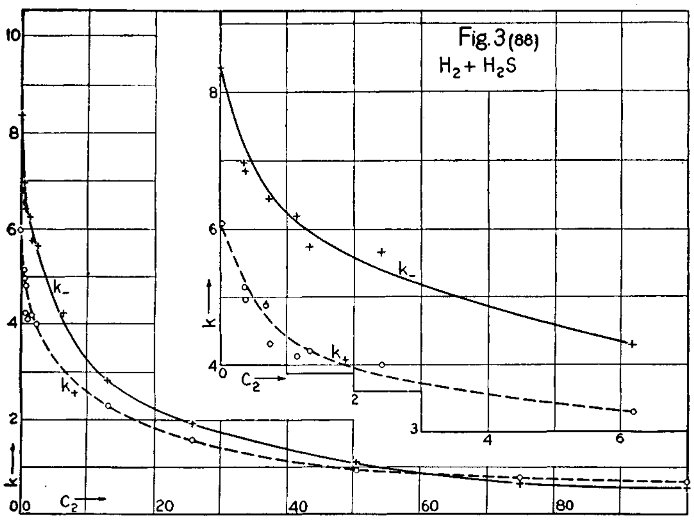
Mixture	Fig.	Mixture	Fig.
Air + H_2O	9	Air + *n*-$C_5H_{11}OH$	9
Air + HCl	7	$O_2 + H_2$	1
Air + NH_3	7	$O_2 + Cl_2$	1
Air + CO_2	6	$H_2 + Cl_2$	1
Air + CCl_4	8	$H_2 + H_2S$	3
Air + $CHCl_3$	8	$H_2 + NH_3$	2
Air + CH_3OH	9	$H_2 + CO_2$	6
Air + C_2H_5OH	9	$H_2 + (C_2H_5)_2O$	5
Air + *n*-C_3H_7OH	9	$H_2 + CH_3I$	4
Air + *n*-C_4H_9OH	9	$H_2 + C_2H_2$	4

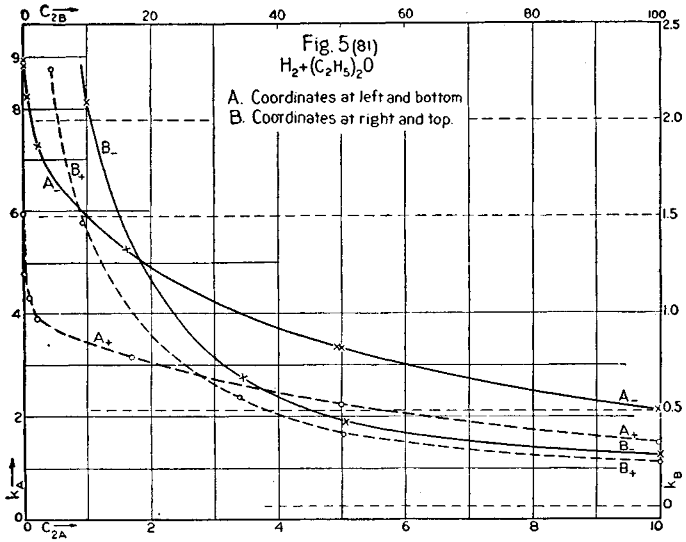


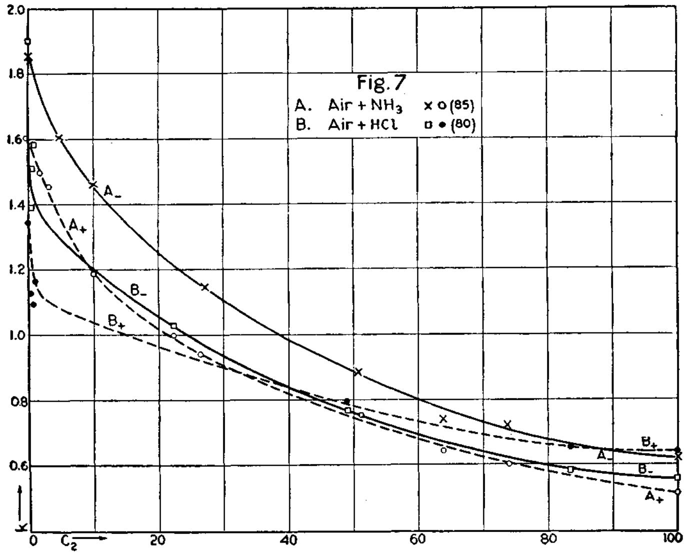


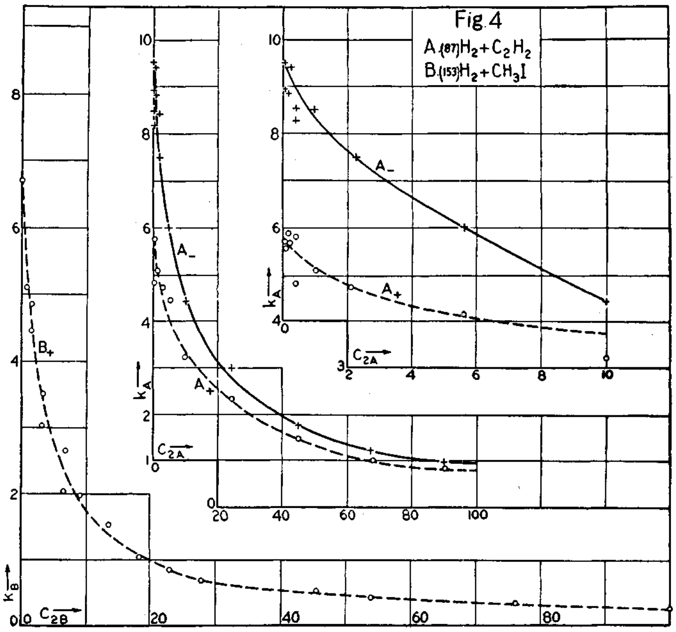
FIGS. 1 to 9.—Mobility (*k*) of normal ions in mixed gases.

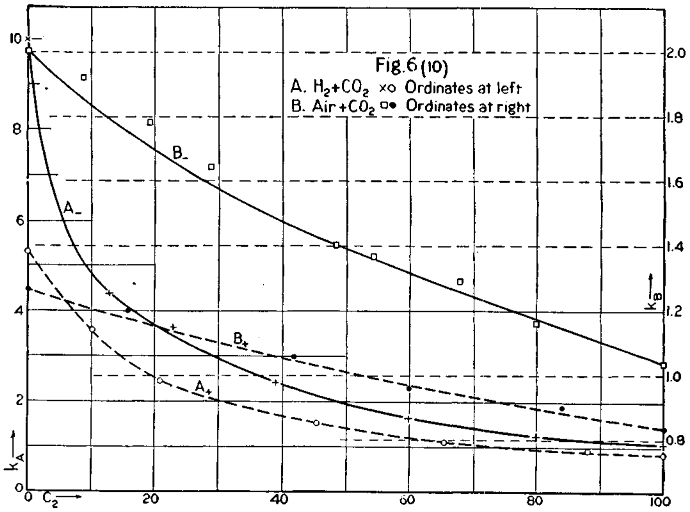
(For symbols and index, *see* Table 2.) P = 760 mm Hg, t = 15°C, C_2 = concentration of the second constituent; *e.g.* in Fig. 2, C_2 = concentration of NH_3; sign of ion is indicated by a subscript, + or −; literature reference is enclosed in ( ). Unit of C_2 = 1%; of k is nominally 1 cm²/(volt sec) but data are suitable for ratios only within the group of which they form a part.

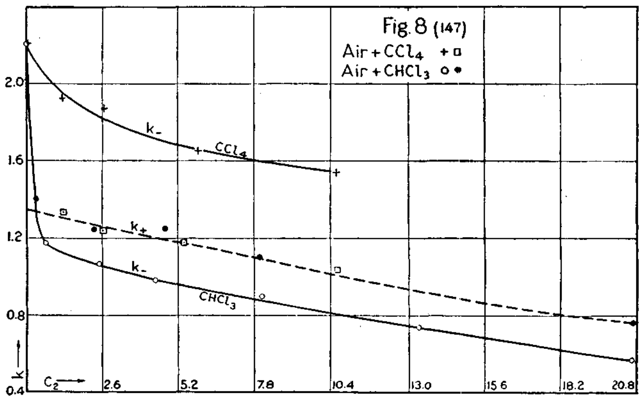






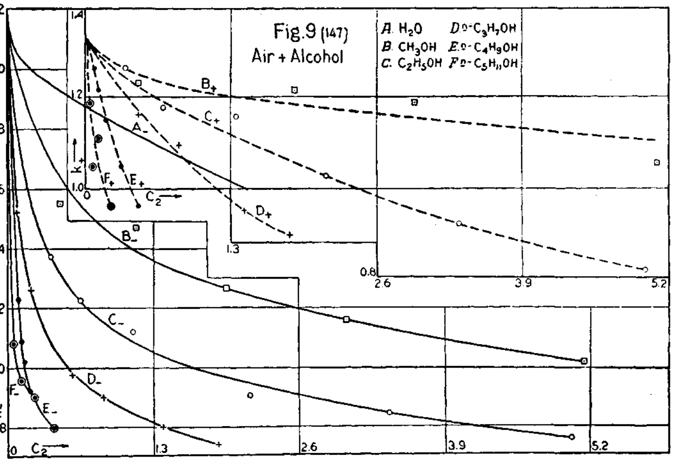






FIGS. 1 to 9.—Mobility (k) of normal ions in mixed gases.

(For symbols and index, *see* Table 2.) P = 760 mm Hg, t = 15°C, C_2 = concentration of the second constituent; *e.g.* in Fig. 2, C_2 = concentration of NH_3; sign of ion is indicated by a subscript, $_+$ or $_-$; literature reference is enclosed in ( ). Unit of C_2 = 1%; of k is nominally 1 cm²/(volt sec), but data are suitable for ratios only within the group of which they form a part.



FIGS. 1 to 9.—Mobility (k) of normal ions in mixed gases.

(For symbols and index, *see* Table 2.) P = 760 mm Hg, t = 15°C, C_2 = concentration of the second constituent; *e.g.* in Fig. 2, C_2 = concentration of NH_3; sign of ion is indicated by a subscript, $_+$ or $_-$; literature reference is enclosed in ( ). Unit of C_2 = 1 %; of k is nominally 1 cm²/(volt sec), but data are suitable for ratios only within the group of which they form a part.

TABLE 3.—MOBILITY (k) OF NORMAL IONS: VARIATION WITH PRESSURE (P)

For a given gas at a given temperature, Pk is a constant if P lies between a few mm of Hg and 75 or 100 atm. (**27, 57, 59, 92, 136, 149, 156**); at other pressures, variations are observed. At least a part of the variation at low pressures arises from the fact that an appreciable fraction of the ions present are not completely formed (**56, 97, 155, 156**) (*cf.* Table 5). Sign of ion is indicated by subscript $_+$ or $_-$. Recent results in SO_2 indicate that for saturated vapors this law may not hold (**89**). Unit of k = 1 cm²/(volt sec); of P = 1 mm of Hg or 1 atm. Temperature = 15°C.

P	Pk_+	Pk_-	P	Pk_+	Pk_-	P	Pk_+	Pk_-
Air (**57**) P, atm.			Air (**92**).—(*Cont'd*)			CO_2*.—(*Cont'd*)		
13.3	1.32	1.84	155.04	1.68	2.21	0.93	1.30	
21.1	1.30	1.75	164.73	1.71	2.32	0.525	1.40	
31.2	1.35	1.87	175.40	1.61	2.19	0.507	1.50	
36.8	1.37	1.87	181.50	1.65	2.17	0.451	1.55	
41.7	1.32	1.87	O_2* (**136**) P, mm			0.350	1.65	
47.6	1.30	1.86	1.57	1.59		0.300	1.78	
50.6	1.32	1.85	1.39	1.86		0.210	1.70	
53.0	1.37	1.94	1.27	1.78		0.136	1.72	
59.5	1.34	1.89	1.06	1.99		0.091	2.22	
70.6	1.36	1.91	0.79	2.08		0.053	2.27	
74.6	1.39	1.96	0.63	2.09		H_2* (**136**) P, mm		
Air (**92**) P, atm.			0.48	2.48		3.54	6.32	
66.86	1.32	1.89	0.41	2.71		2.68	6.64	
87.21	1.41	1.86	0.25	2.60		1.50	6.40	
96.90	1.46	1.89	0.172	3.63		1.27	7.36	
108.50	1.48	2.04	0.151	2.96		0.99	8.00	
116.28	1.50	2.07	0.091	3.55		0.67	8.42	
123.10	1.52	2.05	CO_2* (**136**) P, mm			0.42	8.95	
132.75	1.60	2.04	1.47	1.09		0.38	9.60	
145.35	1.60	2.21	1.13	1.20				

* Thermions from hot salts.

TABLE 4.—MOBILITY (k) OF NORMAL IONS IN DRY AIR: VARIATIONS WITH TEMPERATURE (T)

At constant density and near room temperature, k is practically independent of T. For theoretical and other discussions, *see* (**45, 61, 76, 112, 128**). P = pressure; sign of ion is indicated by subscript $_+$ or $_-$. Unit of k = 1 cm²/(volt sec). T = absolute temperature, °K; T_0 = value of T at 0°C.

TABLE 4.—(*Continued*)

T, °K	$(kT_0/T)_-$	T, °K	$(kT_0/T)_+$	$(kT_0/T)_-$	T, °K	k_+‡	k_-‡
P = 1 atm. (**56**)		P = 1 atm. (**104**)			Constant density*		
698	2.19	411	1.33	1.66	(**32**).—(*Cont'd*)		
643	2.32	399	1.34	1.64	311	1.209	1.81
570	2.15	383	1.32	1.64	297	1.327	1.740
540	2.20	373	1.33	1.62	273	1.365	1.755
503	2.18	348	1.31	1.67	252	1.30	1.663
468	2.30	333	1.31	1.64			
463	2.20	285	1.33	1.71	Constant density		
428	2.35	209	1.24	1.61	(**31**)		
416	2.27	94	0.682	0.68	T, °K	k_+	k_-
409	2.22				293	1.35	1.89
388	2.05	Constant density*			209	1.34	1.82
378	2.00	(**32**)			93	1.20	1.24
360	2.00	T, °K	k_+†	k_-†			
340	2.10	336	1.207	1.729	Constant density§		
335	2.04	318	1.278	1.809	(**128**)		
300	1.91	306	1.326	1.777	T, °K	$k_+\Vert$	$k_-\Vert$
296	1.88	297	1.364	1.693	288	1.88	2.43
268	1.83	273	1.361	1.522	332	1.86	2.47
237	1.77	252	1.321	1.596	395	1.75	2.33
202	1.53	89	1.20	1.24	T, °K	k_+¶	k_-¶
180	1.32	T, °K	k_+‡	k_-‡	288	1.59	2.21
149	1.14	343	1.101	1.510	370	1.52	2.43
84.5	0.717	325	1.178	1.701	288	1.62	2.29

* The density is that corresponding to 0°C and 1 atm.

† Air dried over $CaCl_2$ and liquid air; vessel unheated.

‡ Air dried over liquid air; during filling, vessel heated to 373°K = 100C°.

§ The density is that corresponding to 15°C and 1 atm.

‖ Air of highest purity in contact with Na. ¶ Dry air of less purity.

TABLE 5.—MOBILITY (k) OF NEWLY FORMED IONS

Very new + ions have the same mobility as the − ions; mobility of − ions appears to be independent of age. Values of k on any one line of the table are relatively correct, but are not in all cases comparable with those on any other line.

U_n = upper limit for the age of the new ions; L_o = lower limit for the old ions. The same age limits apply to both + ions and − ions. Pressure = 760 mm of mercury; temperature = 15°C. Unit of U and L = 1 sec; of k = 1 cm²/(volt sec).

Gas	Carrier	Age limits		k_+		k_-		Lit.
		U_n	L_o	New	Old	New	Old	
Air.........	AcA and AcB	0.002	0.002	4.35	1.55			(**36**)
Air.........	ThA and ThB	0.002	0.002	4.35	1.55			(**39**)
Air.........	RaA and RaB	0.002	0.002	4.35	1.55			(**39**)
Air.........	C_2H_2	0.002	0.03	1.80	1.80	>*	>*	(**40**)
Air.........	A	0.005	0.013	1.80	1.36	1.80	1.80	(**37**)
Air.........	CO_2	0.005	0.02	1.80	1.36	1.80	1.80	(**35**)
Air†........	Air	0.008	0.013	1.80	1.35	1.80	1.80	(**149**)
Air.........	H_2	0.008	0.013	1.80	1.36	>*	>*	(**37**)
Air.........	Pt	0.03	0.03	1.80	1.36	1.80	1.80	(**34, 38**)
Air.........	Air	0.03	0.10	1.89	1.36	1.89	1.89	(**33**)
Air.........	Air and C_2H_2	0.03	0.10	1.89	1.89	>*	>*	(**40**)
O_2.........	O_2	0.03	0.10	1.89	1.36	1.89	1.89	(**33**)
N_2.........	N_2	0.03	0.10	1.89	1.36	1.89	1.89	(**33**)
Air and NH_3	Air	0.06	0.06	1.89	1.89	1.89	1.89	(**41**)
He†........	He	0.001	0.010	8.70	5.13			(**152**)
$(C_2H_5)_2O$†..	$(C_2H_5)_2O$	0.005	0.02	0.22	0.19	0.22	0.22	(**79**)

* The > indicates that negative ion is slightly faster than initial positive ion. † Mobility of (k') measured at P = 5 to 50 mm and reduced to P = 760 mm by equation $k = k'P/760$.

TABLE 6.—DIFFUSIVITY (Δ) OF NORMAL IONS

For methods of measurements and discussion of relation of Δ and k, *see* (47, 84, 97, 133, 139)

$\frac{dN}{dt} = -\Delta\frac{dn}{dz}dxdy$; dN = resultant number of ions, of the species considered, which diffuses, in the direction of increasing z, through the area $dxdy$ in the time dt, when the gradient of the concentration (n) of these ions normal to $dxdy$ is dn/dz; n = number per unit of volume. For these data, $P\Delta$ for a given gas and a given species of ion is essentially a constant; all observations were made near room temperature. At $P = A_n$, $\theta = 0°C$, and for any given gas and species of ion $\Delta/k_0 = A_n/n_o e = 7.85 \times 10^{-5}$ erg/es; k_0 = mobility constant of the ion considered; n_o = Loschmidt's number; e = electronic charge. Sign of ion is indicated by subscript $_+$ or $_-$. Unit of $\Delta = 0.01$ cm²/sec; of P = 1 mm of Hg; of temperature (θ) = 1°C.

Dry gases

Gas	P	Δ_+	Δ_-	θ	Lit.
Air	1128	2.2	2.7		(127)
Air	772	3.17	4.29	19	(138)
Air		2.90*	4.48*		(47)
Air	760	3.2	4.2		(127)
Air	758	3.2	4.2		(127)
Air	550	4.20	5.42	18	(138)
Air	400	5.78	7.80	16	(138)
Air	300	7.86	10.3	13	(138)
Air	200	11.8	15.5	12	(138)
N_2	1302	1.7	2.6		(127)
N_2	1120	2.0	2.8		(127)
N_2	1000	2.3	3.14		(127)
N_2	760	2.9	4.1		(127)
N_2	760	2.95	4.14		(127)
O_2	760	3.0	4.1		(127)
CO_2	760	2.5	2.6		(127)

Effect of moisture (139)

Gas	Δ_+		Δ_-	
	Dry	Moist	Dry	Moist
Air	2.8	3.2	4.3	3.5
O_2	2.5	2.88	3.96	3.58
CO_2	2.3	2.45	2.6	2.55
H_2	12.3	12.8	19.0	14.2

* Estimated correct within 6 %.

TABLE 7.—COEFFICIENT (α) OF RECOMBINATION OF NORMAL IONS: ONE PRESSURE AND ROOM TEMPERATURE

$-\frac{dn}{dt} = \alpha n_+ n_-$; n_+, n_- = number of + ions and − ions, respectively, per cm³; n = either n_+ or n_-; t = time, in seconds. Unit of pressure (P) = 1 mm of mercury; of $\alpha = 10^{-6}$ cm³ per (ion sec).

Gas	P	α				
Air	760	1.63	1.50	1.72	1.89	1.61
O_2	760	1.61				
H_2	760	1.49				1.40
CO	757			0.87		
CO_2	760	1.67	1.62	1.67	2.33	1.66
CH_3I	28				0.56	
C_2H_5Cl	100				1.35	
C_2H_5Br	28				0.69	
$(C_2H_5)_2O$	95				1.51	
N_2O	749			1.35		
SO_2	680			1.31		
Lit.		(137)	(60)	(132)	(106)	(91*)

* McClung used α-particles from radium.

TABLE 8.—COEFFICIENT (α) OF RECOMBINATION OF NORMAL IONS: VARIATION WITH PRESSURE (P) (*cf.* TABLE 7)

For methods of measurement and discussion of observations, *see also* (29, 53, 61, 91, 105, 106, 120, 123, 135, 137). Unit of P = 1 mm of Hg; of $\alpha = 10^{-6}$ cm³ per (ion sec).

P	α	P	α	P	α
Air (60)		Air (53).—(*Cont'd*)		CO_2 (132).—(*Cont'd*)	
152	0.28	250	0.99	729	1.64
375	0.67	450	1.26	CO (132)	
760	1.50	760	1.57	247	0.22
1 550	1.7	(120)		409	0.44
2 320	1.5	280	1.77	556	0.62
3 800	1.0	420	1.85	690	0.76
(132)		540	2.05	757	0.87
197	0.44	745	2.13	SO_2 (132)	
307	0.73	CO_2 (60)		83.5	0.26
363	0.82	135	0.18	200	0.42
462	1.02	352	0.88	338	0.72
644	1.44	550	1.20	444	0.91
662	1.47	758	1.60	504	1.07
743	1.66	1 560	1.47	680	1.31
(53)		2 380	0.98	N_2O (132)	
10	0.48	(132)		200	0.33
20	0.55	175	0.49	294	0.53
35	0.60	265	0.67	430	0.81
50	0.63	373	0.92	596	1.13
100	0.74	498	1.19	749	1.33
150	0.84	614	1.44		

TABLE 9.—COEFFICIENT (α) OF RECOMBINATION OF NORMAL IONS: VARIATION WITH TEMPERATURE (*cf.* TABLE 7)

Data for variation with temperature are very discordant. For relative values for CO_2 and H_2, *see* (30). Following values are for air at constant density (α_d) and at constant pressure (α_P); the latter are relative to $\alpha = 1.7 \times (10)^{-6}$ cm³ per (ion sec) at 289°K = 16°C. Unit of α_d and $\alpha_P = 10^{-6}$ cm³ per (ion sec); temperature = T, °K.

T	94	205	285	289	337	373	428	449	546	Lit.
α_d	2.55	1.92	1.18		0.78	0.59	0.47			(29)
α_P				1.7		0.85	0.68	0.61	0.30	(105)

TABLE 10.—MOBILITY (k) OF SLOW IONS

Moist air at pressure = 1 atmosphere; p = partial pressure of water vapor present. Sign of ion is indicated by subscript $_+$ or $_-$. (For classification of slow ions, *see* p. 110.) Unit of $k = 10^{-4}$ cm²/(volt sec); of p = 1 mm of Hg; temperature = t, °C.

p	k	p	k
Ions of Type I (107), t = 20°C			
0.67	7.99	11.80	3.67*
5.87	6.85	14.90	3.25
8.85	4.33*	15.51	3.17
10.24	3.90*	16.05	3.10
11.11	3.79*		

* A single measurement.

p	k_+	k_-	t
Ions of Type II (108)			
0.78	668		21.8
0.73	658		20.8
0.68		568	19.7
4.97		257	18.4
7.33	207		24.8
5.92		233	20.0
6.41		189	21.3
11.67		202	20.9
Ions of Type II.—(*Cont'd*)			
10.82		189	20.9
14.18	187		24.5
6.66		183	15.3
13.29	181		20.4
11.29	178		20.1
14.11	166		21.6
15.66	158		23.9
15.43	153		22.6
13.16	146		21.0
15.58	116		24.3
14.40	110		24.2
13.89	91		22.1
14.35		81	22.2
15.43		73.8	22.2
16.67		71.5	24.5

TABLE 10.—(*Continued*)

Ions of Type II.—(*Cont'd*)

p	k_+	k_-	t	p	k_+	k_-	t
14.87		64.1	23.4	16.88	28.6		19.5
14.06	63.6		22.8	17.09	24.6		19.7

Heterogeneous Slow Ions (8)

Source is hot Pt. Air is saturated with water vapor; k refers to the type of ion that is the most numerous. Unit of $k = 10^{-2}$ cm²/(volt sec); of age = 1 sec.

Age..	2	4	6	8	12	16	22	32	45	58	70
k....	6	4.2	2.9	2.6	2.3	2.0	1.6	1.2	0.9	0.75	0.65

TABLE 11.—MIGRATIONAL (v) AND THERMAL (u) VELOCITIES OF ELECTRONS IN GASES AT 15°C

If k = mobility of electrons in the gas considered, $v = kF$, where F = strength of the electric field; the velocity of agitation $u = 1.15c(10)^7$ cm/sec, where c^2 is determined from the lateral scattering of a beam of electrons in an electric field due to diffusion (*see* (139)); the mean free path (l) of the electrons is that defined (139) by $v = 0.815eFl/mu$; l_1 is the value of l when pressure (P) is 1 mm of Hg, and temperature = 15°C; in the units named below, $l_1 = 0.0797vcP/F$. For actual values of F and P, *see* original papers. Unit of F = 1 volt/cm; of P = 1 mm of Hg; of l_1 = 0.01 cm; of $v = 10^5$ cm/sec; of $k = 10^3$ cm²/(volt sec); c is dimensionless; $u = 1.15c(10)^7$ cm/sec.

A (141); $10 < F < 50$; $2 < P < 150$

F/P	v	c^2	l_1
15.00	82.0	324	7.92
10.00	65.0	324	9.42
5.00	40.0	310	11.3
1.25	7.7	320	8.88
0.950	6.00	280	8.52
0.710	4.85	240	8.52
0.525	4.15	200	9.02
0.440	3.85	180	9.44
0.355	3.6	160	10.3
0.275	3.4	140	11.8
0.195	3.25	120	14.7
0.125	3.1	100	20.0

H$_2$ (140); $4 < F < 35$; $0.6 < P < 40$

56	248	146	4.27
50	217	138	4.07
40	166	123	3.67
30	106	104	2.87
20	72	78	2.53
10	40.7	44	2.15
5	26.7	25.5	2.14
3	20.2	18.6	2.31
1.5	14.4	12	2.66
1	11.9	9	2.86
0.5	9.0	5.2	3.25
0.25	6.5	3.1	3.64

H$_2$ (78); $10 < F < 100$; $100 < P < 760$

$k_0 = 432/[55.2 + F(760/P)^{3/4}]$,
$v = 760k_0F/P$

He (142); $2 < F < 27$; $5 < P < 240$

F/P	v	c^2	l_1
5.0	30.2	172.0	6.4
4.0	23.5	152.0	5.85
3.0	17.5	137.0	5.5
2.5	15.0	124.0	5.4
2.0	12.7	105.0	5.25
1.5	10.5	79.5	5.0
1.00	8.25	53.0	4.85
0.50	5.74	27.0	4.8
0.20	3.93	11.3	5.3
0.10	2.96	6.20	5.95
0.05	2.14	3.68	6.6
0.02	1.33	2.12	7.8
0.013	1.11	1.77	9.14

He (78); $10 < F < 100$; $100 < P < 760$

$k_0^2 = 757/[1.565 + 760F/P]$,
$v = 760k_0F/P$

N$_2$ (140); $4 < F < 34$; $0.3 < P < 20$

60	193	126	2.89
50	171	108	2.83
40	146	89	2.75
30	117	72.5	2.67
20	86	59.5	2.66
10	48.5	48.5	2.69
5	27	41.3	2.77
3	17.8	35.5	2.82
2	13.1	30.5	2.88
1	8.7	21.5	3.20
0.5	6.2	13	3.55
0.25	5.15	7.5	4.50

N$_2$ (78); $10 < F < 100$; $100 < P < 760$

$k_0 = 363.7/[11.9 + 760F/P]$,
$v = 760k_0F/P$

N$_2$ (151); $P = 760$; alternating potential of frequency $1000n$ per sec.

F	k	n
1.01	17.9	5.30
1.16	18.1	6.21
1.22	17.7	6.30
2.2	18.0	11.50
2.9	17.6	15.05
3.6	17.4	18.60
4.2	17.5	21.50
5.0	17.0	25.00
6.3	16.2	29.70
5.5	16.2	16.67
6.9	15.5	30.90
8.0	15.9	37.00
13.0	13.3	50.50
17.5	11.85	60.1
23.2	10.30	68.5
26.1	9.42	71.1
33.5	7.95	77.0
35.8	7.52	79.1
39.0	7.25	81.3
43.3	6.80	84.5
48.0	6.11	85.3
55.5	5.50	87.7

TABLE 11.—(*Continued*)

O$_2$ (140); $4 < F < 35$; $1 < P < 10$

F/P	v	c^2	l
50	201	136	3.74
20	86	70	2.89
14	61	55.5	2.57
10	46	50	2.58
6	36	45	3.22
2	30	22.5	5.6

A + H$_2$ (141); (?) $< F <$ (?); (?) $< P <$ (?)

96% A + 4% H$_2$

64.8	26.5	140	0.39
42.4	25.4	100	0.48
26.0	23.5	70	0.61
15.6	20.8	50	0.76
10.8	19.0	40	0.89
6.55	16.7	30	1.12
3.25	13.6	20	1.51
2.25	12.2	16	1.75
1.72	11.1	13	1.87
1.28	10.00	10	1.99
1.0	9.10	8	2.08
0.75	7.95	6	2.09
0.5	6.35	4	2.05

Air (140); (?) $< F <$ (?); (?) $< P <$ (?)

F/P	v	c^2	l
100	270	160	2.72
50	173	102	2.78
20	90	57	2.71
10	52	46	2.82
5	30	38	2.96
2	17.5	22	3.28
1	12.5	11	3.30
0.5	9	5.7	3.37

For relations found with parallel plates, P = 40 to 90 mm, *see* (75).

NO (129); $2 < F < 35$; $1 < P < 10$

13	84	37.0	1.42
10	74	21.7	0.88
8	66	16.7	0.73
5	51	13.3	0.84
4	45	12.2	0.97
3	38	11.0	1.10
2	30	9.3	1.21
1	22	7.0	1.37

N$_2$O (129); $2 < F < 17$; $0.6 < P < 10$

13.33	48	13.9	
6.66	49	9.2	
3.33	46	5.0	
1.66	32	2.70	
0.83	16.2	1.81	
0.42	7.5	1.32	

CO (129); $2 < F < 35$; $0.3 < P < 40$

50	152	86	2.24
40	114	68	1.87
30	80	52	1.53
20	57	42	1.47
10	38	34	1.76
5	28.5	22.7	2.16
3	26.0	16.0	2.76
2	23.0	11.0	3.04
1	18.0	5.5	3.36
0.5	13.0	4.80	4.52
0.25	9.0	3.20	5.14

CO (150); $5 < F < 100$; $100 < P < 723$

$k = 1\,870/[P\sqrt{0.005 + (F/P)}]$
$v = Fk \times 10^{-2}$

TABLE 12.—NUMBER (N) OF MOLECULAR IMPACTS OF AN ELECTRON BEFORE ITS ATTACHMENT TO FORM A NORMAL NEGATIVE ION

N appears to be independent of pressure (observations from P = 20 mm to P = 760 mm), but increases with the initial velocity (v_i) of the electron (*see* end of table). Values tabulated refer to 15°C and are rather rough approximations. $N = A \times 10^n$ (**5, 72, 77, 79, 88, 148**).

Gas	A	n	Observer	Gas	A	n	Observer
A..........	∞		Franck	He..........	∞		Franck
Cl$_2$..........	<2.1	3	Wahlin	N$_2$..........	∞		Loeb
H$_2$..........	∞		Loeb	Ne..........	∞		Townsend

TABLE 12.—(*Continued*)

Gas	A	n	Observer	Gas	A	n	Observer
O_2	8.7	3	Loeb	C_2H_4	4.7	7	Wahlin
HCl*	<2	3	Loeb	C_2H_5Cl	3.7	5	Wahlin
H_2S*	2	4	Loeb	C_2H_6	2.5	6	Wahlin
SO_2*	<2	3	Loeb	$(C_2H_5)_2O$*	4	4	Loeb
NH_3	9.9	7	Wahlin	Air§	1.98	5	Loeb
N_2O	6.1	5	Loeb	Air	4.3	4	Loeb
CO	1.6	8	Wahlin	Air_{33}‖	3.0	5	Bailey
CO_2†	1.5	7	Loeb	Air_{45}‖	5.0	5	Bailey
CO_2‡	2.1	5	Loeb	Air_{60}‖	1.4	6	Bailey
C_2H_2	7.8	6	Wahlin				

* Values estimated relative to air, from pressure at which free electrons appear (79, 80, 88, 89). † Fresh CO_2. ‡ CO_2, 22 hr old. § Accurate absolute value; dry air, P between 20 and 760 mm (77). ‖ Subscript indicates value of v_i; unit $= 10^6$ cm/sec; *e.g.*, for air_{33}, $v_i = 33 \times 10^6$ cm/sec.

TABLE 13.—CONDENSATION OF VAPORS ON IONS AND NUCLEI

The degree of supersaturation (S) of a vapor subjected to adiabatic expansion is defined as the ratio of the vapor pressure after the expansion to the pressure of the saturated vapor at the temperature of the gas after its expansion.

When water vapor is supersaturated by adiabatic expansion, four stages of condensation are recognized: Condensation occurs on dust particles and on certain products of chemical action if $S < 4$; begins to occur on $-$ ions at $S = 4$ *ca.*, on $+$ ions at $S = 6$ *ca.*, and on uncharged water nuclei at $S > 6$. The nature of the gas in which the vapor is distributed has no effect upon the value of S required to initiate a given type of condensation. $E \equiv V_2/V_1 =$ adiabatic expansion necessary to produce condensation, $V_1[V_2] =$ volume of moist gas before [after] expansion. E_0, E_-, $E_+ =$ value of E corresponding to condensation on uncharged water nuclei, on $-$ ions, on $+$ ions; S_0, S_-, and S_+ are the values of S corresponding to E_0, E_-, and E_+. When the sign of the ion is not known the value of E is placed between the columns for E_- E_+.

<table>
<tr><th>Formula</th><th>Vapor</th><th>E_0</th><th>E_-</th><th>E_+</th><th>S_+</th><th>Lit.</th></tr>
<tr><td>H_2O</td><td>Water*</td><td>1.38</td><td>1.25</td><td>1.31</td><td>5.8</td><td>(157)</td></tr>
<tr><td>H_2O</td><td>Water</td><td>1.42</td><td>1.29</td><td></td><td></td><td>(28)</td></tr>
<tr><td>H_2O</td><td>Water</td><td>1.366</td><td>1.265</td><td>1.314</td><td></td><td>(111)</td></tr>
<tr><td>H_2O</td><td>Water†</td><td>1.31</td><td>1.270</td><td>1.32</td><td></td><td>(3)</td></tr>
<tr><td>H_2O</td><td>Water</td><td></td><td>1.251</td><td></td><td></td><td>(58)</td></tr>
<tr><td>CCl_4</td><td>Carbon tetrachloride</td><td></td><td colspan="2">1.89</td><td></td><td>(28)</td></tr>
<tr><td>CS_2</td><td>Carbon disulfide</td><td>1.08</td><td colspan="2">1.05</td><td></td><td>(28)</td></tr>
<tr><td>CS_2</td><td>Carbon disulfide</td><td></td><td colspan="2">1.02</td><td></td><td>(111)</td></tr>
<tr><td>$CHCl_3$</td><td>Chloroform</td><td></td><td>1.598</td><td>1.528</td><td>3.0</td><td>(111)</td></tr>
<tr><td>C_2H_5I</td><td>Ethyl iodide</td><td></td><td>1.530</td><td>1.484</td><td></td><td>(111)</td></tr>
<tr><td>C_6H_5Cl</td><td>Chlorobenzene</td><td>1.60</td><td colspan="2">1.48</td><td></td><td>(28)</td></tr>
<tr><td>C_6H_6</td><td>Benzene</td><td>1.78</td><td colspan="2">1.53</td><td></td><td>(28)</td></tr>
<tr><td>C_6H_6</td><td>Benzene</td><td>1.74</td><td colspan="2">1.50</td><td></td><td>(3)</td></tr>
<tr><td>C_6H_6</td><td>Benzene‡</td><td></td><td colspan="2">1.642</td><td></td><td>(111)</td></tr>
<tr><td>C_3H_6O</td><td>Acetone</td><td></td><td colspan="2">2.009</td><td></td><td>(111)</td></tr>
<tr><td>CH_4O</td><td>Methyl alcohol</td><td>1.42</td><td></td><td>1.32</td><td></td><td>(28)</td></tr>
<tr><td>CH_4O</td><td>Methyl alcohol</td><td>1.378</td><td>1.306</td><td>1.251</td><td>2.3</td><td>(111)</td></tr>
<tr><td>C_2H_6O</td><td>Ethyl alcohol</td><td>1.25</td><td></td><td>1.20</td><td></td><td>(28)</td></tr>
<tr><td>C_2H_6O</td><td>Ethyl alcohol</td><td>1.254</td><td>1.200</td><td>1.175</td><td>2.3</td><td>(111)</td></tr>
<tr><td>C_2H_6O</td><td>Ethyl alcohol</td><td>1.190</td><td>1.158</td><td>1.180</td><td></td><td>(3)</td></tr>
<tr><td>C_3H_8O</td><td>n-Propyl alcohol</td><td>1.237</td><td>1.201</td><td>1.178</td><td>3.1</td><td>(111)</td></tr>
<tr><td>$C_4H_{10}O$</td><td>Isobutyl alcohol</td><td>1.260</td><td>1.215</td><td>1.198</td><td>3.6</td><td>(111)</td></tr>
<tr><td>$C_5H_{12}O$</td><td>Isoamyl alcohol</td><td>1.293</td><td>1.233</td><td>1.218</td><td>5.5</td><td>(111)</td></tr>
<tr><td>$C_5H_{12}O$</td><td>Isoamyl alcohol</td><td></td><td></td><td>1.182</td><td>4.1</td><td>(58)</td></tr>
<tr><td>$C_5H_{12}O$</td><td>n-Amyl alcohol</td><td>1.354</td><td>1.307</td><td>1.271</td><td></td><td>(111)</td></tr>
<tr><td>$C_7H_{16}O$</td><td>Heptyl alcohol</td><td>1.362</td><td>1.306</td><td>1.269</td><td></td><td>(111)</td></tr>
<tr><td>CH_2O_2</td><td>Formic acid</td><td></td><td></td><td>1.782</td><td>25.1</td><td>(58)</td></tr>
<tr><td>$C_2H_4O_2$</td><td>Acetic acid</td><td></td><td></td><td>1.441</td><td>9.3</td><td>(58)</td></tr>
<tr><td>$C_3H_6O_2$</td><td>Propionic acid</td><td></td><td></td><td>1.343</td><td>9.4</td><td>(58)</td></tr>
<tr><td>$C_4H_8O_2$</td><td>n-Butyric acid</td><td></td><td></td><td>1.380</td><td>15.0</td><td>(58)</td></tr>
<tr><td>$C_4H_8O_2$</td><td>Isobutyric acid</td><td></td><td></td><td>1.360</td><td>13.3</td><td>(58)</td></tr>
<tr><td>$C_5H_{10}O_2$</td><td>Isovaleric acid</td><td></td><td></td><td>1.220</td><td>6.0</td><td>(58)</td></tr>
<tr><td>$C_4H_8O_2$</td><td>Ethyl acetate</td><td></td><td></td><td>1.486</td><td>8.9</td><td>(58)</td></tr>
<tr><td>$C_5H_{10}O_2$</td><td>Methyl n-butyrate</td><td></td><td></td><td>1.334</td><td>5.3</td><td>(58)</td></tr>
<tr><td>$C_5H_{10}O_2$</td><td>Methyl isobutyrate</td><td></td><td></td><td>1.347</td><td>5.2</td><td>(58)</td></tr>
<tr><td>$C_5H_{10}O_2$</td><td>Ethyl propionate</td><td></td><td></td><td>1.414</td><td>7.8</td><td>(58)</td></tr>
<tr><td>$C_5H_{10}O_2$</td><td>n-Propyl acetate</td><td></td><td></td><td>1.310</td><td>5.0</td><td>(58)</td></tr>
</table>

* For H_2O, $S_0 = 7.9$, $S_- = 4.15$ (157). † For H_2O, $S_0 = 6$ (3). ‡ For C_6H_6, ions of unknown sign, $S = 4.3$ (111).

EFFECTIVE SECTIONAL AREA OF MOLECULES* (1, 2, 11, 12, 13, 14, 15, 16, 17, 48, 54, 64, 65, 66, 93, 95, 113, 114, 115, 116, 117, 119, 121, 130, 161, 162)

When a beam of electrons passes through a gas, the number (n_x) of electrons remaining in the beam after it has gone a distance x is given by the equation, $n_x = n_o e^{-qpx}$, where p is the pressure of the gas. If the cross-sectional area of an electron is negligible as compared with that of a molecule, and if the velocities of the molecules are negligible, as compared with that of the electron, then qp will be the sum of the cross-sectional areas of all the molecules in a unit volume. By definition the mean free path of an electron, L_e is defined as $1/qp$. If the effective cross-sectional area of a molecule for an encounter with another molecule were the same as that for an encounter with an electron, then we would have $L_e = 4\sqrt{2}L$, where L is the mean free path of the molecule in the gas.† It is found that qp varies with the velocity of the electrons and that $1/qp$ or L_e is not equal to $4\sqrt{2}L$. (It should be noticed that L_e is not the same quantity as that denoted by l in Table 11.) The absorbing cross-section of all the molecules in a unit volume of gas at the temperature t and at unit pressure is q. The effective radius, r, of the absorbing cross-section of a single molecule is given by the equation $\pi r^2 = q/N_t$, where N_t is the number of molecules per unit volume at the temperature t and at unit pressure. For electrons with high velocities (β-rays), q has such a value that r is of the same order of magnitude as the radius of the nucleus, as deduced from the scattering of α-particles. In actual measurements, the beam of electrons must have a finite width, and, consequently, those electrons that have been deviated from their initial path by less than a certain amount, determined by the apparatus used, are not eliminated from the beam. This source of error makes the computed value of q too small, and causes the results of different observers to differ slightly. In most cases, the deviation of an observer's separate determinations from the mean curve representing all his values is less than 10%.

Typical data are shown in Figs. 10 to 14:

Molecule	A	Cd	CH_4	CO	CO_2	H_2	He	Hg
Figures	10	14	11	12	13	11	11	14

Molecule	Kr	N_2	NO	N_2O	Ne	O_2	Xe	Zn
Figures	10	12	13	13	10	13	10	14

*In collaboration with R. B. Brode.

† In figures, short line followed by symbol for gas on axis of ordinates indicates gas kinetic value, $4\sqrt{2}L$.

LITERATURE

(For a key to the periodicals see end of volume)

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(10) Blanc, *51*, **7**: 825; 08. (11) Brode, *2*, **23**: 664; 24. (12) Brode, *5*, **109**: 397; 25. (13) Brode, *2*, **25**: 636; 25. (14) Brüche, *8*, **81**: 537; 26. (15) Brüche, *8*, **82**: 25; 27. (16) Brüche, *8*, **82**: 912; 27. (17) Brüche, *8*, **83**: 1065; 27. (18) Busse, *8*, **76**: 493; 25. (19) Busse, *8*, **81**: 262; 26.

(20) Busse, *8*, **81**: 587; 26. (21) Busse, *8*, **82**: 697; 27. (22) Busse, *8*, **82**: 873; 27. (23) Busse, *8*, **83**: 80; 27. (24) Chattock, *3*, **48**: 401; 99. (25) Compton, *2*, **22**: 333; 23. (26) Compton, *2*, **22**: 432; 23. (27) Dempster, *2*, **34**: 53; 12. (28) Donnan, *3*, **3**: 305; 02. (29) Erikson, *3*, **18**: 328; 09.

(30) Erikson, *3*, **23**: 747; 12. (31) Erikson, *2*, **3**: 151; 14. (32) Erikson, *2*, **6**: 345; 15. (33) Erikson, *2*, **20**: 117; 22. (34) Erikson, *2*, **21**: 720; 23. (35)

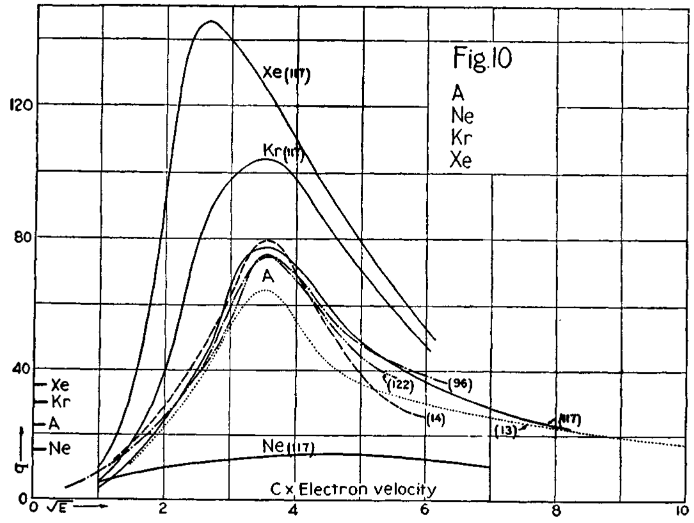
Fig.10
A
Ne
Kr
Xe

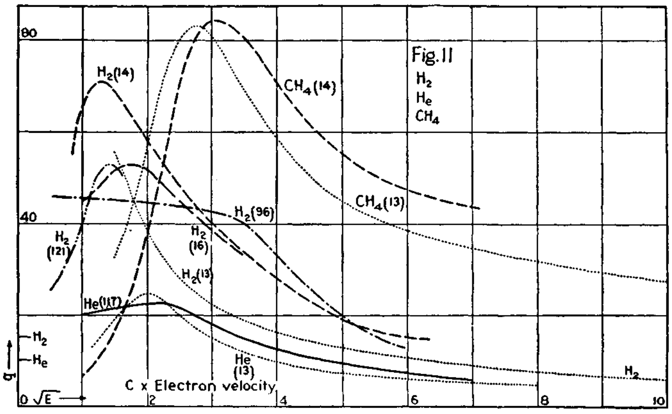
Fig.11
H_2
He
CH_4

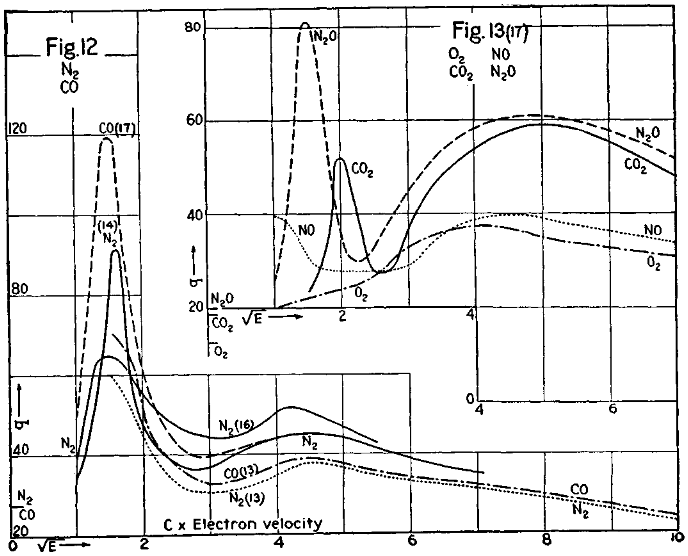
Fig.12
N_2
CO

Fig.13(17)
O_2 NO
CO_2 N_2O

Erikson, *2*, **24**: 502; 24. (36) Erikson, *2*, **24**: 622; 24. (37) Erikson, *2*, **26**: 465; 25. (38) Erikson, *2*, **26**: 625; 25. (39) Erikson, *2*, **26**: 629; 25.
(40) Erikson, *2*, **28**: 372; 26. (41) Erikson, *2*, **30**: 339; 27. (42) Franck, *88*, **11**: 397; 09. (43) Franck, *88*, **12**: 291; 10. (44) Franck, *88*, **12**: 613; 10. (45) Franck, *200*, **9**: 235; 12. (46) Franck and Pohl, *88*, **9**: 69; 07. (47) Franck and Westphal, *88*, **11**: 146; 09. (48) Glockler, *197*, **10**: 155; 24. (49) Grindley and Tyndall, *3*, **48**: 711; 24.
(50) Haines, *3*, **30**: 503; 15. (51) Harries, *96*, **42**: 26; 27. (52) Haselfoot, *5*, **87**: 350; 12. (53) Hendren, *2*, **21**: 314; [illegible] (54) Hertz, *64P*, **25**: 90; 23.

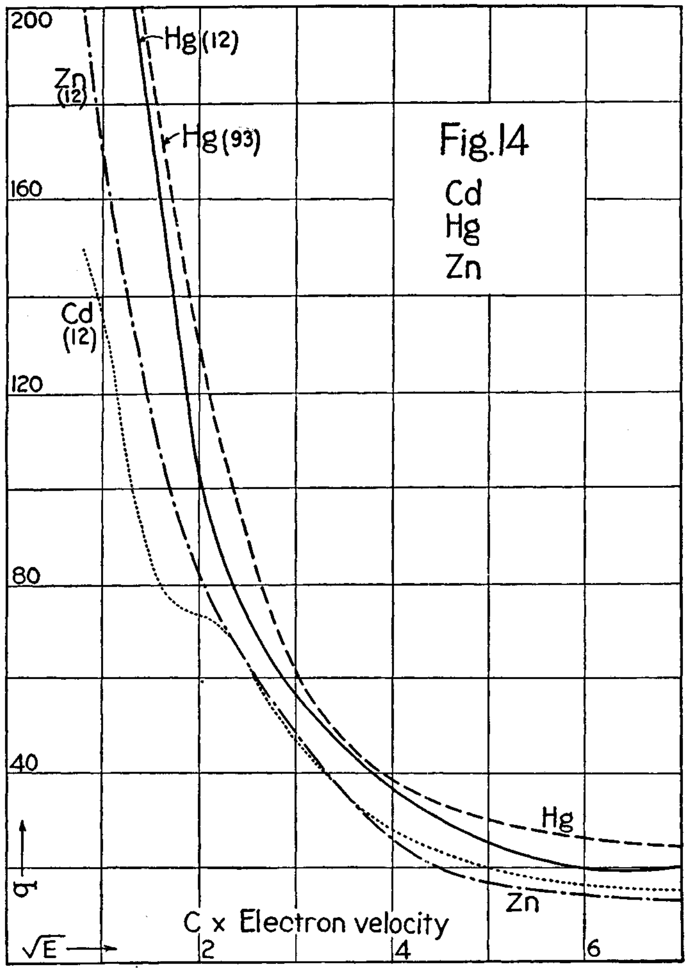
Fig.14
Cd
Hg
Zn

FIGS. 10 to 14.—Effective sectional areas of molecules.

(For general discussion and index, *see* p. 117.) These curves represent typical values deduced from electronic data. q = sum of the effective absorbing cross-sectional areas of all the molecules contained in a unit volume of the gas at 0°C and a pressure of 1 mm Hg; unit of $q = 1$ cm² per cm³. The velocity of the electrons is indicated by numbers equal to the square root of the voltage through which the electron has been accelerated. The equation connecting velocity (v) and volts (V), for slow electrons only, is $\frac{1}{2}\,\mathrm{m}v^2 = \mathrm{e}V$, or $v = 0.595 \times 10^8\sqrt{V}$ cm/sec, where m is the mass of an electron and e its charge.

For some gases, the corresponding sum of the cross-sectional areas involved in the molecular encounters considered in the kinetic theory of gases is indicated by a short dash at the axis of ordinates. Literature references are enclosed in ( ).

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(70) Loeb, *2*, **19**: 24; 22. (71) Loeb, *2*, **20**: 397; 22. (72) Loeb, *3*, **43**: 229; 22. (73) Loeb, *143*, **196**: 537; 23. (74) Loeb, *143*, **196**: 771; 23. (75) Loeb, *197*, **9**: 335; 23. (76) Loeb, *3*, **48**: 446; 24. (77) Loeb, *143*, **197**: 45; 24. (78) Loeb, *2*, **23**: 157; 24. (79) Loeb, *197*, **11**: 428; 25.
(80) Loeb, *197*, **12**: 35; 26. (81) Loeb, *197*, **12**: 617, 677; 26. (82) Loeb, *143*, **201**: 279; 26. (83) Loeb, *197*, **13**: 703; 27. (84) Loeb, *Kinetic theory of gases*. New York, McGraw-Hill, 1927. (85) Loeb and Ashley, *197*, **10**: 351; 24. (86) Loeb and Cravath, *2*, **27**: 811; 26. (87) Loeb and Du Sault, *197*, **13**: 510; 27. (88) Loeb and Du Sault, *197*, **14**: 192; 28. (89) Loeb and Du Sault, *197*, **14**: 384; 28.
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(100) Nolan, *2*, **24**: 16; 24. (101) Nolan, *3*, **1**: 417; 26. (102) Nolan, *8*, **82**:

273; 27. (103) Nolan and de Sachy, *539*, **37**: 71; 27. (104) Phillips, *5*, **78**: 167; 06. (105) Phillips, *5*, **83**: 246; 10. (106) Plimpton, *3*, **25**: 65; 13. (107) Pollock, *3*, **29**: 514; 15. (108) Pollock, *3*, **29**: 636; 15. (109) Przibram, *75*, **117 IIa**: 665; 08.

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(120) Rümelin, *8*, **43**: 821; 14. (121) Rusch, *63*, **26**: 748; 25. (122) Rusch, *8*, **80**: 707; 26. (123) Rutherford, *3*, **44**: 422; 97. (124) Rutherford, *201*, **9**: 401; 98. (125) Rutherford, *3*, **5**: 95; 03. (126) Rutherford, *Radioactive substances and their radiations.* Cambridge, Cambridge Univ. Press, 1913. (127) Salles, *16*, **2**: 273; 14. (128) Schilling, *8*, **83**: 23; 27. (129) Skinker and White, *3*, **46**: 630; 23.

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(150) Wahlin, *2*, **21**: 517; 23. (151) Wahlin, *2*, **23**: 169; 24. (152) Wahlin, *197*, **10**: 475; 24. (153) Wellisch, *5*, **82**: 500; 09. (154) Wellisch, *62*, **209**: 249; 09. (155) Wellisch, *3*, **34**: 33; 17. (156) Wellisch, *12*, **44**: 1; 17. (157) Wilson, *62*, **189**: 265; 97. (158) Yen, *197*, **4**: 91; 18. (159) Yen, *197*, **4**: 106; 18.

(160) Zeleny, *62*, **195**: 193; 01. (161) Zwicky, *63*, **24**: 171; 23. (162) Zwicky, *197*, **12**: 461; 26.

IONIZATION OF GASES

O. Stuhlman, Jr.

This section includes ionization by impact of electrons, of positively charged residues, and of α-particles, by electromagnetic radiation and by chemical action. Data for the conductivity of flames, for ionization potentials, and for photoelectric thresholds are given elsewhere; *consult* p. 156, 69 and 67, respectively.

The following symbols will be used:

c	velocity of light in vacuum.
C	Coefficient of ionization; $n = Cp/T$.
C_r	C_1/C_2 for the same ionizing radiation (corpuscular or electromagnetic) = coefficient of relative molecular ionization of gas (1) with reference to gas (2).
E_i	Energy expended in producing one pair of ions.
E_1	Kinetic energy possessed by the charged particle at the beginning of its ionizing career.
e	Electronic charge.
^-i	α/p; $^+i = \beta/p$.
^-I	$\int_0^\infty {}^-i dx$; $^+I = \int_0^\infty {}^+i dx$.
$^-Np[^+Np]$	Number of encounters of an electron [a + ion] per cm of its path; the superior $^-[^+]$ may be omitted where convenient.
n	Number of ions produced per sec in 1 cm³ of a thin layer of gas at pressure p and absolute temperature T.
p	Pressure of the gas being ionized.
p_m	Pressure at which α is a maximum for a given X.
V	Potential difference required to confer the energy E upon a charge = **e**; $\mathbf{e}V_1 = E_1$, $\mathbf{e}V_i = E_i$, etc.
v	Velocity of the ionizing particle.
X	Intensity of the applied electric field.
$\alpha[\beta]$	Number of pairs of ions produced per cm of path by each electron [each + ion].
λ	Wave-length of the exciting radiation.

If the density of the gas remains constant, α, β and the number of ions produced per sec by a given electromagnetic radiation are all independent of the temperature (10, 11, 14, 32, 33, 44); tested (10) from −180 to +1600°C. If the velocity of the particles arises solely from X, then, for a given temperature and gas, α/p and β/p depend solely upon X/p (63, 65, 66, 67, 69). If X is so great that the effects of thermal agitation may be neglected, $\alpha = N_p \mathrm{e}^{-N_pV_i/X}$ (63); hence $(\alpha_{\max.})_{p\ \mathrm{const.}} = Np$ and $(\alpha_{\max.})_{X\ \mathrm{const.}}$ occurs when $p(=p_m) = X/NV_i$ or $X/p_m = NV_i$; the value of N is determined from that of $(\alpha_{\max.})_p$.

For expressions for the total current resulting from ionization by both electrons and positive residues, *see* (3, 63); for ionization of mixed gases, *see* (3, 26); for theory, *see* Bohr (5, 6) and Fowler (19, 20).

TABLE 1.—IONIZATION OF AIR BY ELECTRONS: VARIATION WITH VELOCITY (4, 15, 16, 27, 71)

$$V_1 = 5.082 \times 10^5 \left\{ \frac{1}{\sqrt{1-(v/\mathbf{c})^2}} - 1 \right\} \text{ volt.}$$

For $V_1 < 4000$ volt, $v/\mathbf{c}$ has been computed from observed value of V_1 by means of the approximate relation $v/\mathbf{c} = 0.001983\sqrt{V_1}$, V_1 being expressed in volts; the corresponding expression for E_1 is $E_1 = 1.592 V_1 \times 10^{-12}$. Unit of α = 1 per cm; of p = 1 mm of Hg; of V_1 = 1 volt; $V_1 = A \times 10^n$.

A	n	100v/c	α/p	A	n	100v/c	α/p
		100	0.054	4.63	4	40	0.32
1.12	6	95	0.063	2.45	4	30	0.42
6.57	5	90	0.073	1.53	4	24	0.43*
3.39	5	80	0.092	1.05	4	20	1.04
2.03	5	70	0.125	9.42	3	19	1.14
1.27	5	60	0.173	8.43	3	18	1.25
7.86	4	50	0.242	7.50	3	17	1.38
6.63	3	16	1.50	7.00	2	5.246	6.19
5.82	3	15	1.68	6.00	2	4.857	5.43
4.77	3	13.6	2.01	4.94	2	4.407	6.43
2.225	3	9.353	3.46	3.97	2	3.951	7.84
1.808	3	8.432	4.98	3.72	2	3.825	9.18
1.500	3	7.680	6.96	3.47	2	3.694	9.36
1.400	3	7.420	7.85	2.95	2	3.406	9.12
1.200	3	6.869	10.32	2.47	2	3.116	13.8
1.105	3	6.601	12.04	1.98	2	2.790	14.6
1.050	3	6.425	12.85	1.56	2	2.477	23.6
9.92	2	6.246	13.82	1.22	2	2.190	37.8
9.85	2	6.223	13.91	8.4	1	1.82	51.4
9.72	2	6.183	13.69	4.7	1	1.36	95.0
9.52	2	6.118	13.50	4.1	1	1.27	111.2
9.05	2	5.965	12.36	3.5	1	1.17	108.2
8.90	2	5.916	10.14	2.8	1	1.05	82.7
8.00	2	5.609	6.72	1.8	1	0.841	51.2

* This value (15) seems to be much too small; it is the only value available between v/c = 0.20 and v/c = 0.30.

TABLE 2.—IONIZATION OF GASES BY ELECTRONS: VARIATION WITH VELOCITY (34)

For air, $v > 0.025\mathbf{c}$, *see* Table 1. (v is computed from Einstein's formula, $m_0\mathbf{c}^2\left(\frac{1}{\sqrt{1-(v/\mathbf{c})^2}} - 1\right) = V_1\mathbf{e}$.) Unit of V_1 = 1 volt; of α = 1 per cm; of p = 1 mm of Hg. Error ≤ 4%.

Gas		A	H_2	He	N_2	Ne	CH_4	CO*
V_1	100v/c	α/p						
300	3.44	4.14	1.264	0.648	4.460	1.502	4.36	4.296
280	3.33	4.54	1.362	0.699	4.775	1.557	4.72	
260	3.20	4.83	1.463	0.744	5.100	1.608	5.05	5.16†
240	3.09	5.31	1.568	0.782	5.420	1.666	5.41	
220	2.96	5.68	1.678	0.815	5.650	1.710	5.74	
200	2.80	6.03‡	1.785	0.844	6.080	1.754	6.20	6.052
180	2.67	6.36	1.902	0.867	6.425	1.800	6.43	
160	2.52	6.67	2.018	0.880	6.780	1.828	6.78	
140	2.36	6.95	2.137	0.881	7.125	1.820	7.14	
120	2.18	7.21	2.260	0.870	7.450	1.768	7.47	
100	1.99	7.45	2.376	0.846	7.640	1.651	7.82	7.595
80	1.78	7.65	2.487	0.804	7.470	1.450	8.06	
60	1.54	7.48	2.518	0.730	6.880	1.130	7.80	7.48†
40	1.25	6.74	2.280	0.500	5.580	0.630	6.79	
35	1.17	6.36	2.153	0.380	4.96	0.480	6.28	
30	1.08	5.56	1.947	0.229	4.09	0.320	5.55	
29	1.06	5.35	1.882	0.192	3.89	0.287	5.37	
28	1.04	5.13	1.825	0.155	3.68	0.255	5.20	
27	1.02	4.88	1.755	0.120	3.47	0.220	5.00	
26	1.00	4.61	1.670	0.082	3.24	0.180	4.80	
25	0.98	4.31	1.600		3.02	0.140	4.55	
24	0.96	4.00	1.500		2.80	0.095	4.30	
23	0.94	3.67	1.383		2.54	0.044	4.02	
22	0.92	3.30	1.260		2.28		3.72	
21	0.90	2.90	1.130		2.00		3.40	
20	0.88	2.45	0.980		1.72		3.05	
19	0.85	1.90	0.800		1.42		2.67	
18	0.83	1.29	0.595		0.80		2.26	
17	0.81	0.45	0.350				1.80	
16	0.79						1.28	
15	0.76						0.75	
14	0.73						0.10	

* Jesse (35). † Corresponds to V_1 midway between bracketed lines. ‡ Jesse (35) found 6.44.

Table 3.—Relative Molecular Ionization of Gases by β-Rays from Various Substances

$n_r \equiv n/n_a = C_r p T_a / p_a T$; n_a, p_a, T_a refer to air; $p_a = 760$ mm Hg; values of C_r

Gas	U-X (37, 38)	Ra (60)	Ac (37, 38)
Air	1.00	1.00	1.00
H_2	0.165*	0.157	0.159
O_2†	1.17	1.21	
SO_2	2.25	2.31	
N_2O†	1.55		
NH_3†	0.89		
CO_2†	1.60*	1.57	
CCl_4	6.28	5.83	
CS_2	3.62		
C_2N_2		1.86	
$CHCl_3$	4.94	4.89	
CH_3Br	3.73		
CH_3I	5.11	5.18	5.34
CH_4O	1.69		
C_2H_4O‡	2.12		
C_2H_5Br	4.41		4.43
C_2H_5Cl	3.24		3.33
C_2H_5I	5.90		
$C_4H_{10}O$§	4.39		4.28
C_5H_{12}‖	4.55		
C_6H_6¶	3.95		

* Bloch (4) finds: H_2, 0.13; CO_2, 1.59; illuminating gas (40 % H_2), 0.63.

† Commercial purity.

‡ Acetaldehyde. ‖ Pentane.

§ Ethyl ether. ¶ Benzene.

Table 4.—Total Number (I) of Pairs of Ions Produced by an Electron in Field of Zero Intensity

$I = \int_0^\infty i\,dx$, where $i \equiv \alpha/p$. If $0.6 < 100v/\mathbf{c} < 2.8$, $I = c_1 (V - c_2)$; c_2 is not V_1, *cf.* Table 7. Unit of $\alpha = 1$ per cm; of $p = 1$ mm of Hg; of V and $c_2 = 1$ volt; of $I = 1000$; of $c_1 = 1$ per volt.

Air: various β-rays				Slow electrons (36)		
Rays	α/p	I	Lit.	Gas	c_1	c_2
Ac-C″	0.174	10	(24)	H_2	0.0258	11
Th-C″	0.174	17	(24)	He	0.0244	20
Ra-B	0.171	3.7	(24)	N_2	0.0276	12
Ra-C	0.138	7.7	(24)	O_2	0.0275	11
		12	(18)			
Ra-E	0.088	3.3	(24)			
U-X	0.099	11.3	(24)			

Table 5.—Ionization of Gases by Accelerated Electrons: Variation with Intensity (X) of Field

For ionization and conductivity of mixed gases, *see* (3). For certain gases $\frac{\alpha}{p} = a\left(\frac{X}{p} - \frac{X_i}{p}\right)^b$, where X_i is weakest field in which ionization occurs (3); $X_i/p = {}^{-}NV_i$. Unit of $X = 1$ volt/cm; of $p = 1$ mm of Hg; of $\alpha = 1$ per cm.

X/p	α/p				
	A	H_2*	H_2	He	He
600	9.2				
500	8.5				
400	7.5		3.7		
300	6.2		3.3		
200	4.4		2.62	2.37	
100	2.0		1.36	1.98	
70		0.62	0.76	1.65	
60		0.43	0.59	1.50	1.35
50	0.58	0.27	0.36	1.31	1.20
40		0.14	0.21	1.10	1.00
30		0.04	0.08	0.86	0.77
25		0.015			
22.5		0.006			
20	0.05			0.57	0.40
15				0.42	
10				0.28	0.12
5				0.12	
Lit.	(25, 63)	(3)	(63)	(26)	(63)

X/p	α/p				
	N_2	H_2O	HCl	CO_2†	Air‡
1500			17.5		
1200				13.7	
1000		9.7	15.4	12.6	10.5
900		9.4			
800		9.0	14.0	11.0	9.3
700		8.5	13.0	10.2	8.7
600	7.0	7.95	11.9	9.1	7.9
500	6.2	7.2	10.5	7.8	7.0
400	5.2	6.35	8.9	6.4	5.82
300	3.95	5.2	6.8	4.8	4.4
200	2.3	3.6	4.1	2.8	2.6
100	4.2	1.31	1.21	0.82	0.72
70				0.27	0.17
60				0.17	0.078
50				0.079	0.029
40				0.020	
Lit.	(63)	(63)	(63)	(3, 63)	(3, 63, 64, 68)

* $a = 266.7 \times 10^{-6}$, $b = 1.615$, $X_i/p = 200$; if $200 \leq X/p \leq 685$ (3).

† $a = 402.9 \times 10^{-6}$, $b = 1.515$, $X_i/p = 356$; if $356 \leq X/p \leq 755$ (3).

‡ $a = 159.4 \times 10^{-6}$, $b = 1.615$, $X_i/p = 400$; if $400 \leq X/p \leq 725$ (3).

Table 6.—Ionization of He by Accelerated Electrons: Variation with Pressure, Field Constant

α is a maximum when $p_m = X/16$; compare with Table 7 where value for NV_i indicates a pressure less than half as great. Unit of $X = 1$ volt/cm; of $p = 1$ mm of Hg; of $\alpha = 1$ per cm.

$X = 120$ (69)				$X = 50$ (66)			
α	p	α/p	X/p	α	p	α/p	X/p
3.05	19	0.160	6.3	1.37	10.5	0.130	4.75
3.46	10	0.346	12.0	1.22	10.0	0.122	5
3.57	6	0.595	20.0	1.56	3.13	0.498	16
3.37	4	0.842	30.0				

Table 7.—Energy (E_i) Expended by Electrons in Ionizing a Molecule: Various Gases

$E_i = \mathbf{e}V_i$; Np = number of collisions per unit length of path of electron = maximum value of α for given p; $NV_i = X/p_m$, where p_m is the pressure at which α is a maximum for a given X. Unit of $V_i = 1$ volt; of $Np = 1$ per cm; of $p = 1$ mm of Hg.

Gas	V_i	N	NV_i	Lit.
Air	25	14.6	365	(63)
	27.1	12.6	341	(51)
	10.21*			(3)
A	17.3	13.6	235	(63)
H_2	26.0	5.0	130	(63)
	27.8	5.5	153	(51)
	9.66*			(3)
He	12.3	2.8	34.4†	(63)

Table 7.—(*Continued*)

Gas	V_i	N	NV_i	Lit.
He.—(*Continued*)	14.5	2.4	34.8†	(63)
N_2	27.6	12.4	342	(63)
	27.9	12.4	346	(51)
O_2	23.9	11.2	268	(51)
H_2O	22.4	12.9	289	(63)
HCl	16.5	22.2	366	(63)
CO_2	23.3	20.0	466	(63)
	23.5	16.2	381	(51)
	6.21*			(3)

* Observations at pressures >1 cm Hg.

† This exceeds twice the value of X/p_m given in Table 6.

TABLE 8.—IONIZATION OF AIR BY α-PARTICLES: VARIATION WITH VELOCITY

No appreciable ionization is produced by an α-particle unless $v > 0.025\mathrm{c}$ (53, 55). If, at a distance x from its source, an α-particle of range R, in the gas considered, produces βdx pairs of ions in a length of path $= dx$, then, quite roughly, $\beta = a/(R - x)^{1/3}$ and $v/\mathrm{c} = b(R - x)^{1/3}$ (22); for air, $a = 4.50 \times 10^4\ \mathrm{cm}^{-2/3}$ (23), $b = 0.0342\ \mathrm{cm}^{-1/3}$ (Vol. I, p. 362). For values of R and v_1 (initial velocity), *see* Vol. I, p. 362, 363. For α-particles from Ra-C′ in air at 12°C and 1 atm., β varies as follows (21):

x	1	2	3	4	5	6	6.5±	7± cm
$\beta/1000$	22.5	23	24	28	36	55	76	40 cm^{-1}

The total number of ions produced is $I = \int_0^R \beta dx = KR^{2/3}$, where $K = 1.50a$; for air, $K = 6.76 \times 10^4\ \mathrm{cm}^{-2/3}$ (22). Unit of $I = 1000$. Gas is air.

Source	$100v_1/\mathrm{c}$	I	Source	$100v_1/\mathrm{c}$	I
U_I	4.56	133	Rd-Ac	5.59	187
Th	4.69	137	Ra-A	5.65	187
U_{II}	4.79	143	Th-C	5.72	189
Io	4.85	146	Tn	5.74	195
Ra	5.00	152	Ac-C	5.89	205
Pa	5.10	160	Th-A	6.00	209
Ra-F*	5.23	167	An	6.00	211
Rd-Th	5.27	169	Ac-A	6.27	228
Rn	5.40	171	Ra-C′	6.41	237
Th-X	5.46	177	Th-C′	6.88	274
Ac-X	5.50	178			

* $I = 158$ (2).

TABLE 9.—RELATIVE MOLECULAR AND TOTAL (I_r) IONIZATION OF GASES BY α-PARTICLES FROM RADIUM AND POLONIUM

$n_r \equiv n/n_a = C_r p T_a/p_a T$; n_a, p_a, T_a refer to air. $v_1 = 0.0500\mathrm{c}$; for ionization of air, *see* Table 8

Gas	Ra		Po	Gas	Ra		Po
	C_r*	I_r*	I_r†		C_r*	I_r*	I_r†
Air	1.00	1.00	1.00	N_2O	1.53	1.02	
A	1.24		1.38	NH_3	0.81	0.90	
Br	3.90			CO	1.00	1.02	
H_2	0.23	0.99	1.07	CO_2	1.55	1.02	
He	0.22		1.26	CCl_4	5.30	1.32	
Kr			1.53	CS_2	2.99	1.38	
N_2	0.94‡	0.96	0.98	C_2N_2	1.93		
Ne			1.28	$CHCl_3$	4.08§	1.29	
O_2	1.14	1.13	1.08	CH_3Br	2.75	1.32	
Xe			1.68	CH_3I	3.43§	1.33	
HCl		1.29		CH_4	1.06	1.18	
HBr		1.29		CH_4O	1.74	1.22	
HI		1.29		C_2H_2	1.40	1.26	
SO_2	2.02	1.03		C_2H_4	1.65	1.22	
NO	1.28			C_2H_4O‖	2.14	1.05	

Table 9.—(*Continued*)

Gas	Ra		Po	Gas	Ra		Po
	C_r*	I_r*	I_r†		C_r*	I_r*	I_r†
C_2H_5Cl	3.10	1.29		C_4H_{10}‖	4.02		
C_2H_5I	4.00	1.28		$C_4H_{10}O$‖	4.40	1.33	
C_2H_6	2.02	1.30		C_5H_{12}‖	4.85	1.35	
C_2H_6O‖	2.46	1.23		C_6H_6‖	4.30	1.29	
C_3H_8	3.05						

* From (8, 9, 17, 37, 38, 39, 43, 46, 60, 61). † From (30, 62).

‡ Another observer (9) finds 0.24 for α from Ra-C′.

§ Strutt (60) finds 4.44 for $CHCl_3$, and 3.51 for CH_3I.

‖ C_2H_4O = acetaldehyde, C_2H_6O = ethyl alcohol, C_4H_{10} = butane, $C_4H_{10}O$ = ethyl ether, C_5H_{12} = pentane, C_6H_6 = benzene.

TABLE 10.—IONIZATION OF GASES BY ACCELERATED POSITIVE RESIDUES: VARIATION WITH INTENSITY (X) OF FIELD

The ionization is produced by the positive residues which result from ionizing the gas by impact of electrons. Unit of X = 1 volt/cm; of p = 1 mm of Hg; of β = 1 per cm.

X/p	$100\beta/p$			
	A	H_2	He	Air
610	24.5			
600	21.5			10.0
520	14.9			6.4
500	13.8			5.6
450	11.6			3.8
400	9.5			2.3
350	7.0	33.0		1.4
300	5.3	26.4		0.62
250	3.8	17.8		0.28
200	2.0	8.2	16.5	0.20
180	1.4	5.9	13.9	0.18
160	0.85	4.1	11.3	0.12
140	0.50	2.6	9.0	0.10
120	0.40	1.60	7.0	
100	0.30	1.03	5.4	
80	0.20	0.64	4.0	
50	0.10	0.20	2.0	
30			1.0	
Lit.	(25)	(64, 68)	(26)	(25, 63, 64, 68)

TABLE 11.—ATOMIC IONIZATION RELATIVE TO AIR

If C_r = coefficient of molecular ionization of the gaseous compound $F_f G_g H_h$ relative to air, and $E_r = E_i/E_{ia}$, where E_{ia} = value of E_i for air, then, in many cases, quite approximately $C_r = fc_f + gc_g + hc_h$ and $E_r = fe_f + ge_g + he_h$, where c_f, c_g, c_h and e_f, e_g, e_h are numbers characteristic of the several constituent species of atoms. The c's are called the atomic ionization relative to air. The atomic stopping power is ec.

Atom	α-particles; Ra		β-rays; U-X	γ-rays	γ, Zn*
	e	c	c	c	c
Br	0.685	1.72	2.67	2.81	4.71
C	0.894	0.51	0.46	0.46	0.44
Cl	0.676	1.16	1.44	1.44	1.50
H	0.754 1.14†	0.17_5 0.11_6†	0.18	0.18	0.18
I	0.658	2.26	4.10	4.50	10.88
N	1.05	0.47	0.47_5	0.45	0.41
Ni				1.82	2.56
O	0.962	0.55	0.58	0.58	0.57
S	0.603	1.24	1.60	1.60	1.48
Lit.	(38)	(38)	(37)	(37)	(37)

* Secondary rays from Zn. † Pure atomic H.

TABLE 12.—RELATIVE MOLECULAR IONIZATION OF GASES BY γ-RAYS AND X-RAYS

See also Table 13. $n_r \equiv n/n_a = C_r p T_a / p_a T$; n_a, p_a, T_a refer to air. $E_r = (E_i)_{\text{gas}}/(E_i)_{\text{methyl acetate}}$. R_{sec} = relative amount of secondary radiation emitted by the gas. Soft X-rays are those stopped by 0.3 mm Pb; hard X-rays are those which pass through 0.3 mm Pb (45).

Gas	γ-rays, C_r						X-rays				
	Primary			Secondary			C_r		R_{sec}	E_r	
	Ra	Ra	Ra	C	Pb	Zn	Hard	Soft		Hard	Soft
Air	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		
H_2	0.16$_9$	0.19	0.16$_0$	0.084	0.139	0.088	0.17$_7$*	0.10$_5$*			
								0.11$_4$†			
							0.18		0.12		
O_2	1.17		1.16	1.18	1.07	1.11	1.17*	1.30*			
								1.39‡			
SO_2§	2.13		2.27	2.49		2.17	4.79*	11.05*			
							2.3‖	7.97‖	4.10		
H_2S		1.23									
N_2O			1.55			1.34		1.47	1.53		
NH_3			0.90	0.92	0.91$_4$						
CO_2§	1.53		1.58	1.58	1.55	1.53	1.49	1.57			
							1.33*	1.46*			
								1.60†			
							1.33*		1.54*		
CCl_4	5.67	5.6	6.33	6.00	6.16	6.35	71.0	67.3	8.6	0.7	0.89
								45.3†			
CS_2			3.66	3.43	3.31	3.40					
$CHCl_3$	4.88	4.8	4.93	5.08		5.20		31.9†			
CH_3Br			3.81	6.47	5.83	6.15		71.0	215		
CH_3I	4.80	5.2	5.37	15.19	10.36	12.07	125	145	41.5	1.0	0.52
								72†			
C_2N_2	1.71										
C_2H_2				1.24		1.20					
C_2H_4O			2.17			2.16					
C_2H_5Br			4.63	6.30		6.05	118	72	217	0.7	0.86
C_2H_5Cl			3.19			3.39	17.3	18.0	3.2	1.00	0.61
C_2H_5I			6.47	15.60		12.46					
$C_3H_6O_2$¶							3.90	4.95	2.72	1.00	1.00
$C_4H_{10}O$¶			4.29	4.35	4.34	4.29					
C_5H_{12}¶			4.53		4.17	4.36					
$Hg(CH_3)_2$								425			0.69
$Ni(CO)_4$§			5.98			6.60	97	89	8.1	1.1	0.57
Lit.	(60)	(17)	(8)	(8)	(8)	(8)	All (12, 13) except as indicated.				

* (45). † (60). ‡ (48). ‖ (17). § *See also* Table 13. ¶ $C_3H_6O_2$ = methyl acetate, $C_4H_{10}O$ = ethyl ether, C_5H_{12} = pentane.

TABLE 13.—RELATIVE MOLECULAR AND TOTAL (I_r) IONIZATION OF GASES BY SECONDARY X-RAYS

See also Table 12. $n_r \equiv n/n_a = C_r p T_a / p_a T$; n_a, p_a, T_a refer to air. Unit of p = 1 mm of Hg

Gas	CO_2		SO_2		SeH_2
Radiator	C_r	I_r	C_r	I_r	I_r
Ag					231
As	1.510	0.91	11.73	1.22	
Cu	1.552	0.89	11.84	1.08	29.2
Fe	1.581	0.90	11.34	1.07	30.3
I					286
Mo	1.541	0.92	11.45	1.00	190
Ni	1.546	0.88	11.57	1.25	
Se	1.533	0.86	11.76	1.11	30.6
Sn					250
Sr	1.527	0.94	11.81	1.04	122
Zn	1.538	0.91	11.52	1.18	
Lit.	(49)	(49)	(49)	(49)	(1)

TABLE 14.—ENERGY (E_i) EXPENDED IN IONIZING GASES

For X-rays, Kulenkampff (41) finds $E_i = (5.56 \pm 0.79) \times 10^{-11}$ erg per ion-pair and independent of wave-length (λ) if $0.56 < \lambda < 2$ Å. At shorter wave-lengths others find $E_i = ae^{-b\lambda}$; for air $a = 2.2 \times 10^{-10}$ erg per ion-pair, $b = 5.08$ Å^{-1}. In the table, E_i = observed value from which V_i is computed by relation $E_i = eV_i$. Unit of λ = 1 Å; of $E_i = 10^{-11}$ erg per ion-pair; of V_i = 1 volt.

(1) X-rays; air

λ	E_i	V_i	Lit.	λ	E_i	V_i	Lit.
0.56	1.25	7.86	(7)	0.275	5.37*	33.7	(29, 40)
0.397	2.97*	18.6	(29, 40)	0.205	7.57*	47.5	(29, 40)
0.333	3.54*	22.2	(29, 40)	0.166	9.57*	60.1	(29, 40)
0.325	4.33	27.2	(7)				

* Published in arbitrary units and here reduced to basis of others by dividing by the empirical factor 3.50×10^{-11}.

TABLE 14.—(*Continued*)

(2) α-rays from Po (30)

Gas	E_i	V_i	Gas	E_i	V_i
A	3.8	24	N_2	5.25	33
H_2	4.9	31	Ne	4.12	25.9
He	4.17	26.2	O_2	4.86	30.5
Kr	3.43	21.5	Xe	3.12	19.6

TABLE 15.—IONIZATION OF GASES MIXED WITH VAPOR OF P (59)

The gas is in equilibrium with a liquid containing P. For column "*A*" the liquid is almond oil; for "*W*" it is H_2O. *See also* (28, 31, 47, 58).

Relative ionizations

Gas	A*	W*	Gas	A*	W*
Air	1.0	1.0	CO_2	59.6	28.7
H_2	48.2	15.3	N_2O		22.1
O_2	5.5	2.9			

* For air, the ionization over *W* is 2.16 times that over *A*; this ratio probably depends upon the relative amounts of P and upon its state of dispersion in the two liquids.

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ELECTRICAL RESISTANCE OF ELEMENTARY SUBSTANCES AT TEMPERATURES BELOW −80°C*

H. KAMERLINGH ONNES AND W. TUYN

As it is impracticable to determine the volume resistivity at very low temperatures, merely the ratio of the resistance of a given specimen at a given temperature to the resistance of the same specimen at 0°C is given; except that in a few cases the actual resistance of the specimen at each of a series of low temperatures is given, instead of its ratio. Extremely low temperatures are occasionally expressed in terms of the pressure of saturated helium vapor at the same temperatures; this is especially convenient for those cases in which a small change in temperature is accompanied by a great change in the resistance.

If the resistances of a number of impure specimens (1, 2, . . . *n* . . .) of the same metal, all of the same dimensions at 0°C, are measured at a series of temperatures, and if the observations are plotted in rectangular coordinates (R_{nt} *vs.* t) and are connected by smooth curves, a curve for every specimen, then it is found (133) that these curves differ, roughly, solely by a displacement parallel to the axis of R, and that the purer the specimen the more nearly does its resistance approach zero as t approaches the absolute zero. The composite curve obtained by displacing these curves parallel to the axis of R until they all pass through the point $R = 0$ at the absolute zero is called the curve corresponding to a specimen of the metal of "ideal" purity and condition, and of the same dimensions at 0°C as the actual specimens. If the resistances corresponding to the points upon this "ideal" curve be denoted by R_{it} and if $p_n x_n$ is the displacement which makes the curve corresponding to specimen n coincide with the "ideal" curve, then

$$R_{x_n t} = R_{it} + p_n x_n$$

If x_n is the percentage of admixed impurity, p_n has a large value which, over a certain temperature range, is independent of t, but depends upon the nature and the amount of the impurity, and upon the state, or condition, of the specimen (133).

Expressions which are independent of the actual dimensions of the specimens may be obtained by dividing each equation by the

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* Published in somewhat greater detail in (141).

Rosse (24) that $i_l - i_d = C\sqrt{I}$, provided I is neither very small nor extremely great; here b and C are independent of I but dependent upon λ and other physical parameters. For dependence of i_l upon duration of illumination, *see* (3, 10, 16, 29); for a more complete bibliography of the entire subject, *see* (5, 12, 23).

TYPICAL DATA FOR SELENIUM BRIDGES

Annealed Bridge of the Braun Condenser Type (16). Useful area = 151 mm²; thickness = 0.1 to 0.2 mm. Unit of $\lambda = 1 m\mu = 10^{-7}$ cm; of $I_\lambda = 10^{-8}$ watt/mm²; of $V = 1$ volt; of i_d, $i_l = 10^{-5}$ ampere.

λ	I_λ	V	i_d	$i_l - i_d$	V	i_d	$i_l - i_d$
451	2.83	5.60	15.7	1.09	11.03	34.9	2.23
529	4.07	5.60	15.6	1.76	11.02	34.7	3.56
674	3.68	5.35	14.7	4.26	10.70	33.8	9.78

Crystal Bridge (19). Useful area = 132 mm²; thickness = 0.2 to 0.3 mm; illumination by gas-filled tungsten (W) lamp, total unfiltered radiation; $I = 0.5$ phot. = 0.5 lumen/cm² = 5000 m-candle = 464 ft. candle. Unit of $V = 1$ volt; of i_d, $i_l = 1$ ampere.

V	i_d	$i_l - i_d$	V	i_d	$i_l - i_d$
2.0	1.11×10^{-4}	1.80×10^{-4}	20.0	1.43×10^{-3}	1.56×10^{-3}

Tellurium.—Some observers, neglecting effects due to the high thermoelectric power of Te with respect to other metals, have concluded that the resistivity of Te is affected by illumination. Careful investigation shows that this conclusion is incorrect (18). The absence of such an effect is in agreement with a recent interpretation of the low resistivity of Te (17).

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THE ELECTRICAL CONDUCTIVITY OF PURE NON-METALLIC LIQUIDS[1]

J. R. PARTINGTON

Abbreviations.—"Non." = a "non-conductor." κ = conductivity in ohm⁻¹cm⁻¹.

Elementary Substances* and Atmospheric Air; 𝔄-Table

Substance	*t*, °C	κ = A × 10⁻ⁿ A	n	Lit.
Br	17.2	13	14	(36); *cf.* (122, 144); Fig. 6
Cl	−70(?)	<1	16	(81)
I	110	13	11	(36, 143); *cf.* Fig. 6
P	25	4	7	(37, 38); *cf.* Fig. 7
S	115	1	12	(37)
	130	5	11	(135)
	440	12	8	(87)
Se	*v.* p. 141			
Air		*ca.* 0		(27)
Air under Ra rays		13	15	(27)

* Except data below −80°C, for which *v.* p. 124.

Chemical Compounds, 𝔅-Table

Standard arrangement; *v.* Vol. III, p. viii

Substance	*t*, °C	κ = A × 10⁻ⁿ A	n	Lit.
H_2O	18	4	8	*v.* p. 152
HCl	−96	1	8	(2)
HBr	−80	8	9	(1)
HI	B. P.(?)	2	7	(114)
SO_2; *cf.* (18, 19, 31, 132, 133)	−15	9*	8	(34)
	(?)	<5	8	(13)
	35	15	8	(4)
SO_3		"Non."		(122)
H_2S	B. P.(?)	1	11	(96.5); *cf.* (114)
H_2SO_4	25	1	2	(7); *cf.* (48)

𝔅-Table.—(*Continued*)

Substance	*t*, °C	κ = A × 10⁻ⁿ A	n	Lit.
S_2Cl_2	25	"Non."		(122)
$SOCl_2$	25	2	6	(122)
SO_2Cl_2	25	3	8	(124)
SO_2OHCl	25	16	5	(123)
$SeOCl_2$	25	2	5	(64)
$SeOBr_2$	45 to 50	6	5	(78)
NH_3; *cf.* (18, 19)	−33	<1	8	(39, 40)
	−79	13	8	(41)
$2H_3PO_4.H_2O$		*ca.* 1	2	(97)
PCl_5		> "Non."		(122)
$POCl_3$	25	22	7	(122)
PBr_5		"Non."		(122)
$AsCl_3$	25	12	7	(124)
$AsBr_3$	35	15	7	(123)
$SbCl_3$	75(?)	85	8	(73)
$SbCl_5$		"Non."		(122)
Sb_2S_3	See Fig. 8			(75)
Carbon compounds, *v. infra.*				
$SiCl_4$		"Non."		(122)
$Si(OCH_3)_4$	25	16	7	(84)
$Si(OC_2H_5)_4$	25	<3	8	(84)
$GeBr_4$	30	78	6	(30)
$SnCl_4$		"Non."		(122)
OsO_4	40(?)	<1	11	(134.5)
$Ni(CO)_4$		1	9	(85)
BCl_3		"Non."		(122)
$B(OCH_3)_3$	0	5	6	(127)
	25	6	6	
NaOH, KOH	400 to 600			(3)

* Probably high.

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[1] Except fused salts, for which *see* p. 147.

Carbon Compounds; ℭ-Table; *v.* Vol. III, p. viii

Natural oils at end of table; for anisotropic liquids, *v.* (116)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$		Lit.
			A	*n*	
$CBrN$	Cyanogen bromide	55	*ca.* 2	2	(43)
CCl_4	Carbon tetrachloride	18	4	18	(8); *cf.* (55)
CCl_2O	Carbonyl chloride	25	7	9	(42.5)
CN_4O_8	Tetranitromethane		"Non."		(127)
CS_2	Carbon disulfide	18	78	19	(8); *cf.* (55, 76, 97.2)
$CHBr_3$	Bromoform	25	< 2	8	(93)
$CHCl_3$	Chloroform	25	< 2	8	(93); *cf.* (126)
CHN	Hydrogen cyanide	0	33	7	(129); *cf.* (18, 19, 22, 68)
CH_2O_2; *cf.* (17, 91, 105, 107, 129)	Formic acid	18	56	6	(106)
		25	64	6	
CH_3I	Methyl iodide	25	< 2	8	(93); *cf.* (101)
CH_3NO	Formamide	0	18*	6	(127)
		19	18*	5	(129)
		25	4	6	(70)
CH_3NO_2	Nitromethane	0	44	8	(125)
		18	6	7	(12); *cf.* (26, 95)
		25	54	8	(125)
CH_3NO_3	Methyl nitrate	25	45	7	(93)
CH_4O; *cf.* (18, 19, 60, 61, 98, 102, 115, 121)	Methyl alcohol	(?)	4	8	(51.5); *cf.* (62)
		18	44	8	(117)
		20	58	7	(108)
		25	22	8	(133.5); *cf.* (127)
CH_5N	Methylamine		*ca.* 7	7	(38.5)
C_2N_2	Cyanogen		< 7	9	(22)
C_2HBr_3O	Bromal	25	8	8	(99)
$C_2HCl_3O_2$	Trichloroacetic acid	25	3	9	(69); *cf.* (97.1)
		60	62	10	(70)
C_2H_2	Acetylene		"Non."		(82)
$C_2H_2Br_2O$	Bromoacetyl bromide	0	73	8	(124)
$C_2H_2Cl_2O_2$	Dichloroacetic acid	0	4	8	(97.1)
		25	7	8	
C_2H_3BrO	Acetyl bromide	0	2	6	(127)
		25	24	7	(127)
C_2H_3ClO	Acetyl chloride	0	35	8	(127)
		25	4	7	(127)
$C_2H_3ClO_2$	Chloroacetic acid	60	14	7	(70)
C_2H_3N	Acetonitrile	0	1	6	(125); *cf.* (100)
		20	7	6	(42)
		25	19	8	(127)
C_2H_3NO	Glycolic nitrile	0	52	7	(125)
		25	83	7	
C_2H_3NS	Methyl thiocyanate	0	13	7	(130); *cf.* (65)
		25	15	7	
C_2H_3NS	Methyl isothiocyanate†	50	3	7	(125)
$C_2H_4Cl_2$	1, 1-Dichloroethane	25	<17	9	(101)
$C_2H_4Cl_2$	Ethylene chloride	25	3	8	(131)
$C_2H_4Br_2$	Ethylene bromide	19	< 2	10	(42)
C_2H_4O	Acetaldehyde	0	14	7	(125, 127)
		15	17	7	(127)
		20.5	55	7	(42)
$C_2H_4O_2$; *cf.* (46, 49, 58, 69, 70)	Acetic acid	0	5	9	(97.1)
		18	5*	7	(54)
		25	11.2	9	(97.1)
		30	8	9	(54)
		40	14*	8	(54)
		(?)	8	10	(14.5)
$C_2H_4O_2$	Methyl formate; *see* Fig. 3				
C_2H_4OS	Thioacetic acid	0	39	7	(127)
		25	27	7	
C_2H_5Br	Ethyl bromide	25	< 2	8	(93)
C_2H_5I	Ethyl iodide	25	< 2	8	(93)
C_2H_5NO	Acetamide	100	<43	6	(134); *cf.* (6.5)
$C_2H_5NO_3$	Ethyl nitrate	0	23	8	(127); *cf.* (101); *see also* Fig. 2)
		25	53	8	
C_2H_6O; *cf.* (18, 19, 26, 44, 61, 62, 63, 66, 76, 92, 117, 119, 120)	Ethyl alcohol	0	15*	8	(127)
		18	64*	9	(121)
		25	135	11	(28)

* Probably high.

ℭ-Table.—(*Continued*)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$		Lit.
			A	*n*	
$C_2H_6O_2$	Glycol	0	24	8	(127)
		25	3	7	(130)
$C_2H_6O_4S$	Dimethyl sulfate	0	16	8	(127)
		25	3	7	
$C_2H_6N_2O$	Dimethylnitrosamine	0	12	6	(127); *cf.* (129)
		25	16	6	
C_2H_7N	Ethylamine	−33.5	46	9	(35)
		0	4	7	(113)
C_3H_4O	Acrolein (not quite pure; had an acid reaction)	10	16	8	(89)
C_3H_5ClO	Epichlorohydrin	25	34	9	(127); *cf.* (26, 112)
$C_3H_5ClO_2$	Ethyl chloroformate				(5)
C_3H_5N	Propionitrile	25	< 1	7	(125); *see* Fig. 6
C_3H_5NO	Lactonitrile(α-hydroxypropionitrile)	0	18	8	(127)
		25	31	8	
C_3H_5NS	Ethyl isothiocyanate	0	87	9	(127)
		25	126	9	
C_3H_5NS	Ethyl thiocyanate	25	12	7	(127)
$C_3H_6Cl_2O$	Dichlorohydrin	25	12	6	(101)
C_3H_6O; *cf.* (26, 42, 112)	Acetone	−15	11	10	(130)
		0	6	8	(61)
		18	2	8	(32)
		20	12*	8	(108)
		25	6	8	(69, 70)
C_3H_6O	Allyl alcohol	25	7	6	(80)
C_3H_6O	Propionaldehyde	0	7	7	(125); *cf.* (26)
		25	85	8	
$C_3H_6O_2$	Ethyl formate, *see* Fig. 2				
$C_3H_6O_2$	Methyl acetate	25	34	7	(93); *cf.* Fig. 3
$C_3H_6O_2$	Propionic acid	25	< 1	9	(70)
$C_3H_6OS_2$	Ethyl xanthogenate(?)	25	< 2	8	(93)
C_3H_7Br	*n*-Propyl bromide	25	< 2	8	(93)
$C_3H_7ClO_2$	Chlorohydrin	25	5	7	(101)
C_3H_8O	*n*-Propyl alcohol	18	5	8	(32); *cf.* (59, 104)
		25	2	8	(72)
		25	9	9	(11)
C_3H_8O	Isopropyl alcohol	25	35	7	(101)
$C_3H_8O_3$	Glycerol	25	64	9	(29); *cf.* (20, 47, 108, 109)
C_3H_9N	Trimethylamine	−33.5	22	11	(35)
$C_4H_4N_2$	Succinonitrile	60	15	7	(125)
$C_4H_5Cl_3O_2$	Ethyl trichloroacetate	25	3	8	(97.1); *cf.* (5)
$C_4H_5NO_2$	Methyl cyanoacetate	0	3	7	(127); *see* Fig. 7
		25	45	8	
C_4H_5NS	Allyl isothiocyanate	25	25	6	(84); *cf.* (65)
$C_4H_6Cl_2O_2$	Ethyl dichloroacetate	25	7	8	(97.1); *cf.* (5)
$C_4H_6O_3$	Acetic anhydride	0	1	6	(125)
		20	75*	8	(108)
		25	48	8	(127)
$C_4H_7ClO_2$	Ethyl chloroacetate	25	2	7	(97.1); *cf.* (80)
C_4H_7N	*n*-Butyronitrile	25	12	6	(33)
$C_4H_8Br_2$	Butylene bromide	25	< 2	8	(93)
C_4H_8O	Methyl ethyl ketone	25	1	7	(95)
$C_4H_8O_2$	Ethyl acetate	25	< 1	9	(69, 71); *cf.* (101)
$C_4H_8O_2$	Propyl formate; *see* Fig. 1				
$C_4H_8O_2$	Methyl propionate; *see* Fig. 3				
$C_4H_9NO_3$	Isobutyl nitrate	25	< 2	8	(93); *see* Fig. 1
$C_4H_{10}O$	Ether	25	< 4	13	(97.2); *cf.* (18, 19, 21, 42, 76, 124)
$C_4H_{10}O$	Isobutyl alcohol	18	< 1*	7	(32); *cf.* (101)
		25	8	8	(131)
		25	95	10	(11)
$C_4H_{10}O_3S$	*asym.*-Diethyl sulfite	0	3	7	(127)
		25	5	7	
$C_4H_{10}O_3S$	*sym.*-Diethyl sulfite	0	2	7	(127)
		25	4	7	
$C_4H_{10}O_4S$	Diethyl sulfate	0	16	8	(127)
		25	26	8	
$C_4H_{11}N$	Diethylamine	−33.5	22	10	(35)

† In the original, the compound in question is called "methylene mustard oil," and the formula "CN.CNS" is given. The boiling point (117°) indicates, however, that the liquid is probably methyl mustard oil.

ℭ-Table.—(*Continued*)

Formula	Name	*t*, °C	$\kappa = A \times 10^{-n}$		Lit.
			A	*n*	
$C_5H_4O_2$	Furfural	0	97	8	(127)
		20	11	7	(108); *cf.* (101)
		25	15	7	(127)
		25	16	8	(128)
$C_5H_4O_3$	Citraconic anhydride	0	1	7	(127)
		25	2	7	
C_5H_5N; *cf.* (51, 52, 80, 96)	Pyridine	0	57*	9	(94)
		18	53	9	(32)
		25	< 5	8	(79)
		25	68	9	(50)
$C_5H_7NO_2$	Ethyl cyanoacetate	0	19	8	(127); *cf.* (80)
		25	19	8	
$C_5H_8O_2$	Acetylacetone	0	2	7	(127)
		25	3	7	
$C_5H_8O_4$	Dimethyl malonate	0	8	8	(127)
		25	12	8	
C_5H_9N	Valeronitrile	25	57	7	(101)
C_5H_{10}	Amylene (fusel amylene)	25	< 2†	8	(93)
$C_5H_{10}O$	Isovaleraldehyde	0	8	8	(125)
		25	10	8	
$C_5H_{10}O$	Methyl propyl ketone	25	1	6	(80)
$C_5H_{10}O_2$	Ethyl propionate; *see* Fig. 2				
$C_5H_{10}O_2$	Isovaleric acid	80	< 4	13	(97.2)
$C_5H_{10}O_2$	Isobutyl formate; *see* Fig. 1				
$C_5H_{10}O_2$	Methyl butyrate; *see* Fig. 3				
$C_5H_{10}O_2$	Propyl acetate; *see* Fig. 1				
$C_5H_{10}O_3$	Diethyl carbonate	25	17	9	(101)
			See also Fig. 2		
$C_5H_{11}Br$	Isoamyl bromide	25	< 2	8	(93)
$C_5H_{11}I$	Amyl iodide	25	35	7	(93)
$C_5H_{11}N$	Piperidine	25	< 2	7	(80)
$C_5H_{11}NO_2$	Amyl nitrite	25	19	8	(80)
$C_5H_{11}NO_3$	Amyl nitrate	25	28	8	(101); *see* Fig. 3
C_5H_{12}	Pentane	19.5	< 2	10	(42)
$C_5H_{12}O$	Isoamyl alcohol	18	5*	8	(44); *cf.* (42, 96)
		20	4*	8	(108)
		25	15	9	(72)
$C_5H_{12}S$	Amyl hydrogen sulfide (amylmercaptan)	25	< 2	8	(93)
$C_5H_{13}N$	Isoamylamine	25	< 8	8	(67)
C_6H_5Br	Bromobenzene	25	< 2	11	(97.2); *cf.* (24, 101)
$C_6H_5NO_2$; *cf.* (14, 66, 86)	Nitrobenzene	0	5	9	(97.2)
		18	2*	7	(26)
		20	< 2	10	(42)
		25	< 2*	8	(93)
C_6H_6	Benzene		76	9	(15, 23, 55, 74, 76, 93, 111, 118, 126)
			< 1	18	
C_6H_6ClN	*m*-Chloroaniline	25	5	8	(100); *cf.* (131)
C_6H_6O	Phenol	25	<17	9	(101)
C_6H_7N	Aniline	0	9‡	9	(94)
		25	24	9	
		35	82	9	
C_6H_7N	Picoline	25	55	8	(101)
$C_6H_{10}O_3$	Ethyl acetoacetate	25	4	8	(66); *cf.* (45, 131)
$C_6H_{10}O_4$	Diethyl oxalate	25	76	8	(80); *cf.* (101)
$C_6H_{10}O_5$	Dimethyl malate	0	3	7	(127)
		25	55	8	(126)
$C_6H_{11}N$	Capronitrile	25	37	7	(101)
$C_6H_{11}NS$	Amyl thiocyanate	25	15	6	(65)
$C_6H_{12}O_2$	Amyl formate; *see* Fig. 3				
$C_6H_{12}O_2$	Ethyl butyrate; *see* Fig. 2				
$C_6H_{12}O_2$	Ethyl isobutyrate; *see* Fig. 2				
$C_6H_{12}O_2$	Isobutyl acetate; *see* Fig. 1				
$C_6H_{12}O_2$	Methyl valerate; *see* Fig. 3				
$C_6H_{12}O_2$	Propyl propionate; *see* Fig. 1				
$C_6H_{12}O_3$	Paraldehyde		<36	8	(80)
C_6H_{14}	Hexane	18	< 1§	18	(8); *cf.* (24, 56, 57, 111)
C_7H_5N	Benzonitrile	25	5	8	(131); *cf.* (79)
C_7H_5NS	Phenyl isothiocyanate	25	14	7	(84)
C_7H_6O	Benzaldehyde	18	17	8	(26)
		20	4	7	(42, 108)
		25	15	8	(26, 125)
$C_7H_6O_2$	Benzoic acid	125‖	3	9	(97.2)
$C_7H_6O_2$	Salicylaldehyde	0	1	7	(125)
		25	16	8	(80)
$C_7H_7NO_2$	*o*-Nitrotoluene	25	< 2	7	(80)
$C_7H_7NO_2$	*m*-Nitrotoluene	25	< 2	7	(80)
C_7H_8	Toluene		< 1	14	(23); *cf.* (76, 110, 111)
C_7H_8O	Benzyl alcohol	25	18	7	(80)
C_7H_8O	*m*-Cresol	25	<17	9	(101)
$C_7H_8O_2$	Guaiacol	25	28	8	(101)
C_7H_9N	Benzylamine	25	<17	9	(101)
C_7H_9N	*o*-Toluidine	25	< 2	6	(101)
C_7H_9N	*p*-Toluidine	100	62	9	(6)
$C_7H_{12}O_4$	Diethyl malonate		"Non."; *see* Fig. 2		(90)
$C_7H_{14}O_2$	Amyl acetate; *see* Fig. 3				
$C_7H_{14}O_2$	Ethyl valerate; *see* Fig. 2				
$C_7H_{14}O_2$	Propyl butyrate; *see* Fig. 1				
C_7H_{16}	Heptane		< 1	13	(24, 56)
C_8H_7N	Benzyl cyanide	0	1	7	(127); *cf.* (108)
		25	< 5	8	(131)
C_8H_7N	Tolunitrile	25	57	7	(101)
C_8H_8O	Acetophenone	16.5	21	8	(25); *cf.* (69, 80)
		25	6	9	(88)
$C_8H_8O_2$	*p*-Methoxybenzaldehyde (anisaldehyde)	0	8	8	(128)
		20	86	9	(108)
		25	12	8	(130)
$C_8H_8O_2$	Methyl benzoate; *see* Fig. 3				
C_8H_{10}	Xylene		< 1	15	(16); *cf.* (24, 76)
$C_8H_{10}O$	*o*-Cresyl methyl ether	25	<17	9	(101)
$C_8H_{10}O$	Phenetole	25	<17	9	(101)
$C_8H_{14}O_3$	Isobutyric anhydride	0	1	7	(125)
		25	16	8	
$C_8H_{14}O_4$	Diethyl succinate; *see* Fig. 2				
$C_8H_{16}O_2$	Caprylic acid	80	< 4	13	(97.2)
$C_8H_{16}O_2$	Amyl propionate; *see* Fig. 3				
$C_8H_{16}O_2$	Isobutyl butyrate; *see* Fig. 1				
$C_8H_{16}O_2$	Propyl valerate; *see* Fig. 1				
C_9H_7N	Quinoline	0	16	9	(94); *cf.* (101)
		25	22	9	
		50	74	9	
$C_9H_{10}O_2$	Ethyl benzoate	19	< 2	10	(42)
		25	< 1	9	(69, 70, 71)
$C_9H_{14}O_6$	Triacetin; *see* Fig. 4				
$C_9H_{18}O_2$	Amyl butyrate; *see* Fig. 3				
$C_9H_{18}O_2$	Isobutyl valerate; *see* Fig. 1				
C_9H_{20}	Nonane	25	<17	9	(101)
$C_{10}H_7Br$	Bromonaphthalene	25	4	11	(97.2)
$C_{10}H_8$	Naphthalene	82	4	10	(97.2); *cf.* (75)
$C_{10}H_{12}O_2$	Eugenol	25	<17	9	(101)
$C_{10}H_{14}$	Cymene	25	< 2	8	(93)
$C_{10}H_{16}$	*d*(*l*)-Limonene	18	3	12	(24)
		25	<17¶	9	(101)
$C_{10}H_{16}$	Pinene	23	< 2	10	(42)
$C_{10}H_{16}$	Terpinene	25	<17	9	(101)
$C_{10}H_{18}O$	Menthone	2	<17	9	(101)
$C_{10}H_{18}O$	α-Terpineol	25	<17	9	(101)
$C_{10}H_{18}O_2$	Acetylmethyl hexyl ketone	25	<17	9	(101)
$C_{10}H_{20}O_2$	Amyl valerate; *see* Fig. 3				
$C_{11}H_{12}O_2$	Ethyl cinnamate; *see* Fig. 2				
$C_{11}H_{12}O_3$	Ethyl benzoylacetate	0	7	8	(127)
		25	8	8	(125)
$C_{11}H_{14}O_2$	Isobutyl benzoate; *see* Fig. 1				
$C_{12}H_{14}I_3N$	Quinolinium *n*-propyl triiodide; *see* Fig. 5				
$C_{12}H_{16}O_2$	Amyl benzoate	25	<17	9	(101)
$C_{13}H_{16}I_3N$	Quinolinium butyl and isobutyl triiodide; *see* Fig. 5				
$C_{14}H_8O_4$	Alizarin	233	99**	−4	(75)
$C_{14}H_{10}$	Anthracene	230	3	10	(97.2); *see* Fig. 8
$C_{14}H_{12}O_2$	Benzyl benzoate	25	< 1	9	(70, 71)

---

* Probably high.

† $\kappa = 14 \times 10^{-14}$ under the influence of radium rays; "almost a perfect insulator when shielded from the rays" (27).

‡ No noticeable change in conductivity on darkening.

§ The conductivity of the liquid decreases when enclosed by a lead mantle (111).

‖ Other temperatures also.

¶ Probably high.

** With a polarisation of 1.5 volt.

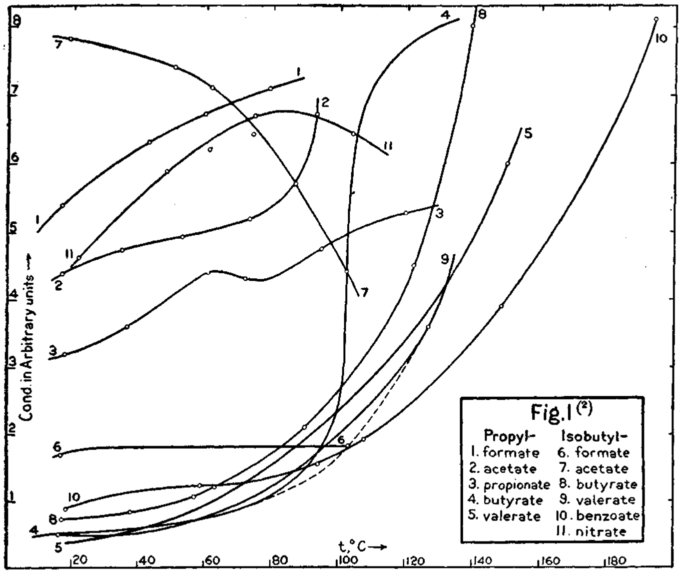
Fig.1 (2)
Propyl-
1. formate
2. acetate
3. propionate
4. butyrate
5. valerate
Isobutyl-
6. formate
7. acetate
8. butyrate
9. valerate
10. benzoate
11. nitrate
Cond. in Arbitrary units →
t,°C →
20
40
60
80
100
120
140
160
180

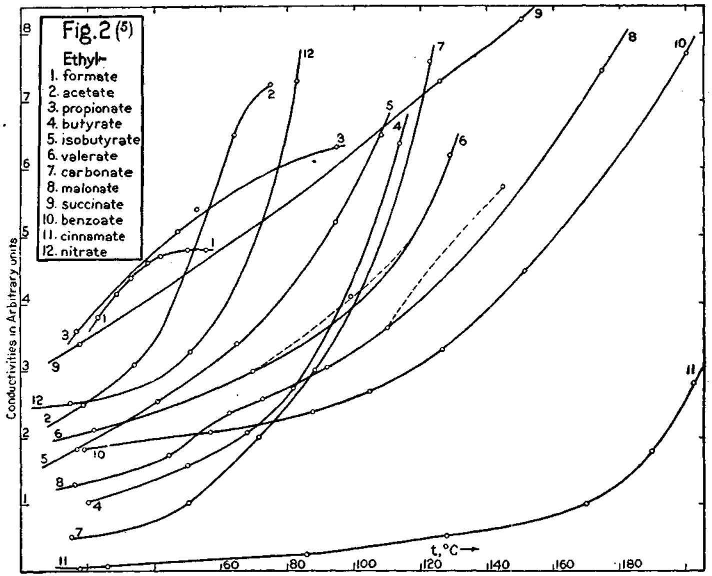
Fig.2 (5)
Ethyl-
1. formate
2. acetate
3. propionate
4. butyrate
5. isobutyrate
6. valerate
7. carbonate
8. malonate
9. succinate
10. benzoate
11. cinnamate
12. nitrate
Conductivities in Arbitrary units
t,°C →
60
80
100
120
140
160
180

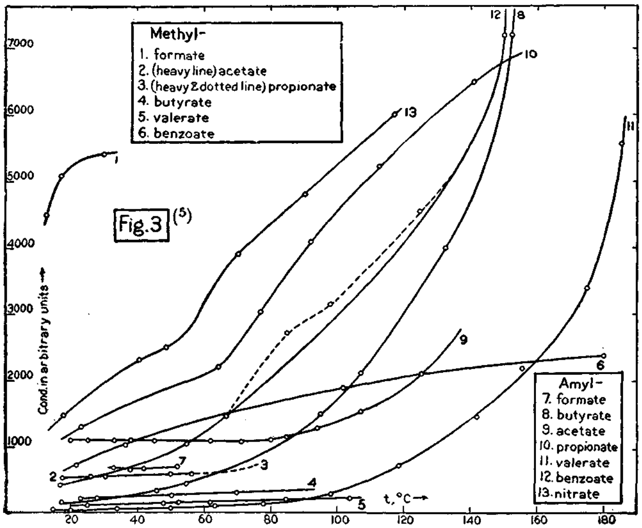
Fig.3 (5)
Methyl-
1. formate
2. (heavy line) acetate
3. (heavy & dotted line) propionate
4. butyrate
5. valerate
6. benzoate
Amyl-
7. formate
8. butyrate
9. acetate
10. propionate
11. valerate
12. benzoate
13. nitrate
Cond. in arbitrary units →
7000
6000
5000
4000
3000
2000
1000
t,°C →
20
40
60
80
100
120
140
160
180

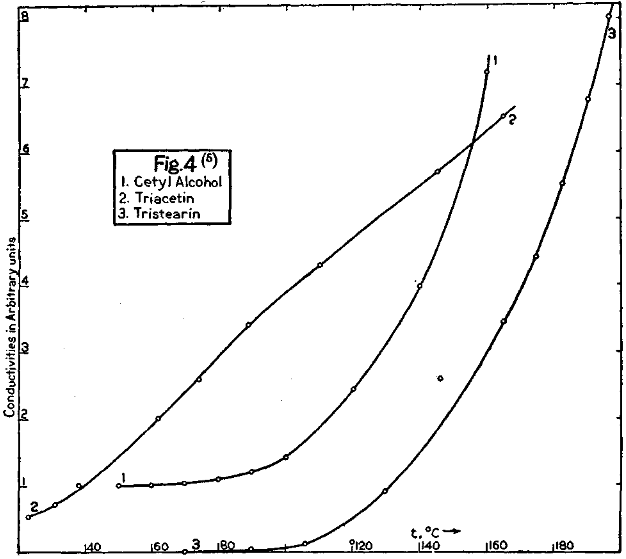
Fig.4 (5)
1. Cetyl Alcohol
2. Triacetin
3. Tristearin
Conductivities in Arbitrary units
t,°C →
140
160
180
120
140
160
180

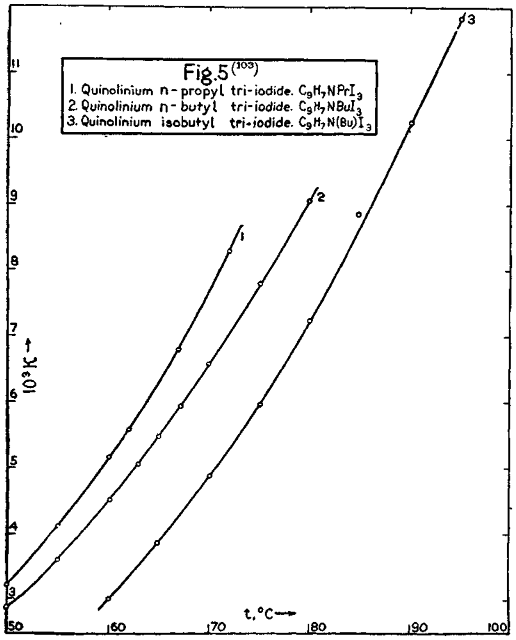
Fig.5 (103)
1. Quinolinium n-propyl tri-iodide. C9H7NPrI3
2. Quinolinium n-butyl tri-iodide. C9H7NBuI3
3. Quinolinium isobutyl tri-iodide. C9H7N(Bu)I3
10³ K →
t,°C →
50
160
170
180
190
100

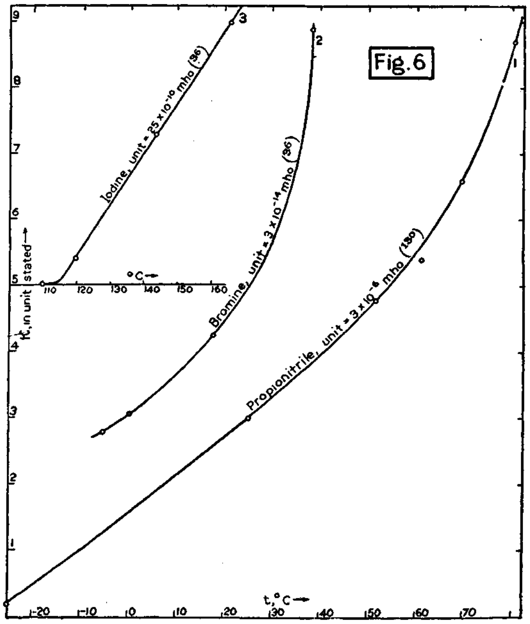
Fig.6
Iodine, unit = 2.5 × 10⁻¹⁰ mho (36)
Bromine, unit = 3 × 10⁻¹⁴ mho (36)
Propionitrile, unit = 3 × 10⁻⁶ mho (120)
K, in unit stated →
°C →
110
120
130
140
150
160
t,°C →
-20
-10
10
20
30
40
50
60
70

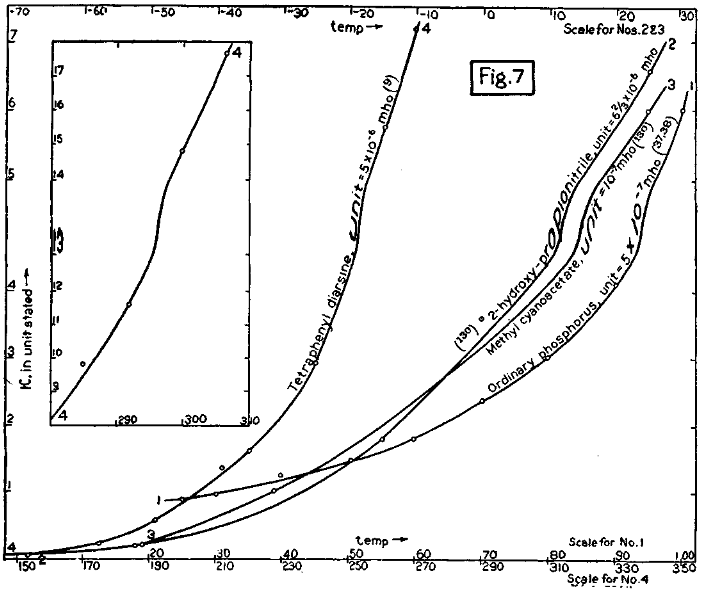
Fig.7

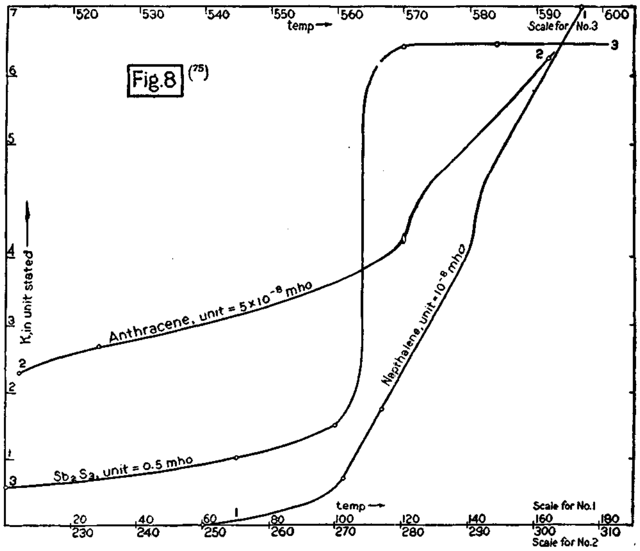
Fig.8 (75)

ℭ-Table.—(*Continued*)

Formula	Name	t, °C	$\kappa = A \times 10^{-n}$		Lit.
			A	n	
$C_{14}H_{15}N$.......	Dibenzylamine	25	17	9	(101)
$C_{16}H_{32}O_2$......	Palmitic acid	80	< 4	13	(97.2)
$C_{16}H_{34}O$.......	Cetyl alcohol; *see* Fig. 4				
$C_{18}H_{34}O_2$......	Oleic acid	15	< 2	10	(42)
$C_{18}H_{36}O_2$......	Stearic acid..........	80	< 4	13	(97.2)
$C_{24}H_{20}As_2$......	Tetraphenyldiarsine..	151.5	47	8	(9); *see* Fig. 7
$C_{57}H_{110}O_6$......	Tristearin; *see* Fig. 4				

Substance	t, °C	$\kappa = A \times 10^{-n}$		Lit.
		A	n	
Almond oil........	25			(76)
Benzine..........		< 1	12	(10, 27, 83, 111)
Castor oil.........				(76)
Kerosene.........		<17	9	(101)
Ligroin...........		59	17	(118)
Linseed oil........		1	16	(76)
Olive oil..........		1	13	(118); *cf.* (76)
Paraffin oil........		7	17	(118); *cf.* (53)
Petroleum........		3	13	(118)
Petroleum ether...		34	16	(118); *cf.* (27)
		1	18	(55); *cf.* (27)
Turpentine........		2	13	(83)
Vaseline (oil of)...		8	17	(118); *cf.* (27, 76, 83)

LITERATURE

(For a key to the periodicals see end of volume)

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(90) Mulliken, *11*, **15**: 523; 93. (91) Novák, *3*, **44**: 9; 97. (92) Partington, *4*, **99**: 1937; 11. (93) Patten, *50*, **6**: 554; 02. (94) Pearce, *50*, **19**: 14; 15. (95) Philip and Courtman, *50*, **97**: 1261; 10. (96) Polliack, *Diss.*, Lausanne, 1913. (96.5) Quam and Wilkinson, *1*, **47**: 989; 25. (97) Rabinovich, *93*, **129**: 60; 23. (97.1) Rabinovich, *7*, **119**: 59; 26. (97.2) Rabinovich, *7*, **119**: 70: 26. (97.5) Rabinovich, *7*, **119**: 79; 26. (98) Rimbach and Weitzel, *7*, **79**: 279; 12. (99) Sakhanov and Przheborovskii, *9*, **20**: 39; 14.

(100) Sakhanov and Rabinovich, *53*, **47**: 849; 15. (101) Sammis, *50*, **10**: 593; 06. (102) Schall, *7*, **14**: 701; 94. (103) Schall, *9*, **14**: 397; 08. (104) Schlamp, *7*, **14**: 272; 94. (105) Schlesinger and Calvert, *1*, **33**: 1924; 11. (106) Schlesinger and Coleman, *1*, **38**: 271; 16. (107) Schlesinger and Martin, *1*, **36**: 1589; 14. (108) Schmidt, *7*, **75**: 305; 11. (109) Schmidt and Jones, *11*, **42**: 37; 09.

(110) Schweidler, *8*, **4**: 307; 01. (111) Schweidler, *8*, **5**: 483; 01. (112) Shaw, *50*, **17**: 162; 13. (113) Shinn, *50*, **11**: 537; 07. (114) Steele, McIntosh and Archibald, *62*, **205**: 99; 06. *7*, **55**: 129; 06. (115) Stenquist, *9*, **12**: 860; 06. (116) Svedberg, *20*, **9**: No. 9; 13. (117) Tijmstra, *7*, **49**: 345; 04. (118) Trapesnikow, *242*, **57**: 227; 12. (119) Turner, *11*, **40**: 558; 08.

(120) Vignon, *34*, **148**: 844; 09. (121) Völlmer, *8*, **52**: 328; 94. (122) Walden, *93*, **25**: 209; 00. (123) Walden, *93*, **29**: 371; 02. (124) Walden, *7*, **43**: 385; 03. (125) Walden, *7*, **46**: 103; 03. (126) Walden, *25*, **38**: 345; 05. (127) Walden, *7*, **54**: 129; 06. (128) Walden, *7*, **55**: 683; 06. (129) Walden, *83*, **6**: 71; 10.

(130) Walden, *7*, **73**: 257; 10. (131) Walden, *7*, **78**: 257; 12. (132) Walden and Centnerszwer, *134*, **15**: 17; 01. (133) Walden and Centnerszwer, *7*, **39**: 513; 02. *93*, **30**: 145; 02. (133.5) Walden, Ulich and Laun, *7*, **114**: 275; 24. (134) Walker and Johnson, *4*, **87**: 1592; 05. (134.5) Wartenberg, *13*, **440**: 97; 24. (135) Wigand, *88*, **10**: 495; 08.

ELECTRICAL CONDUCTIVITY OF ELECTROLYTIC CONDUCTORS AT HIGH TEMPERATURES

E. B. Millard

The published values of the conductivities of compressed powders (p) are, in general, quite discordant; they are here included by literature reference only. The numerical data refer either to molten materials (l) or to solidified melts (s); in general, the latter form part of a continuous series including the former, but in some cases solid rods (r), either cast or machined from a solidified melt, were used. Some data refer to the undercooled melt; when so stated by the author, they are listed, like other molten materials, under l; in all other cases, data for temperatures below the melting point are taken as referring to a solid and are placed under (s). For compressed powders of metallic nitrides, *see* (68); for Auer mantle at 1200°C, *see* (66); for recent discussions, *see* (16, 20, 38, 60, 61, 62). Specific conductivity $= \kappa = C \times 10^n$ ohm^{-1} cm^{-1}; if $n = 0$, $\kappa = C$; t = temperature, °C; $\alpha(10)^{-3} = (R_t - R_0)/R_0t$, where R_0, R_t = resistance of same solid specimen at 0°C, at t, °C.

Im allgemeinen sind die veröffentlichten Werte über die Leitfähigkeit komprimierter Pulver (p) ganz widersprechend und werden nur durch die Literaturstellen angegeben. Die numerischen Daten beziehen sich entweder auf geschmolzenes Material (l) oder feste Schmelzen (s). Im allgemeinen sind letztere Bestandteile einer ununterbrochenen Serie die ersteren einschliessend, aber in manchen Fällen werden feste Stäbe (r) verwendet, die entweder gegossen oder aus einer festen Schmelze maschinell hergestellt wurden. Manche Daten beziehen sich auf unterkühlte Schmelzen. Ist dies vom Autor angegeben, so stehen die Daten wie auch die anderen Schmelzen unter l. In allen anderen Fällen, bei einer Temperatur unterhalb des Schmelzpunktes werden die Daten als auf den festen Zustand sich beziehend angenommen und stehen dann unter (s). Für gepresste Pulver von Metallnitriden, *siehe* (68); für Auerstrümpfe bei 1200°C, *siehe* (66); neuere Diskussionen darüber, *siehe* (16, 20, 38, 60, 61, 62). Spezifische Leitfähigkeit $= \kappa = C \times 10^n$ Ohm^{-1} cm^{-1}; wenn $n = 0$, $\kappa = C$; t = Temperatur, °C; $\alpha(10)^{-3} = (R_t - R_0)/R_0t$, wo R_0,R_t = Widerstand einiger fester Formen bei 0°C bezw. t, °C bedeutet.

En général, les valeurs publiées concernant les conductibilités des poudres comprimées (p) sont tout à fait discordantes, aussi ne sont-elles mentionnées ici que par leur références bibliographiques. Les données numériques se rapportent soit à des matières fondues (l) soit à des matières fondues solidifiées (s); en général ces dernières constituent une partie d'une série continue comprenant les premières, mais dans certains cas il a été fait usage de baguettes solides (r) préparées soit par moulage soit par usinage à partir d'une masse fondue solidifiée Certaines données se rapportent à des liquides surfondus; lorsque cet état a été établi par l'auteur, ces données sont inscrites sous l comme pour les autres matières fondues; dans tous les autres cas, les données pour des températures au dessous du point de fusion se rapportent à un solide et sont placées sous (s). Pour les poudres comprimées des nitrures métalliques, *voir* (68); pour le manchon d'Auer à 1200°C, *voir* (66); pour les discussions récentes, *voir* (16, 20, 38, 60, 61, 62). Conductibilité spécifique $= \kappa = C \times 10^n$ ohm^{-1} cm^{-1}; si $n = 0$, $\kappa = C$; t = température, °C; $\alpha(10)^{-3} = (R_t - R_0)/R_0t$, où R_0, R_t = résistance de la même éprouvette solide à 0°C, à t, °C.

In generale i valori pubblicati delle conducibilità di polveri compresse (p) sono molto discordanti; essi sono qui inclusi solamente come citazione bibliografica. I valori numerici si riferiscono sia a materiali allo stato di fusione (l) o a sostanze fuse e lasciate solidificare (s); in genere queste ultime sono parte di una serie continua che include anche le precedenti, ma in alcuni casi furono usate bacchette (r) o preparate di getto o ricavate al tornio. Alcuni valori si riferiscono a sostanze mantenute liquide allo stato di soprafusione; quando l'affermazione è fatta dall'autore i valori sono inclusi nell'elenco dei materiali allo stato di fusione (l); in tutti gli altri casi invece i valori per temperature inferiori al punto di fusione sono supposti riferentisi allo stato solido e sono collocati sotto (s). Per le polveri compresse di azoturi metallici, *vedi* (68); per le reticelle Auer a 1200°C, *vedi* (66); per discussioni recenti, *vedi* (16, 20, 38, 60, 61, 62). Conducibilità specifica $= \kappa = C \times 10^n$ ohm^{-1} cm^{-1}; se $n = 0$, $\kappa = C$; t = temperatura, °C; $\alpha(10)^{-3} = (R_t - R_0)/R_0t$, dove R_0, R_t = resistenza dello stesso campione solido a 0°C e a t, °C.

I. Pure Substances

𝔄-𝔅-Table; Standard Arrangement

v. Vol. III, p. viii

Unit of $\kappa = 1$ ohm^{-1} cm^{-1}; temperature = t, °C; $\kappa = C \times 10^n$

$TeCl_2$ (64)

l, $n = -3$

t	C
206	42.0
210	45.8
221	58.9
230	66.8
235	71.2
250	89.3
252	90.4
271	113
271	114
290	133
304	150
305	151

$TeCl_4$ (64)

l, $n = -3$

t	C
236	114.5
254	136
277	161
290	175
316	203

NH_4NO_3 (23)

l, $n = 0$

t	C
162	2.794
185	2.183

(49)

t	C
172	0.320
187	0.369

NH_4NO_3.—*(Cont'd)*

t	C
202	0.397
213	0.447

$SbCl_3$ (13); *cf.* (37)

l, $n = -3$

t	C
73	0.11

$SbBr_3$ (31)

l, $n = -6$

t	C
99	244
109	261
127	317
158	364
178	405
197	446

SbI_3 (31)

l, $n = -6$

t	C
169	306
172	334
180	347
184	360
190	372
204	382
218	431
225	440
230	442
239	461
254	482
266	491
307	586
378	683

$BiCl_3$ (64)

l, $n = -3$

t	C
266	442
295	481

$BiCl_3$.—*(Cont'd)*

t	C
315	506
335	533
350	555

C, p (53)

$(CH_3)_2NH.HNO_3$*

t	C
74	178
78	187
89	210
98	234
112	259

$C_2H_5NH_2.HCl$*

t	C
100	50.5
110	60.1
122	71.6
130	79.3

*l, $n = -3$ (65).

†l, $n = -4$ (65).

$C_2H_5NH_2.HNO_3$*

t	C
25	23.0
43	39.8
53	50.2
70	67.7
78	75.2
90	87.9
101	98.7

$(C_2H_5)_2NH.HNO_3$*

t	C
100	75.9
105	80.5
116	89.1
125	96.5

$C_6H_5N(CH_3)_2.HBr$†

t	C
70	8.97
88	33.2
100	49.9
110	64.3
119	764

$ZrSiO_4$, *p* (44)

SnS (30)

$r, \alpha = -6.62$

$15° < t < 920°$

$\rho_0 = 1071$ ohm cm

PbO_2, *p* (55); *cf.* (21)

$PbCl_2$ (43, 49)

t	C
$l, n = 0$	
500	1.33
525	1.57
550	1.70
575	1.84
600	1.95
650	2.25
700	2.5

p (36)

$PbBr_2$ (43)

t	C
$l, n = -3$	
372	540
382	612
392	648
402	684
412	720
422	756
432	790
442	824
452	857
462	890
472	922
482	953
492	984

p (36)

PbS (30)

$r, \alpha = +5.01$

$-25° < t < 900°$

$\rho_0 = 0.000298$ ohm cm

$ThCl_4$ (64)

t	C
$l, n = 0$	
814	0.61
843	0.67
866	0.71
889	0.76
922	0.78

TlCl (58)

t	C
$s, n = -3$	
250	0.05
300	0.24
350	0.90
400	3.70
421	6.11
$l, n = 0$	
431	1.090
450	1.170
500	1.332
550	1.532
600	1.700

TlBr (58)

t	C
$s, n = -3$	
250	0.04
300	0.12
350	0.55
400	1.6
446.5	5.15

TlBr.—(*Cont'd*)

t	C
$l, n = 0$	
460	0.807
500	0.905
550	1.024
600	1.127

TlI (58)

t	C
$s, n = -3$	
250	0.10
300	0.39
350	1.02
400	2.73
429	4.80
$l, n = 0$	
439	0.528
450	0.551
500	0.651
550	0.747
600	0.840

s (24)

Tl_2S, *l, s* (46)

$ZnCl_2$ (15)

t	C
$s, n = -3$	
319	0.2
324	1.4
331	2.1
336	2.4
337	2.5
340	2.8
341	2.9
342	3.05
344	3.32
364	6.5
367	6.76
373	8.34
$l, n = -1$; *cf.* (23)	
373	0.083
402	0.153
460	0.509
500	0.838
542	1.43
581	2.10
612	2.55
650	3.12

$Zn(NO_3)_2.6H_2O$, *s* (34)

$CdCl_2$ (15)

t	C
$s, n = -2$	
534	0.07
543	0.4
554	1.2
$l, n = 0$	
576	1.925
581	1.92
591	1.92
595	1.95
597	1.97
623	2.01
635	2.06
636	2.04
660	2.14
668	2.12
692	2.17
721	2.23

$CdCl_2$.—(*Cont'd*)

t	C
750	2.32
755	2.30
795	2.37
801	2.37

$HgCl_2$ (31)

t	C
$l, n = -3$	
276	0.77

s (31)

$HgBr_2$ (31)

t	C
$l, n = -3$	
132	1.46

s (31)

HgI_2 (31)

t	C
$l, n = -3$	
253	11.76
260	8.48
263	7.94
288	7.14
298	6.94
320	6.62

s (31)

CuCl (15)

t	C
$s, n = -3$	
349	17
358	42
359	28
368	65
370	36
371	86
375	46
$n = 0$	
379	0.11
385	0.08
387	0.14
395	0.13
398	0.14
407	0.33
409	0.22
426	2.93
$l, n = 0$	
430	3.27
443	3.28
443	3.29
492	3.44
533	3.49
577	3.63

s (24)

CuBr, *s* (24)

CuI, *s* (24)

Cu_2S (19)

t	C
$l, n = 0$	
1120	76.22
1150	78.69
1200	83.30
1250	88.34
1300	94.10
1350	100.68
1400	108.25
1450	117.07
1500	127.17
1550	139.51

p (45, 59)

$Cu(NO_3)_2.6H_2O$, *s* (34)

AgCl (42, 58)

t	C
$s, n = -3$	
250	0.30
300	1.5
350	6.5
400	26
450	112
$l, n = 0$	
500	4.25*
550	4.35
600	4.45
650	4.55
700	4.65
750	4.8
800	4.9

p, s (10, 24, 40)

* ±0.05.

$AgClO_3$ (27)

t	C
$l, n = -3$	
200	321.9
210	352.7
215	367.6
220	382.9
230	413.4
240	444.4
250	474.3

AgBr (42, 58)

t	C
$s, n = -3$	
150	0.08
200	0.75
250	4.4
300	23
$n = 0$	
350	0.11
400	0.53
$l, n = 0$	
450	3.0*
500	3.1
550	3.2
600	3.3
650	3.3
700	3.4
750	3.5
800	3.6

p, s (10, 24, 40)

* ±0.01.

AgI (2, 42, 58)

t	C
$s, n = -3$	
142.4	0.333
145.0	*
$n = 0$	
146.5	1.308
150	1.33
200	1.57
250	1.78
300	1.97
350	2.14
400	2.28
450	2.41
500	2.52
550	2.64

AgI.—(*Cont'd*)

t	C
$l, n = 0$	
550	2.3†
600	2.35
650	2.4
700	2.45
750	2.5
800	2.6

s (24)

* Transition temp.

† ±0.1.

Ag_2S, *p* (45, 59)

$AgNO_3$ (27, 49)

t	C
$l, n = 0$	
200	0.65
225	0.75
250	0.85
275	0.95
300	1.06
325	1.16
350	1.27

s (48)

$Mn(NO_3)_2.6H_2O$, *s* (34)

FeS* (30, 39)

$r, \alpha = 7.98$

$0° < t < 100°$

$\rho_0 = 0.1114$ ohm cm

* ρ is greater for heating than for cooling.

FeS_2 (8)

$r, \rho_{20} = 1.513$ ohm cm

$FeO.TiO_2$ (39)

Ilmenite

$Co(NO_3)_2.6H_2O$, *s* (34)

$Ni(NO_3)_2.6H_2O$, *s* (34)

$MoCl_5$ (64)

t	C
$l, n = -6$	
216	1.8
234	4.1
258	7.5

WCl_5 (64); *cf.* (13)

t	C
$l, n = -6$	
250	0.67
255	0.84
260	0.97
265	1.09
270	1.22
275	1.35
280	1.49
285	1.62
290	1.70
295	1.77
300	1.84

WCl_6 (64); *cf.* (13)

t	C
$l, n = -6$	
280	1.98
285	2.13
290	2.28
295	2.44
300	2.60
305	2.85
310	3.11
315	3.38
320	4.05
325	5.13
330	6.94

UCl_4 (64)

t	C
$l, n = 0$	
570	0.34
598	0.42
620	0.48

$CbCl_5$ (17)

t	C
$l, n = -6$	
228*	0.22

* 220 to 235°.

$TaCl_5$ (17)

t	C
$l, n = -6$	
235*	0.3

* 230 to 240°.

$AlBr_3$ (18)

t	C
$l, n = -6$	
195	0.09
210	0.12
225	0.15
232	0.16
243	0.18
250	0.19
260	0.20
266	0.24

AlI_3 (18)

t	C
$l, n = -6$	
209	2.6
218	3.3
226	3.9
238	4.7
246	5.2
260	6.3
265	6.8
270	7.4

$ScCl_3$ (14); *cf.* (64)

t	C
$l, n = 0$	
959	0.51
969	0.55
981	0.57
991	0.59

Yt_2O_3, *p* (44)

$LaCl_3$ (64)

t	C
$l, n = 0$	
950	1.30
975	1.36
1000	1.42
1025	1.49
1050	1.56
1075	1.63
1100	1.70
1135	1.77

$PrCl_3$ (64)

l, n = 0

t	*C*
824	0.82
849	0.89
875	0.97
902	1.06
935	1.16
965	1.26

$NdCl_3$ (64)

l, n = 0

t	*C*
775	0.63
807	0.71
827	0.765
847	0.81
873	0.88
900	0.945

$BeCl_2$ (64)

l, n = −3

t	*C*
451	3.19
460	5.72
472	8.68

MgO (26)

r, n = −6

t	*C*
800	0.0_1
900	0.1_0
1000	0.2_0
1050	0.3_4
1100	1.0
1150	2.6

p (44)

$MgCl_2$ (15)

l, n = 0

t	*C*
729	1.05
743	1.08
772	1.105
774	1.13
822	1.23
830	1.21
884	1.32
909	1.39
941	1.45
959	1.455
997	1.53
1013	1.58

$CaCl_2$ (1, 2)

l, n = 0

t	*C*
800	1.9
850	2.1
900	2.3
950	2.5
1000	2.7
1050	2.8

$SrCl_2$ (1)

l, n = 0

t	*C*
900	1.98
950	2.14
1000	2.29
1050	2.43
1100	2.56

$BaCl_2$ (1)

l, n = 0

t	*C*
900	(1.71)
950	1.89
1000	2.05
1050	2.19
1100	2.31

s (63)

LiCl (15)

s, n = 0

t	*C*
577	0.15
592	0.16
595	0.25

l, n = 0

t	*C*
620	5.865
631	5.94
681	6.14
702	6.21
746	6.40
762	6.44
786	6.53
801	6.585

$LiNO_3$ (27, 33)

l, n = 0

t	*C*
250	0.80
275	0.92
300	1.06
325	1.19
350	1.33
375	1.46
400	1.59
425	1.72
450	1.86

p (9)

NaOH (4, 22); *cf.* (5)

l, n = 0

t	*C*
320	2.12
350	2.38
400	2.82
450	3.27

NaF, *s* (47)

NaCl (49)

l, n = 0

t	*C*
720	2.87
740	3.22
750	3.40
770	3.77
780	4.09

(1)

t	*C*
850	3.50
900	3.66
950	3.82

p, s (10, 35, 47, 57, 63)

NaBr (49)

l, n = 0

t	*C*
710	2.40
750	2.85
760	2.95
780	3.27
800	3.52

NaBr.—(*Cont'd*)

(2)

t	*C*
800	3.06
850	3.23
900	3.30

s (47, 57)

NaI (49)

l, n = 0

t	*C*
615	2.00
650	2.30
670	2.43
680	2.59
700	2.72

s (47)

Na_2SO_4 (1)

l, n = 0

t	*C*
900	2.23
950	2.37
1000	2.50
1050	2.64
1100	2.77

s (63)

$Na_2S_2O_3$ (41)

l, n = −3

t	*C*
0	6.9
5	10.8
10	15.9
15	22.4
20	30.4
25	39.3
30	49.7
35	62.0
40	75.8
45	90.8
50	106.1
55	123
60	141
65	160
70	180
75	201
80	222
85	244

$NaNO_3$ (33, 43)

l, n = 0

t	*C*
300	0.95
325	1.05
350	1.15
375	1.25
400	1.35
425	1.45
450	1.56
475	1.66
500	1.76

p, s (9, 57)

$NaNH_2$ (67)

l, n = 0

t	*C*
210	0.593

$NaPO_3$ (2)

l, n = 0

t	*C*
600	0.30
650	0.425
700	0.55

$NaPO_3$.—(*Cont'd*)

t	*C*
750	0.675
800	0.80
850	0.925
900	1.05
950	1.175
1000	1.30
1050	1.42
1100	1.54

Na_2CO_3 (1)

l, n = 0

t	*C*
850	2.92
900	3.10

$NaC_2H_3O_2$, (41)

Acetate

l, n = −3

t	*C*
0	3.95
5	6.2
10	9.3
15	13.2
20	18.0
25	23.5
30	30.5
35	38.5
40	46.7
45	56.0
50	66.0
55	77.0
60	89.0
65	101.0
70	113.5
75	126
80	139
85	152
90	166

$NaC_{16}H_{31}O_2$,

Palmitate (11)

l, n = −6

t	*C*
170	36.80
174	44.16
178	45.99
182	47.99
186	53.84
190	58.09
194	60.64
198	76.12

$NaC_{18}H_{31}O_2$ (12)

Linoleate

$NaC_{18}H_{33}O_2$ (12)

Oleate

$NaC_{18}H_{35}O_2$ (11)

Stearate

l, n = −6

t	*C*
158	29.84
162	38.06
166	50.18
170	55.75
174	59.99
178	61.32

Na_2MoO_4 (33)

l, n = 0

t	*C*
843	1.411
905.5	1.522
924.5	1.571
977	1.679
1026	1.775
1064.5	1.843
1122.5	1.940
1173	2.016
1217	2.093
1267.5	2.170
1306	2.232
1364	2.330
1408	2.403

Na_2WO_4 (33)

l, n = 0

t	*C*
752.5	1.091
800	1.192
958	1.519
996.6	1.598
1066	1.718
1161	1.893
1209	1.990
1260	2.083
1361.5	2.250
1412	2.335
1501	2.453

KOH, *l* (5)

KF (33)

l, n = 0

t	*C*
863.0	2.948
881.1	3.114
901.3	3.270
905.4	3.299
916.3	3.418
968.3	3.889
975.0	3.952

KCl (1, 2, 33, 49)

l, n = 0

t	*C*
775	2.23
800	2.34
825	2.44
850	2.55
875	2.65
900	2.76
925	2.86
950	2.97
975	3.07

p, s (9, 10, 40, 57)

$KClO_3$ (23)

l, n = 0

t	*C*
359	4.19

KBr (2, 33); *cf.* (49)

l, n = 0

t	*C*
750	1.61
775	1.67
800	1.72
825	1.79
850	1.84
(900)	(1.95)
(950)	(2.08)

s (57, 63)

KI (2, 33, 49)

l, n = 0

t	*C*
600	1.04
650	1.15
700	1.24
750	1.35
800	1.45

K_2SO_4 (1)

l, n = 0

t	*C*
1100	1.84
1150	1.94

KNO_3 (7, 23, 33, 43)

l, n = −3

t	*C*
(250)	(36_0)
(300)	(51_0)
330	602
340	634
350	664
360	694
370	724
380	754
390	784
400	816
410	848
420	876
440	937
460	996
480	1055
500	1116

KNH_2 (67)

l, n = −3

t	*C*
340	389

K_2CO_3 (1)

l, n = 0

t	*C*
900	1.95
950	2.12
1000	2.26

$KC_{16}H_{31}O_2$ (11)

Palmitate

l, n = −6

t	*C*
182	55.75
186	64.94
190	67.32
194	69.85
198	72.63
202	73.58
207	75.09

$KC_{18}H_{31}O_2$ (12)

Linoleate

$KC_{18}H_{33}O_2$ (11)

Oleate

l, n = −6

t	*C*
200	45.05
204	50.18
208	52.57
212	55.20
218	58.70
222	59.34

$KC_{18}H_{35}O_2$ (11)

Stearate

t	C
l, n = −6	
224	110.4
226	122.7
228	138.0
230	169.8
232	184.0
234	256.6
237	315.4
239	368.0

K_2CrO_4, p (10)

$K_2Cr_2O_7$ (43)

t	C
l, n = −3	
397	196
407	220
417	238
427	256
437	275
447	293
457	311
467	329
477	347
487	366
497	384
507	402

RbCl (15)

t	C
l, n = 0	
733	1.49
765	1.58
769	1.59
780	1.62
819	1.70
839	1.74
873	1.81
915	1.87

$RbNO_3$ (33)

t	C
l, n = −3	
318.8	439
341.3	490
351.3	511
357.0	524
376.0	569
379.4	573
409.0	636
422.8	666
435.9	692
448.6	720
468.7	755
493	804

CsCl (15)

t	C
l, n = 0	
660	1.14
685	1.18
711	1.26
722	1.27
751	1.34
775	1.39
809	1.44
831	1.48

$CsNO_3$ (33)

t	C
l, n = −3	
446.6	594
472.7	634
490.2	656
498.0	670
510.1	685
525.3	705
541.7	723
556.3	744

II. Binary Mixtures

A-B-TABLE; STANDARD ARRANGEMENT

v. Vol. III, p. viii

M = mole, M % = mole %, Wt. % = weight %, m_A = mass of A, *l* = molten, *p* = compressed powder, *r* = solid rod, *s* solidified melt, κ = specific conductivity. Unit of κ = 1 ohm^{-1} cm^{-1}; *t* = temperature, °C; $\kappa = C \times 10^n$.

I

B = HgI_2 (31)

t	C
m_A = 10% m_B	
s, n = −3	
110	0.046
208	0.139
226	1.18
233	3.64
m_A = m_B	
s, n = −3	
165	0.14
206	0.645
227	1.05

$SbCl_3$

B = NH_4Cl, TlCl, RbCl, or KCl

l (37)

$SbBr_3$

B = $AlBr_3$

Wt. % A	C
t = 99.5°C (32)	
l, n = −6	
1.09	0.06
3.60	5.31
5.68	85.43
6.37	137.7
7.31	267.4

B = $AlBr_3$.—(*Continued*)

Wt. % A	C
8.75	483.5
9.85	714.8
n = −3	
14.15	1.647
15.27	1.924
19.33	2.884
22.31	3.601
25.58	4.267
29.91	5.348
35.10	6.331
40.00	7.303
45.59	8.248
47.98	8.607
49.52	8.982
55.28	9.894
60.19	11.646
65.29	13.212

t	C
Wt. % A = 15.27	
l, n = −3	
99.5	1.924
110.3	2.173
120.3	2.363
130.5	2.492
140.3	2.542
150.0	2.515
160.6	2.411

B = $AlBr_3$.—(*Continued*)

t	C
170.5	2.248
180.0	2.050
190.1	1.851
Wt. % A = 50.35	
99.5	9.135
110.3	11.62
120.3	13.16
130.5	15.35
140.3	17.58
150.0	20.11
160.6	23.22
170.5	25.43
180.0	27.70
190.1	29.58

$SnCl_2$

B = $PbCl_2$

p (9)

PbO_2

B = MnO_2

s (21)

$PbCl_2$

B = $PbBr_2$

M % B	C, 200°	C, 250°
r (50), n = −6		
0	50	140
15	34	90
30	22	75
40	16	54
50	12	40
60	17	67
70	38	102
85	46	223
100	81	274

M % B	C
t = 300°, n = −3	
0	0.60
15	0.40
30	0.25
40	0.23
50	0.21
60	0.24
70	0.34
85	0.58
100	0.86

Wt. % A	C
l (51), n = 0	
t = 500°C	
0.00	1.030
7.76	1.059
20.15	1.108
43.09	1.201
69.44	1.310
87.21	1.400
100.00	1.472

B = AgCl

M % A	C
r (50), n = −6	
t = 200°C	
0	50
15	65
30	86
40	104
50	92
60	75
70	65
80	32
100	13

Wt. % A	C
l (51), n = 0	
t = 500°C	
0.00	3.653
22.77	2.925
42.00	2.260
63.00	1.771
79.43	1.470
100.00	1.215

TlCl

B = $CdCl_2$

Wt. % A	C
l (51), n = 0	
t = 600°C	
0	1.971
20	1.808
35	1.781
40	1.665
50	1.566
53.7	1.522
60	1.520
75	1.564
85	1.610
90	1.664
100	1.702
t = 700°C	
0	2.101
20	1.990
35	1.950
40	1.857
50	1.789
53.7	1.718
60	1.720
75	1.760
85	1.818
90	1.860
100	1.951

$TlNO_3$*

B = $AgNO_3$*

Wt. % B	C
l (51), n = 0	
t = 250°C	
0	0.436
10	0.465
25	0.512
50	0.580
75	0.695
100	0.812

* In original, table headed TlCl and AgCl; column headed $AgNO_3$; as it is stated that Wt. % A = 50 is equivalent to M % A = 61.02, both salts were probably nitrates.

Cd*

B = $CdCl_2$

M % A	C
l (6), n = 0	
t = 580°C	
0	1.907
2.5	1.898
5.0	1.884
7.5	1.867
10	1.845
t = 600°C	
0	1.968
2.5	1.959
5.0	1.945
7.5	1.928
10	1.906
t = 620°C	
0	2.023
2.5	2.016

B = $CdCl_2$.—(*Continued*)

M % A	C
5.0	2.004
7.5	1.989
10	1.969

* Values for "commercial" products, 3.4, 7.2, and 11.5 M % A, at 10° intervals from 580 to 700°C are also given.

$CdCl_2$

B = KCl

Wt. % A	C
l (51), n = 0	
t = 800°C	
0	2.301
10	2.163
20	2.041
30	1.911
35	1.852
50	1.735
55	1.785
60	1.662
65	1.703
70	1.771
75	1.841
80	1.929
90	2.110
100	2.250
t = 900°C	
0	2.522
10	2.315
20	2.160
30	2.061
35	2.000
50	1.882
55	1.800
60	1.776
65	1.800
70	1.868
75	1.940
80	2.090
90	2.151
100	2.401

$HgBr_2$

B = $AlBr_3$

Wt. % A	C
l (32), n = −6	
t = 99.50°C	
1.38	0.121
3.06	0.439
5.52	8.851
8.14	148.94
10.48	601.74
n = −3	
14.26	1.9785
18.34	4.1683
21.11	5.8380
27.15	9.7988

B = $AlBr_3$.—(*Cont'd*)

$n = -6$

Wt. % A = 7.81

t	*C*
99.5	120.6
110.3	127.1
120.3	135.9
130.5	133.0
140.3	128.6
150.0	121.6
160.6	107.5
170.5	96.2
180.0	84.7
190.1	71.4

$n = -3$

Wt. % A = 14.38

t	*C*
99.5	2.051
110.3	2.369
120.3	2.583
130.5	2.772
140.3	2.892
150.0	2.943
160.6	2.867
170.5	2.786
180.0	2.668
190.1	2.454

Wt. % A = 21.08

t	*C*
99.5	5.814
110.3	7.002
120.3	8.061
130.5	9.059
140.3	10.01
150.0	10.73
160.6	11.32
170.5	11.77
180.0	11.94
190.1	11.96

CuO

B = MnO_2, *s* (21)

AgCl

B = AgBr

s (50), $n = -3$

M % B	*C*
t = 200°C	
0	0.05
10	0.08
30	0.13
40	0.16
50	0.20
60	0.23
70	0.32
80	0.38
90	0.42
100	0.46
t = 250°C	
0	0.20
10	0.35
30	0.66
40	0.92
50	1.26
60	1.56
70	2.10
80	2.31
90	2.40
100	2.60

B = AgBr.—(*Continued*)

M % B	*C*
t = 300°C	
0	1.09
10	1.68
30	3.50
40	5.52
50	7.01
60	8.17
70	10.8
80	11.9
90	12.9
100	14.0
t = 350°C	
0	5.20
10	5.49
30	16.8
40	22.0
50	32.0
60	37.0
70	42.5
80	52.0
90	58.5
100	64.2
t = 400°C	
0	24.0
10	31.8
30	57.0
40	75.3
50	120
60	140
70	164
80	235
90	272
100	304

t = 500°C

l (51), $n = 0$

Wt. % A	*C*
0.00	2.924
24.65	3.130
43.00	3.246
64.00	3.409
100.00	3.653

B = KCl, *p* (10)

MnO_2

B = KBr, *s* (21)

$AlBr_3$

B = KBr

t = 99.5°C (32)

l, $n = -3$

Wt. % B	*C*
11.02	16.33
12.65	18.53
13.07	19.14
15.44	21.95
16.84	23.62
18.46	25.46

Wt. % B = 13.07

t	*C*
99.5	19.14
110.3	23.60
120.3	27.02
130.5	29.14

B = KBr.—(*Cont'd*)

t	*C*
140.3	31.85
150.0	34.74
160.6	36.75
170.5	39.33
180.0	43.02
190.1	45.47

$CaCl_2$

B = NaCl

l (51), $n = 0$

Wt. % B	*C*
t = 850°C	
0.00	2.220
2.51	2.191
5.14	2.190
10.00	2.235
20.00	2.307
35.50	2.404
40.00	2.452
42.26	2.520
50.00	2.635
60.00	2.830
75.00	3.016
80.00	3.260
100.00	3.575
t = 950°C	
0	2.580
10	2.375
40	2.576
50	2.820
75	3.230
100	3.890

B = KCl

l (51), $n = 0$

t = 800°C	
0	2.006
10	1.772
20	1.620
25	1.554
30	1.501
35	1.477
40	1.478
45	1.480
50	1.492
60	1.550
70	1.708
80	1.951
100	2.301
t = 900°C	
0	2.405
10	2.090
20	1.893
25	1.835
30	1.730
35	1.699
40	1.702
45	1.700
50	1.766
60	1.852
70	1.973
80	2.195
100	2.522

LiCl

B = KCl

p (9)

$LiNO_3$

B = $NaNO_3$

p (9)

NaCl

B = KCl

l (51), $n = 0$

t = 850°C

Wt. % A	*C*
0	2.420
5	2.441
25	2.559
50	2.862
65	3.022
75	3.159
90	3.448
100	3.575

p (10)

$NaNO_3$

B = KNO_3

l (27), $n = 0$

t	*C*
$4M_A + 1M_B$	
321.6	0.9119
399.1	1.224
454.1	1.401

B = KNO_3.—(*Continued*)

t	*C*
$1M_A + 1M_B$	
320	0.7475
330	0.7890
340	0.8293
350	0.8680
360	0.9050
370	0.9410
380	0.9768
390	1.011
400	1.045
410	1.078
420	1.111
430	1.143
440	1.174
450	1.205
$1M_A + 4M_B$	
320	0.6318
330	0.6668
340	0.7015
350	0.7358
360	0.7705
370	0.8055
380	0.8393
390	0.8730
400	0.9053
410	0.9370
420	0.9678
430	0.9983
440	1.028
450	1.059

B = KNO_3.—(*Continued*)

l (51), $n = 0$

Wt. % A	*C*
t = 350°C	
0.00	0.670
17.38	0.740
45.16	0.872
71.10	1.030
100.00	1.170
t = 400°C	
0.00	0.818
17.38	0.900
45.16	1.030
71.10	1.221
100.00	1.371

See also (23)

KCl

B = KBr

s (57)

B = K_2CrO_4

p (10)

Permutite
Ag-, and Na-
s (28)

Permutite
Ag-Na, and Ag-K
s (29)

Cryolite mixtures
l (3)

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THE ELECTRICAL CONDUCTIVITY AND THE IONIZATION-PRODUCT OF H_2O

NIELS BJERRUM

ELECTRICAL CONDUCTIVITY

Ice (3)	t, °C	0	−4	−10	−19
	$10^{10}\kappa$, (mho)	280	23	11	2.6

Water.—The specific conductance of pure liquid H_2O (mho) at any temperature may be computed from the following equation using the appropriate value of p_w obtained from the tables which follow:

$$\log_{10} \kappa = [\log_{10} (\Lambda \times d) - 3 - \tfrac{1}{2}p_w],$$

where d is the density of water in g/ml and $\Lambda (= \Lambda_{H^+} + \Lambda_{OH^-})$ is the equivalent conductance for $H^+ + OH^-$, all at t, °C.

Example at 18°: $\log_{10} \kappa = \log_{10} (315.2 + 174)(0.9986) - 3 - 7.11 = 7.42$. $\kappa = 0.038 \times 10^{-6}$ mho, which may be compared with the directly measured value 0.042×10^{-6} for Kohlrausch and Heydweiller's "best" water.

IONIZATION PRODUCT

$K_w = [H^+] [OH^-]$; $[H^+]$ and $[OH^-]$ are the concentrations in moles per 1000 grams of water.

VALUES OF THE IONIZATION-EXPONENT OF WATER: $-\log_{10} K_w = p_w$*

t, °C	Calculated from the conductance of the purest water†	Calculated from the hydrolysis of salts of weak acids and weak bases: Ionization of the salt calculated from conductance		Activity-coefficient of the ions, f, calculated by means of the formula: $-\log_{10} f = 0.3.\sqrt[3]{C_i}$	
	(5, 6)	(9)	(4)	(9)	(4)
0	14.93		15.05		14.99
10	14.52	14.51		14.47	
15		14.34		14.30	
18	14.22		14.34		14.27
25	13.98	13.98	14.09	13.94	14.03
40		13.53		13.49	
50	13.25	13.29		13.25	
		(11)‡	(14)‡		
100		12.28			
156		11.57			
218			11.19		
306			11.46		

* pH in pure liquid $H_2O = \frac{1}{2}p_w - \log_{10} d$.

† The values in the table are calculated from the formula of Heydweiller (2): $-\log_{10} K_w = 6099.6/(273 + t) + 24.25 \log_{10} (273 + t) - 66.4678$.

‡ Recomputed to mole/1000 gram water.

Calculated from the potential of cells with hydrogen electrodes in acid and alkaline solutions

t, °C	Ion-concentrations calculated by means of conductance measurements				Activity-coefficients of the ions calculated on thermodynamical basis	
	(8)	(12)	(10)	(13)	(7)*	(1)†
0	14.87				14.945	14.926
18	14.15		14.13	14.14	14.239	14.222
25	13.92	13.91	13.89		13.998	13.980
30	13.76		13.72			
37			13.50		13.626	13.590
40	13.41		13.42			
50	13.06				13.273	
60	12.90					
70	12.67					
80	12.46					
90	12.37					
100					12.29	

* The potential measurements are made at 25°, and from the value of K_w at 25° the values at the other temperatures are calculated, using for the heat of neutralization $29\,210 - 53T$, which gives for K_w the following formula: $-\log_{10} K_w = 6384.7/(273.1 + t) + 26.676.\log_{10} (273.1 + t) - 73.424$

† Debye-Hückel square-root formula used as the limiting law for $C = 0$.

Best values

t, °C	p_w	t, °C	p_w
0	14.93	50	13.26
5	14.72	60	13.03
10	14.53	70	12.82
15	14.34	80	12.63
18	14.23	90	12.45
20	14.16	100	12.29
25	13.99	150	11.63
30	13.83	200	11.26
35	13.67	250	11.17
37	13.61	300	11.40
40	13.52	306	11.46
45	13.39		

Computed by means of the values in the foregoing tables. Below 100° the values from potential and hydrolysis determinations based upon dissociation computed from conductance data are not used. Of the other values the greatest weight is given to the potential determinations.

LITERATURE

(For a key to the periodicals see end of volume)

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(10) Michaelis, *Die Wasserstoffionenkonzentration.* Berlin, Springer, 1914. (11) Noyes and Kato, *152*, **No. 63**: 153; 07. (12) Poma and Tanzi, *7*, **79**: 55; 12. (13) Sörensen, *205*, **21**: 131; 09. (14) Sosman, *152*, **No. 63**: 193; 07.

ELECTRICAL RESISTIVITY OF (1) SINGLE CRYSTALS, (2) SOLID POOR CONDUCTORS (EXCEPT SALTS), (3) MIXTURES OF RARE EARTH OXIDES AND (4) LIQUID MIXTURES SUITABLE FOR HIGH RESISTANCES

G. M. J. Mackay

Salts (excepting conduction in single crystals), pure liquids, electrolytic solutions, and industrial materials, are specifically excluded from this section of the Tables; *v.* Index at end of Vol. VII.

In view of the large effect produced by traces of impurities, by variations in absorption, polarization, surface leakage, etc., the values given should be regarded, in most cases, as mere approximations. The resistivity of specimens of minerals from different localities may differ by several hundred fold.

For high frequency alternating current resistance, *see* (16, 17); for Hall effect, *see* (24, 27); for mixtures of oxides, *see* Table 3 and (42).

Table 1.—Electrical Resistivity (ρ) of Poor Conductors: Pure Substances

$\rho = A \times 10^n$; s = solid, l = liquid; $\bar{5}$ denotes -5; if $A = 7.8$ and $n = \bar{5}$, then $\rho = 7.8 \times 10^{-5}$. (In certain cases ρ_t can be computed by means of one of the following formulae: $\rho_t = \rho_0\{1 + at(10)^{-3}\}$; $\rho_t = \rho_0\{1 + \alpha t(10)^{-3} \pm \beta t^2(10)^{-6}\} e^{-qt/TT_0}$, $T[T_0]$ = absolute temperature corresponding to $t[0°C]$, $T_0 = 273.1°K$; if $t < 0°C$ use the minus sign before the β. Values of coefficients are given after numerical data.) Unit of ρ = 1 ohm cm = 0.3937 ohm in. Centigrade temperatures, °C.

Elementary Substances

B, Cast* (47)

t	A	n
0	1.8	6
600	1 *ca.*	0

Br (35)

t	A	n
−18.5	1.25	11

C, Diamond (44)

t	A	n
15	4.7 3.2	14 13 (2)
1030	> 1	7
1170	9.2	6
1250	4.4	6
1380	7.5	5

Ce (6)

t	A	n
18	7.8	$\bar{5}$

I (34)

t	A	n
4.1	1.13†	10
42.7	1.1†	8
111s	6.2	7 (5)
112l	1.4	3 (5)

La (7)

t	A	n
18	5.9	$\bar{5}$

Nd (6)

t	A	n
18	7.9	$\bar{5}$

P (18)

t	A	n
15s	8.4	10
42s	1.6	10
25l	2.3	6

Black P‡ (11)

t	A	n
0	1.000	0
50	6.62	$\bar{1}$
100	4.21	$\bar{1}$

Pr (6)

t	A	n
18	8.8	$\bar{5}$

S (18)

t	A	n
20	1.9	17 (15)
30	3.9	16 (15)
55	3.95	15
69	1.78	14
110	4.8	12
115l	9.5	11

See also p. 141

Se; *see* p. 141

Si, Crystalline (267)

t	A	n
	α–form	
−189	2.90	$\bar{1}$
− 30	1.13	$\bar{1}$
+ 15	9.0	$\bar{2}$
129	5.0	$\bar{2}$
210	3.9	$\bar{2}$

$\alpha = 3.682$, $\beta = -8.4$, $q = 800$

Si.—(*Continued*)

t	A	n
	β–form	
210	1.62	$\bar{1}$
435	8.5	$\bar{2}$
	γ–form	
440	1.00	$\bar{1}$
835	2.2	$\bar{2}$

$\alpha = 5.04$, $\beta = -3.1$, $q = 3000$

Te; *see* p. 142

Compounds; Standard Arrangement

v. Vol. III, p. viii

Bi_2O_3 (21)

t	A	n
225	2.34	8
424	1.44	5
645	6.01	3

SiO_2; *see* Table 2

TiO_2 (42)

t	A	n
915	11.73	3
1000	7.49	3
1320	4.40	2

SnO; $\rho <$ for SnO_2 (42)

SnO_2 (42)

t	A	n
785	6.56	3
1000	2.56	2
1320	1.01	1

SnAs (32)

t	A	n
− 81	7.97	$\bar{5}$
+ 25	4.97	$\bar{5}$
250	6.36	$\bar{5}$

Sn_2As_3 (32)

t	A	n
− 81	7.21	$\bar{5}$
+ 25	3.67	$\bar{5}$
250	6.32	$\bar{5}$

Sn_3As_2 (32)

t	A	n
− 81	8.58	$\bar{5}$
+ 25	6.43	$\bar{5}$
250	7.91	$\bar{5}$

PbO (21)

t	A	n
384	2.59	7
572	2.67	5
787	1.22	3

PbO_2§ (33)

t	A	n
0	9.08	$\bar{5}$

a = 0.6, if $22° \leq t \leq 84°C$

ZnO (42)

t	A	n
160	9.34	3
605	5.9	1
1000	2.60	0
1320	1.66	0

CdO (42)

t	A	n
785	6.73	3
1000	7.13	2
1200	3.26	1
1330	5.0	0

CuO (21)

t	A	n
12.2	2.12	6
265	3.55	3 (42)
463	1.67	2
750	2.08	0 (42)
1000	3.2	$\bar{1}$ (42)
1038	9.6	$\bar{2}$
1120	1.5	$\bar{1}$ (42)

MnO; $\rho <$ for Mn_3O_4 (42)

Mn_3O_4 (42)

t	A	n
560	2.01	3
695	3.50	2
1000	1.43	1
1280	7.2	$\bar{1}$

Fe_2O_3 (42)

t	A	n
570	6.24	3
700	10.38	2
1000	8.23	1
1015	6.84	1

Fe_3O_4 (42)

t	A	n
125	4.74	3
600	1.32	1
1000	2.17	0
1320	7.7	$\bar{1}$

NiO (42)

590	6.70	3
700	1.02	3
1000	1.44	2
1245	2.4	1

Cr_2O_3 (42)

345	12.65	2
750	7.8	1
1000	4.0	1
1215	2.13	1

WO, Blue; ρ very low (42)

WC (1)

25	1.2	$\bar{5}$

W_2C‖ (1)

25	8.1	$\bar{5}$
1382	1.05	$\bar{4}$
1942	1.25	$\bar{4}$

U_3O_8, ρ very low (42)

CeO_2 (42)

830	2.24	3
1000	2.13	2
1210	1.87	1

MgO (21)

t	A	n
471	2.71	8
933	2.4	5
1280	1.0	5
1341	2.25	6

CaO (21)

763	7.25	8
1011	2.06	7
1466	9.6	2

BaO (21)

307	1	6
355	1.66	4
497	2.17	1

Na_2O_2 (21)

20	2.5	4
109	6.0	3
284	1.0	3

* For B. ρ varies with emf (29).

† $\rho_t = \rho_0 e^{\lambda t}$; for I, λ = −0.126.

‡ Variation with pressure (11). Unit of P = 1000 kg/cm².

P	ρ/ρ_0		
	0°	50°	100°
0	1.000	0.662	0.421
1	0.796	0.521	0.323
2	0.643	0.406	0.250
4	0.372	0.239	0.1517
8	0.1079	0.0766	0.0542
12	0.0297	0.0238	0.0209

§ Electrolyzed crystalline plates.

‖ Carbonized W filaments.

TABLE 2.—ELECTRICAL RESISTIVITY (ρ) OF MINERALS AND OTHER SINGLE NON-METALLIC CRYSTALS

$\rho = A \times 10^n$; $\rho_t = \rho_0\{1 + at(10)^{-3}\}$; $\rho_t = \rho_0\{1 + \alpha t(10)^{-3} \pm \beta t^2(10)^{-6}\}e^{-qt/TT_0}$; $T[T_0]$ = absolute temperature corresponding to t[0°C], T_0 = 273.1°K; if t < 0°C use the minus sign before the β. ρ = ƒ (v) denotes that ρ varies with the emf. After the name of the mineral the crystal system to which it belongs is indicated. Iso = Isometric, regular, cubic system, $a = b = c$, $a \perp b \perp c \perp a$; Hex = Hexagonal $a_1 = a_2 = a_3 \overset{=}{\neq} c$, $c \perp$ plane of a_1, a_2, a_3; Orth = Orthorhombic, $a \neq b \neq c \neq a$, $a \perp b \perp c \perp a$; Mon = Monoclinic, $a \perp b \perp c$, a not $\perp$ c; Tri = Triclinic, three axes, no two mutually ⊥. These a, b, c are the crystallographic axes. In column (1) the direction of the current with reference to the crystallographic axes is indicated. Unit of ρ = 1 ohm cm = 0.3937 ohm in. Centigrade temperatures, °C.

Sb_2S_3, Stibnite (Orth)

	t	A	n	Lit.
$\parallel c$	17	36	6	(30)
$\parallel c$	37	2.28	6	(30)
	510	2.74	0	(26)
	570	0.25	0	(26)
	ρ = ƒ(v)			(38)

C, Diamond (Iso); *see* Table 1

SiO_2, Quartz (Hex)

$\parallel c$	20	1.18	14	(14)
$\parallel c$	26.5	2.0	22	(37)
$\parallel c$	100	8.18	11	(14)
$\perp c$	20	3.27	16	(14)
$\perp c$	26.4	4.3	24	(37)
$\perp c$	100	1.34	15	(14)
$\parallel c$	25	5	16	(49)

See also p. 341

SiO_2 (after fusing)

t	A	n	Lit.
25	1	20	(49)
486	5.58	8	(21)
869	2.41	6	(21)
1288	3.83	5	(21)

See also p. 341

PbS, Galena (Iso)

−180	5.9	$\bar{3}$	(25)
0	2.42	$\bar{3}$	
+ 20	2.65	$\bar{3}$	
340	6.06	$\bar{3}$	

a = 5.24, if −180° ≤ t ≤ 150°

$CuSO_4.5H_2O$ (purified) (Tri)

17	6.7	14	(22)

Cu_6As, Algodonite (Orth)

	4.15	$\bar{5}$	(9)
	6.34*	$\bar{5}$	

Cu_9As, Whitneyite (Orth)

	t	A	n	Lit.
		3.35	$\bar{5}$	(9)
		4.69*	$\bar{5}$	

Ag_2S; ρ = ƒ(v) (18)

FeS, α Pyrrhotite (Hex)

$\parallel c$	− 73	6.45	$\bar{4}$	(26)
$\parallel c$	0	5.5	$\bar{4}$	
$\parallel c$	+ 18	5.35	$\bar{4}$	
$\parallel c$	165	4.30	$\bar{4}$	
$\parallel c$	350	3.87	$\bar{4}$	
$\perp c$	− 68	5.0	$\bar{4}$	
$\perp c$	0	4.4	$\bar{4}$	
$\perp c$	+ 19	4.23	$\bar{4}$	
$\perp c$	104	3.55	$\bar{4}$	
$\perp c$	310	2.62	$\bar{4}$	

For $\parallel c$, α = 4.75, β = 2.65, q = 610

FeS, β Pyrrhotite (Hex)

$\parallel c$	350	3.80	$\bar{4}$	(26)
$\parallel c$	445	3.75	$\bar{4}$	
$\perp c$	417	2.5	$\bar{4}$	
$\perp c$	463	2.5	$\bar{4}$	

FeS_2, Pyrite† (Iso)

− 78	2.51	$\bar{2}$	(23)
0	2.40	$\bar{2}$	(23)
0	2.9	$\bar{3}$	(4)
+ 20	2.40	$\bar{2}$	(23)
121	3.00	$\bar{2}$	(23)
340	3.88	$\bar{2}$	(23)

α = 3.65, β = 3.7, q = 240

FeS_2, Marcasite (Orth)

$\parallel b$	0	16.56	0	(23)
$\parallel b$	16	10.25	0	
$\parallel b$	118	2.75	0	
$\parallel b$	243	1.30	0	

α = 2.64, β = 9, q = 1850

Fe_2O_3, Specularite† (Hex)

$\parallel c$	0	8.2	$\bar{1}$	(4)
$\parallel c$	0	8.76	$\bar{1}$	(3)
$\parallel c$	16	7.04	$\bar{1}$	(3)
$\parallel c$	123	2.69	$\bar{1}$	(3)
$\parallel c$	237	1.56	$\bar{1}$	(3)
$\perp c$	0	4.2	$\bar{1}$	(4)
$\perp c$	0	4.31	$\bar{1}$	(3)
$\perp c$	18.3	3.51	$\bar{1}$	(3)
$\perp c$	100	1.75	$\bar{1}$	(3)
$\perp c$	238	0.96	$\bar{1}$	(3)

For $\parallel c$, α = 3.87, β = 0.26, q = 1400 (3)

For $\perp c$, α = 3.83, β = 0.45, q = 1290 (3)

Fe_3O_4, Magnetite‡ (Iso)

	− 61	5.1	$\bar{2}$	(26)
	+ 21	3.6	$\bar{2}$	
	111	2.88	$\bar{2}$	
	190	2.77	$\bar{2}$	
(u)	19	1.98	0	(50)
(v)	17	7.4	1	
(w)	25	1.37	1	
(x)	7	6.0	$\bar{1}$	
(y)	10	2.2	1	

MoS_2, Molybdenite (Hex)

	t	A	n	Lit.
	− 65	8.3	0	(25)
	+ 19.5	7.9	$\bar{1}$	
	102	2.1	$\bar{1}$	
		2.6	0	(13)
		1.6	4	

α = 2.6, β = 9, q = 1400

ρ = ƒ(v) (31, 46)

$FeCb_2O_6$, Columbite (Orth)

$\parallel c$	16	1.95	8	(30)
$\parallel c$	25	1.39	8	
$\parallel c$	32	1.0	8	

$(NH_4)_2Al_2(SO_4)_4.24H_2O$
(Iso) purified

17	4.9	14	(22)
63	3.5	12	

CaF_2, Fluorite (Iso)

20	7.9	17	(14)
110	4.21	13	
155	6.67	11	

$CaCO_3$, Iceland spar (Hex)

$\parallel c$	20	1.4§	14	(22)
$\parallel c$	20	9.5	15	(14)
$\parallel c$	100	6.25	10	(22)
$\parallel c$	100	2.37	12	(14)
$\perp c$	20	5.5	14	(14)
$\perp c$	27.8	9.9	22	(36)
$\perp c$	100	4.95	11	(14)

$CaCO_3$, Marble

22	5	9	(15)
22	1	9	

$BaSO_4$, Barite (Orth)

$\parallel b$	726	1.5	5	(26)
$\parallel b$	963	1.0	4	

Polarization emf = 1 to 1.4 volt

NaCl, Rocksalt (Iso)

20	4.6	16	(40)
100	1.38	13	
400	8.27	7	
750	4.28	3	

NaCl, (Iso)

580	1.95	5	(41)
700	1.42	4	
790	2.0	3	

NaBr, (Iso)

440	1.51	6	(41)
600	3.62	4	
740	4.07	3	

$NaNO_3$,‖ (Hex) rhombohedric

240	6.25	6	(41)
250	5.27	6	
300	4.54	5	
310	1.82	5	

KCl, (Iso)

520	4.37	6	(41)
600	5.58	5	
760	8.7	3	

KBr, (Iso)

490	3.55	6	(41)
650	6.45	4	
730	8.33	3	

$KCl.KBr$, Mixed crystal

	t	A	n	Lit.
	520	2.50	6	(41)
	640	1.20	5	
	720	1.17	4	

* After fusing.

† For effect of pressure, *v.* Table 5.

‡ Magnetite: $\Delta = (\rho - \rho_p)/\rho$, where ρ_p = value of ρ for a longitudinal compression of 887 kg/cm².

	Source	a	100Δ
(u)	New York	6.8	0.52
(v)	New York	6.1	2.64 (slaty)

$KAlSi_3O_8$, Orthoclase (Mon)

	t	A	n	Lit.
‖b	800	8.5	3	(26)
‖b	1000	0.80	3	

‡Magnetite.—(*Continued*)

	Source	a	100Δ
(w)	Russia	5.5	0.40
(x)	Arkansas	4.0	0.45
(y)	Tilly Foster, New York	7.9	0.15

§ $\log_{10} \rho = 4780/T - 2.17$.

‖ Perpendicular to rhombohedral face $(10\bar{1}1)$.

TABLE 3.—ELECTRICAL RESISTIVITY (ρ) OF NERNST AND AUER MIXTURES CONTAINING RARE EARTHS (48)

For laboratory construction of Nernst filaments, *v.* (20). Unit of ρ = 1 ohm-cm; t = centigrade temperature, °C; $\rho = A \times 10^n$

Mixture	t	A	n
Nernst (oxides of Zr, Y, Er)	230	2.72	6
	303	1.92	5
	400	1.02	4
	571	3.98	2
	922	1.29	1
	1252	3.49	0
Auer (oxides of Ce, Th)	745	2.19	4
	890	7.85	3
	1068	1.99	3
	1211	6.40	2

TABLE 4.—RESISTIVITY OF MIXED LIQUIDS SUITABLE FOR MAKING HIGH RESISTANCES: MIXTURES OF XYLENE AND ETHYL ALCOHOL (12)

P = % C_2H_5OH by weight; $\rho = A \times 10^n$; $\alpha_{15} = \left(\frac{1}{\rho}\frac{d\rho}{dt}\right)_{15°C}$

Unit of ρ = 1 ohm cm; of P = 1%; Temperature = 25.6°C

P	100	25	20	18	16	14	12	10
A	1.44	2.24	1.00	1.88	3.56	6.94	1.73	5.95
n	5	6	7	7	7	7	8	8

P	9	8	7	6	5	4	0
A	1.18	2.66	6.25	1.69	4.72	1.41	>1
n	9	9	9	10	10	11	15

$P = 25$, $\alpha_{15} = 0.0117$; $P = 10.2$, $\alpha_{15} = 0.0168$; $P = 5.5$, $\alpha_{15} = 0.0124$.

TABLE 5.—EFFECT OF PRESSURE UPON RESISTIVITY OF POOR CONDUCTORS (4)

If $\Delta\rho = \rho_p - \rho_1$, where ρ_p, ρ_1 = volume resistivity when hydrostatic pressure = p, = 1, respectively; then

$$a \times 10^{-6} = \frac{\Delta\rho}{\rho_1(p-1)}\left(1 + \frac{1}{2}\frac{\Delta\rho}{\rho_1}\right).$$

TABLE 5.—(*Continued*)

$\rho_1 = A \times 10^n$; ‖c, ⊥c denote that the current is ‖, ⊥ to the crystallographic c-axis. Unit of ρ = 1 ohm cm; of p = 1 atmosphere; temperature = 0°C.

Substance			A	n	p	$-a$
FeS_2	Pyrite		2.9	$\bar{3}$	2550	23.1
Fe_2O_3	Specularite	‖c	8.2	$\bar{1}$	2510	8.2
		⊥c	4.2	$\bar{1}$	2520	6.8
Fe_3O_4	Magnetite		*v.* Note,‡ Table 2			
P	Phosphorus		*v.* Note,‡ Table 1			

TABLE 6.—SURFACE RESISTIVITY: EFFECT OF HUMIDITY OF AIR (39)

The ability to maintain a high resistance when surrounded by moist air increases in the order glass, ebonite, amber, sulfur, paraffin. H = relative humidity; R = resistance of a 2 cm length of a polished *amber* cylinder 0.5 cm in diameter; observations made in order of the entries in table. (v.s.) = very small. Unit of $R = 10^{12}$ ohm; of H = 1%. Room temperature.

H	77.5	80	82	85	86	88	90	93	82	96	82	99	82	100	82
R	409	294	204	98	65	40	20	4	198	1.6	94	0.4	42	(v.s.)	1.4

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(For a key to the periodicals see end of volume)

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ELECTROELASTIC AND PYROELECTRIC PHENOMENA[1]

W. G. CADY

Electrostriction.—In general, when an isotropic dielectric is subjected to an electrostatic field E, its volume and form are changed. This phenomenon is known as *electrostriction*. The same kinds of effect occur in anisotropic dielectrics, but in them these effects are in many cases obscured by the far larger electrocrystallic ones described as piezoelectric (*see* p. 208). In electrostrictive effects, the tensions tending to stretch any element of the dielectric are proportional to E^2 and to $d\epsilon/dx$, where ϵ = dielectric constant and x is the amount of stretching in the direction considered. In general, $d\epsilon/dx$ depends upon the inclination of x to E; it may be either positive or negative, depending upon the nature of the dielectric (2). There are similar forces tending to move the dielectric bodily in such a way as to increase the integral value of ϵE^2, and if the dielectric is solid and if the field is produced by the charging of electrodes supported by it, then it will be subjected to the pressure arising from the mutual attraction of the electrodes. Deformations resulting from these two types of forces should not be classed as electrostrictive, although one or the other enters into many measurements of electrostriction.

Electrostrictive effects are generally derived from observations of the change in dimension of a condenser of which the dielectric is the substance to be studied (2, 14, 20, 50, 57, 63, 74, 75, 82, 96, 97, 127). If l is the dimension considered, Δl is the increase in l under action of the electric field, and if μ is the corresponding elastic modulus, then $\mu\Delta l/lE^2$ depends solely upon the configuration of the system, and upon ϵ and its variation with Δl. The changes (Δl) are very small and the sources of error are numerous; consequently the results obtained are frequently quite discordant and at times even qualitatively contradictory.

For summaries and discussions, *v.* (20, 50, 79, 81, 82); for recent developments, *v.* (2, 10, 14, 33, 34, 55, 57, 74, 75, 92.5, 123); for bibliography, *v.* (10, 100).

TABLE 1.—ELECTROSTRICTION

The following data are based upon the change in dimensions of a condenser when it is charged. This change frequently increases rapidly for several seconds; the values tabulated are presumably those approximately constant ones corresponding to an application of the field for 15 to 40 sec.

In column (2) the type of the condenser is indicated (c = cylindrical, s = spherical, p = plate) and the quantity corresponding to l in the formula below is stated; c_e = cylindrical condenser with electrodes supported by the dielectric.

Röntgen (93) found that all liquids expanded under the action of E; Quincke (81, 84) found that some contracted, the contraction for $(C_2H_5)_2O$, almond oil, and rape oil being marked.

For air and CO_2, Gans (35) found a reduction in pressure in an electric field, in rough agreement with the value predicted by theory. For other work with gases, *v.* (20, 50, 66, 82).

For other experimental work, *v.* (2, 20, 34, 35, 55, 57, 63, 66, 69, 70, 82, 96, 97, 127).

$\Delta l/lE^2 \equiv A \times 10^{-n}$. Unit of $A \times 10^{-n} = 1$ cm² cgse⁻² = $1.11_3 \times 10^{-5}$ cm² volt⁻².

Dielectric	Condenser	A	n	Lit.
Glass* (1)	c_e, length	5.2	13	(10)
(2)	c_e, length	5.6	13	(10)
(3)		1.3	13	(84)
(4)		2.3	13	(84)
(5)		5.7	13	(18)
(6)		4.4	13	(19)
(7)		7.1	13	(19)
(8)	s, volume	2.6†	7	(84)
Paraffin‡ (1)	c_e, length	8.4	11	(10)
(1)	c, length	9.4	11	(10)
Ebonite§	c_e, length	5.8	12	(10)
		to		
		1.15	10	(10)
	c, length	6.5	10	(10)
		1.0	9	(10)
Rubber‖ (1)	p, thickness	6.7	9	(10)
(2)	p, thickness	5.4	9	(10)
(3)	p, thickness	7.6	9	(10)

* Values for (1) and (2) obtained 15 sec after application of E; at 2 or 3 sec after application of E, A is only 4. From data obtained (125, 126) with various glass tubes, electrodes not supported by the glass, Adams (2) deduces $8\pi\mu\Delta l/lE^2 = -1.35$ to -3.78; *v. also* (10, 57, 69, 70, 100).

† Flint glass. $\Delta v/vE^2$ is unchanged by a variation of E in the ratio of 1 to 5.

‡ Values 35 to 40 sec after application of E; at 5 sec after application of E, A is only 4. Temperature, 24°C. Both recorded values are for same tube.

§ Various specimens of the c_e group have been treated so as to vary μ(1.7×10^9 to 27×10^9); the products of $A \times 10^{-n}$ by the corresponding values of μ are constant (=0.18). For the c group, μ lay between 1.3×10^9 and 1.7×10^9.

‖ (1) and (2) are vulcanized "para-normal" rubber; (3) is unvulcanized pure rubber. The volume of the plate does not change when E is applied.

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[1] This section deals with data pertaining to electrostriction, piezoelectricity and pyroelectricity. All units are of the cgse system unless the contrary is stated.

Piezoelectricity.—In general, when an anisotropic dielectric having no center of symmetry is mechanically strained, it becomes electrically polarized; the direction and magnitude of the polarization (P) depend upon the nature of the crystal, upon the nature and amount of the strain and upon the direction of the strain with reference to the axes of the crystal. Conversely, when such a dielectric is subjected to an electric field (E), not only are stresses of an electrostrictive nature set up in it, but also others which are usually much larger and which depend upon both the direction and magnitude of E. These effects are described as *piezoelectric.* The production of polarization by strain is called the *direct* effect; the other is the *converse* effect.

From experiments with calcite ($CaCO_3$), dolomite ($CaMgC_2O_6$), beryl ($Be_3Al_2Si_6O_{18}$), topaz ($Al_2F_2SiO_4$), barite ($BaSO_4$), and celestite ($SrSO_4$), Voigt (120) concludes that crystals possessing a center of symmetry may possess "central-symmetrical" piezoelectricity. Also some investigators have observed what appears to be a piezoelectric effect for certain apparently non-crystalline substances such as beeswax and resin (3, 28), sheet rubber (12, 85), ebonite, glass, hornoid, sealing wax, celluloid and paraffin (12), but it is difficult to determine how much of the observed effect is due to frictional electricity and to the presence of very small piezoelectric crystals. The observations (85) lead to a value of the order 10^{-5} for the strain-constant d for sheet rubber; this is nearly a thousand times as great as the value for most piezoelectric crystals.

If P_x, P_y, P_z are the components of the polarization (electric moment per unit of volume), E_x, E_y, E_z, the components of E; x_x, y_y, etc., the six strain components; X_x, Y_y, etc., the six stress components; then

$$P_x = e_{11}x_x + e_{12}y_y + e_{13}z_z + e_{14}y_z + e_{15}z_x + e_{16}x_y$$

$$-P_x = d_{11}X_x + d_{12}Y_y + d_{13}Z_z + d_{14}Y_z + d_{15}Z_x + d_{16}X_y$$

The expressions for the components P_y, P_z are obtained from that for P_x by changing the first digit "1" of the subscript of each e to "2," and to "3," respectively: $-P_y$, $-P_z$ are obtained from $-P_x$ by changing similarly the subscripts of each d. For the converse effect:

$$x_x = d_{11}E_x + d_{21}E_y + d_{31}E_z$$

$$-X_x = e_{11}E_x + e_{21}E_y + e_{31}E_z$$

The other five equations of each set (y_y, z_z, y_z, z_x, x_y; and Y_y, Z_z, Y_z, Z_x, X_y) are obtained in order from these by changing the second digit (1) of the subscript of each d (or e) to 2, 3, 4, 5, 6, respectively. The d's and e's are called the piezoelectric constants, the d's being the *strain constants* and the e's the *moduli:* they are mutually related by equations involving the elastic constants of the crystal (81, 82, 91, 117). Excepting triclinic asymmetric crystals, in each special case certain of these 18 parameters are necessarily zero. Those which may not be zero are indicated in Table 2.

When the polarization is parallel to the stress producing it, it is described as a longitudinal effect; it exists only when one or more of the constants with subscripts 11, 22, 33 are finite.

When the polarization is perpendicular to the direction of the strain producing it, it is described as a transverse effect; it exists whenever one or more of the constants with subscripts 12, 13, 21, 23, 31, or 32 are finite, and also for certain directions of the stress when one or more of the constants with subscripts 14, 25, 36 are finite; *v.* (15, 21, 25, 83, 117).

Owing to the smallness of the effect and to various sources of error such as twinning,[1] faulty orientation of crystal plate being studied, presence of impurities, etc., the data available are in most cases somewhat discordant. For many substances, our exact knowledge is limited to the fact that the piezoelectric constants are not all zero.

For full bibliography, including applications, *v.* (16); for recent summary of information regarding piezo- and pyroelectricity, *v.* (36); for description of piezoelectric phenomena, general theory, and bibliography, *v.* (20, 21, 24, 81, 82, 91, 117); for more recent formulation of theory, *v.* (7, 9, 11, 37, 48, 99, 110, 111, 112); for applications to high-frequency circuits, *v.* (15, 17, 27, 38, 59, 67, 78, 98); for equations giving value of P for a pressure applied in an arbitrary direction, *v.* (82, 91, 103, 117); for representation of P by means of piezoelectric surfaces, *v.* (1, 4, 51, 91, 103, 117); for effect of hydrostatic pressure, *v.* (117); *cf.* (56); for discussion of second-order effects, *v.* (82, 117, 119).

A list of crystals for which piezoelectric effects have been observed, and their constants, are given in Table 3.

Table 2.—The Piezoelectric Constants Present for Each Class of Crystals Possessing the Piezoelectric Property

Excepting the plagihedral cubic class (117), all of the 21 classes of crystals having no center of symmetry are piezoelectric.

The parameters are denoted by their subscripts in accordance with the scheme of equations. A repetition of a subscript for any crystal class indicates that for this class the corresponding parameters have the same value. In writing the equations for the five trigonal classes, a factor 2 must precede each d corresponding to parameters 16 and 26, in all other cases the equations are written as above, those parameters corresponding to blanks in the table being necessarily zero.

Hex. = hexagonal, Rho. = rhombic, Mon. = monoclinic,
P = polar

The coordinate axes are assumed to be orthogonal, to form a right-handed system, and to be directed as indicated in the footnotes.

True polar pyroelectric effects (p. 209) may be exhibited by classes 2, 4, 6, 9, 12, 14, 15, 17, 18, 19; for class 19, P_x, P_y, and P_z are all present; for 18, only P_x and P_y are present; for all the other classes, only P_z exists.

Class		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
			Hex.*			Trigonal†					Tetragonal‡					Rho.‡		Mon.§		
Polarization	Parameter	Cubic‖	Polar	Trapezohedral	Tripyramidal polar	Holohedral	Polar	Trapezohedral	Tetartohedral	Tetartohedral polar	Polar	Trapezohedral	Tripyramidal polar	Sphenoidal	Tetartohedral	Polar	Sphenoidal	Polar	Clinohedral	Triclinic¶ asymmetric
P_x	11					11		11	11	11									11	11
	12					−11		−11	−11	−11									12	12
	13																		13	13
	14	14		14	14			14		14	14	14	14	14			14	14		14
	15		15		15		15			15	15		15		15	15		15		15
	16						−22		−22	−22									16	16
P_y	21						−22		−22	−22									21	21
	22						22		22	22									22	22
	23																		23	23
	24		15		15		15			15	−15		15		15	24		24		24
	25	14		−14	−14			−14		−14	14	−14	−14	14			25	25		25
	26					−11		−11	−11	−11									26	26
P_z	31		31		31		31			31	31		31		31	31		31		31
	32		31		31		31			31	−31		31		31	32		32		32
	33		33		33		33			33			33		33	33		33		33
	34																		34	34
	35																		35	35
	36	14									36			36			36	36		36

* z-axis coincides with the c-axis of 6-fold symmetry; where polar, the + direction is direction of the polarization produced by heating the crystal. The y-axis is ⊥ to a face of the first order prism.

† z-axis coincides with the c-axis of 3-fold symmetry. The y-axis and the + direction of the z-axis are as for hexagonal (*v.* *). Polarization of class 7 is not changed by hydrostatic pressure.

‡ Coordinate axes x, y, z coincide, respectively, with crystallographic axes a, b, c.

§ x-axis ‖ c-axis; z-axis ‖ b-axis; y-axis lies in obtuse angle between the a- and c-axes.

‖ Only the tetrahedral (1_a) and the tetartohedral (1_b) classes are piezoelectric.

¶ Only the asymmetric class is piezoelectric. No convention regarding directions of axes of coordinates.

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[1] Partially twinned crystals show a reduced piezoelectric effect; complete twinning removes the piezoelectric property altogether.

Pyroelectricity.—The electrical polarization (P) of many substances is changed when the temperature of the substance is changed; this phenomenon is described as *pyroelectric.* $\delta P/\delta t$ is called the pyroelectric constant of the substance; it decreases with the temperature and perhaps vanishes at absolute zero.

Several types of pyroelectricity are distinguished. The most marked pyroelectric effects are exhibited by those crystals which have a vectorial (polar) structure defining, not merely a line, but a definite direction along that line. The type exhibited by such crystals is called the *polar* or *vectorial* type of pyroelectricity; it is the type commonly associated with the word "pyroelectric." This type can be exhibited only by crystals belonging to the classes 2, 4, 6, 9, 12, 14, 15, 17, 18, and 19 of Table 2. Another type, in which the effects are much smaller, is known as the *central* or *tensorial* type; it may be exhibited (82, 91, 116, 117, 120, 121) by changing uniformly the temperature of crystals which have a certain type of tensorial symmetry; this type of symmetry occurs in every crystal class except those of the cubic system.

As crystals which are pyroelectric are also piezoelectric, the deformations accompanying changes in temperature give rise to polarizations of piezoelectric origin. These *false* pyroelectric effects are superposed upon the *true* pyroelectric effects which result solely from changes of temperature, effects due to accompanying strain being eliminated. In general, any piezoelectric crystal, when deformed by a change in temperature, whether uniform or not, exhibits false pyroelectric effects. Those produced by non-uniform heating are the more common and are called the false pyroelectric effects of the first kind, those produced by uniform heating being called the false effects of the second kind. As the false effects are generally much greater than the true, it is difficult to determine the latter. Indeed, the true pyroelectric effect has been investigated only for tourmaline and its existence for that substance is questioned. The magnitude of the pyro effect observed depends markedly upon both the surface and the volume conductivity of the specimen (61, 94, 114, 117).

The converse, or "electro-caloric," effect (the change in temperature resulting from the application of an electric field) has been detected (58, 102, 117).

For general discussion of pyroelectricity, *v.* (20, 41, 60, 81, 82, 83, 91, 117); for its molecular theory, *v.* (6, 7, 8, 20, 82, 83, 91, 110, 112, 117); most complete quantitative data are by Ackermann (1), discussed by Boguslawski (6).

For data for specific substances, *see* Table 3.

In addition to the substances tabulated below, both pyro and piezo effects have been observed (23, 30, 82, 91, 117, 120, 121) in the following crystals possessing a center of symmetry: topaz ($Al_2F_2SiO_4$), barite ($BaSO_4$), beryl ($Be_3Al_2Si_6O_{18}$), calcite ($CaCO_3$), dolomite ($CaMgC_2O_6$) and celestite ($SrSO_4$); and by means of a high frequency method, in which the orientation of the axes of the crystal could not be determined, traces of the piezoelectric effect have been found (38) in the following crystals: proustite (Ag_3AsS_3), urea (CH_4N_2O), ammonium oxalate ($N_2H_8C_2O_4$), asparagine ($C_4H_8N_2O_3.H_2O$), ammonium acid tartrate ($NH_4HC_4H_4O_6$) pentaerythritol ($C_5H_{12}O_4$), tetraethylammonium iodide ($N(C_2H_5)_4I$), triphenylmethane ($CH(C_6H_5)_3$), potassium acid tartrate ($KHC_4H_4O_6$), magnesium sulfate ($MgSO_4.7H_2O$), ammonium acid phosphate ($NH_4H_2PO_4$), sodium tartrate ($Na_2C_4H_4O_6$), sodium sulfoantimonate ($Na_3S_4Sb.9H_2O$), nickel sulfate ($NiSO_4.6H_2O$) and zinc sulfate ($ZnSO_4.7H_2O$). For other crystals, *v.* (43, 43.5, 44, 45, 46, 49, 64, 65, 68). For piezoelectric effects with apparently non-crystalline substances, *v.* p. 208.

No observation of either kind of effect was found recorded for crystals of classes 3, 5, 8, 10, 11, 13, 14 (*v.* Table 2). Of the other classes, no direct piezo observation was found recorded for classes 2, 4, 9, 12, 15, 18, 19, but all crystals which exhibit pyro effects are also piezoelectric. Crystals of class 7 are not excited by hydrostatic pressure.

The numbers in the column "C. S." indicate the crystal class of the substance, in accordance with the numbers of Table 2. The presence of the mark " ✓ " in a column indicates that the corresponding effect has been actually observed, but the numerical value of the constant is not known with certainty; if the detected pyro effect is necessarily a "false" one, the " ✓ " is replaced by an "f;" blanks indicate that no record of observations was found. In column "C" is the symbol indicating the piezoelectric strain constant which has the value $A \times 10^{-8}$, A being the value adjacent to the symbol. For example, for tourmaline at room temperature, $d_{33} = 5.78 \times 10^{-8}$ (es/cm^2)/(dyne/cm^2). Units are cgse. Data for pyro effect refer to the total effect, the sum of the "true" and the "false."

TABLE 3.—A LIST OF SUBSTANCES FOR WHICH EITHER PIEZO- OR PYROELECTRIC EFFECTS HAVE BEEN OBSERVED; TOGETHER WITH THEIR CONSTANTS AT ROOM TEMPERATURE

Formula	Substance	C. S.	Pyro		Piezo		
			$\delta P/\delta t$	Lit.	C	A	Lit.
Variable	Tourmaline (*v.* Table 4)	6	1.1 1.3	(1)	d_{33}	5.78	(89, 115)
$Ba(CHO_2)_2$	Barium formate	16	f	(45)			(45)
$Ba(SbO)_2(C_4H_4O_6)_2.H_2O$	Barium antimonyl tartrate	12	✓	(104, 113)			(81, 113)
$(Be, Mn, Fe)_7Si_3O_{12}S$	Helvite	1_a	f	(43, 43.5)			(43, 43.5)
C	Diamond	1_a	0.0*	(113)		0†	(113)
$C_3H_8N_4O_4$	Methylene diisonitramine methyl ester $CH_2(N_2O_2.CH_3)_2$	15	✓	(81, 109)			
$C_4H_6O_6$	Tartaric acid	17	7.5	(47)	d_{33}‡	6.4	(103)
$C_4H_{12}N_2O_6$	Ammonium tartrate	17	2.84§	(1, 47)			(38)
$C_6H_3N_3O_7$	Picric acid	15	✓	(13)			
$C_6H_6O_2$	Resorcinol	15	7.7	(47)			(38)
$C_6H_{12}O_5$	Quercitol	17	✓	(81)			
$C_6H_{12}O_5.H_2O$	*d*-Rhamnose (isodulcitol)	17	3.63 0.505	(47)			
$C_6H_{16}ClN$	Triethylamine hydrochloride	2	✓	(42)			
$C_7H_7BrO_4$	Bromoshikimilactone	4	✓	(107)			
$C_{10}H_{15}NO$	Carvoxime $C_{10}H_{14}.NOH$	17	✓	(81)			
$C_{10}H_{13}Br_5O$	Carvone pentabromide	17	✓	(122)			

* Value is relative to tourmaline (kind not specified) as unity. † No trace of piezoelectricity. ‡ *v.* Table 7.

TABLE 3.—(*Continued*)

Formula	Substance	C. S.	Pyro		Piezo		
			$\delta P/\delta t$	Lit.	C	A	Lit.
$C_{10}H_{17}NO$	Fenchoneoxime	17	✓	(81)			
$C_{12}H_{22}O_{11}$	Saccharose (cane sugar)	17	0.53	(47)	d_{33}‡	−10.2	(51)
$C_{12}H_{22}O_{11}.H_2O$	Lactose	17	✓	(81)			
$C_{14}H_{10}O_2$	Benzil	7			d_{11}	24	(113)
$C_{14}H_{12}O$	Phenyl *p*-tolyl ketone $C_6H_5.CO.C_6H_4.CH_3$	6	✓	(5)			
$C_{15}H_{26}O$	Patchouli camphor	7(?)			d_{11}	0.14	(113)
$CaAl_2Si_3O_{10}.3H_2O$	Scolecite	18	0.99	(47)			
$2CaO.Al_2O_3.3SiO_2.H_2O$	Prehnite	15	✓	(92, 108)			
$3Ca_3P_2O_8.CaF_2$	Fluoroapatite	4	✓	(44)			
$K_2C_4H_4O_6.\frac{1}{2}H_2O$	Potassium tartrate	17	5.96§	(1, 47)			(38)
$KBrO_3$	Potassium bromate	6	✓	(107)			
$K_2S_2O_6$	Potassium dithionate	7	f	(46)			(46)
$KLiSO_4$	Potassium lithium sulfate	4	4.86§	(1, 47)			
$(KLiSO_4)_x + (KLiCrO_4)$	Mixture	4	✓	(105)			
$(KLiSO_4)_{18} + KLiMoO_4$	Mixture	4	✓	(105)			
$K_2SO_4 + Li_2CrO_4$	Mixture	4	✓	(105)			
$KLiSeO_4$	Potassium lithium selenate	4	✓	(105)			
$KNaC_4H_4O_6.4H_2O$	Rochelle salt (*v.* Table 6)	16	✓	(110, 111, 112)	d_{14} d_{14}	340 to 1180 8100	(80) (111)
$Li_2SO_4.H_2O$	Lithium sulfate	17	23.2§	(1, 47)			(38)
$Li_2SeO_4.H_2O$	Lithium selenate	17	17.17§	(1, 47)			
$LiNa_3(MoO_4)_2.6H_2O$	Lithium trisodium molybdate	6	✓	(113)	d_{33}	14	(113)
$LiNaSO_4$(anhydrous)	Lithium sodium sulfate	6	2.3§	(1, 47)			
$LiNa_3(SeO_4)_2.6H_2O$	Lithium trisodium selenate	6	5.38§	(1, 47)			
$6MgO.8B_2O_3.MgCl_2$	Boracite‖	1_a	0.07*	(32, 113)			(23, 24, 113)
$NaBrO_3$	Sodium bromate	1_b	f	(46)			(46)
$NaClO_3$	Sodium chlorate	1_b	f	(23, 31, 32, 46)	d_{14}	−4.8	(80); *cf.* (23, 32, 46)
$NaIO_4.3H_2O$	Sodium periodate	9	✓	(46)			
$Pb(CHO_2)_2$	Lead formate	16	f	(45)			(45)
$Pb(SbO.C_4H_4O_6)_2$	Lead antimonyl tartrate	4	✓	(106)			
$Rb_2C_4H_4O_6$	Rubidium tartrate	7			d_{11}	8.2	(113)
SiO_2	Quartz (*v.* Table 5)	7	0.50f*	(31, 113)	d_{11}	−6.9	(22, 95)
$Sr(CHO_2)_2$	Strontium formate	16	f	(45)			(45)
$Sr(HC_4H_4O_6)_2.4H_2O$	Strontium acid tartrate	19	0.73§ 6.7*	(1, 47, 113)			
$Sr(SbO.C_4H_4O_6)_2$	Strontium antimonyl tartrate	4	✓	(106)			
$SrS_2O_6.4H_2O$	Strontium dithionate	7	f	(46)			(46)
$2ZnO.SiO_2.H_2O$	Calamine (hemimorphite)	15	5.0*	(113); *cf.* (23)			
$ZnS(\beta)$	Sphalerite	1_a	0.13*	(30, 32, 113)	d¶	4.8	(113)

§ *v.* Table 8. ‖ Isotropic if $t > 265$°C. ¶ For pressure along an axis of 3-fold symmetry; the resulting polarization is in same direction.

TABLE 4.—TOURMALINE: PYRO- AND PIEZOELECTRIC CONSTANTS

The z-axis coincides with the ternary (optical) axis of the crystal, and the x-axis lies in any one of the three planes of trigonal symmetry. The positive direction of z passes through the end of the crystal which becomes charged positively when the crystal is uniformly heated. This end is called the "analogous" end of the crystal; frequently it is not possible, by mere inspection, to determine which is the analogous end (124). The opposite end is called the antilogous end. The values found for the constants vary considerably from one specimen to another; in general, those for the darker specimens are the smaller in numerical value. The permanent electrical polarization along the z-axis is about 8×10^4 cgse (87, 90, 91); hydrostatic pressure increases it about 8×10^{-8} cgse per barye (56). Whether tourmaline exhibits "true" pyroelectric effects is doubtful; Voigt (114, 117) thought the true effect amounted to 20% of the total, but Röntgen (94, 118) and Lindmann (61) decided that it is too small to measure. The values given below represent the total pyroelectric effect. Writing $\delta P/\delta t = a + 2b(t - t_0)$, where P = the polarization along the z-axis, and t and t_0 are final and initial temperatures, values of a varying, with the specimen, from 0.52 to 2.03, and of b varying from −0.000256 to +0.0117 were found (88, 91); experiments extended to t = 160°C. For pyroelectric data, *v.* (1, 81, 83, 91, 113, 117); for piezoelectric, *v.* (81, 89, 91, 114, 115, 117, 120). P = polarization, T = absolute temperature, $A_{15} \times 10^{-8} = d_{15}$, etc.; $B_{15} \times 10^4 = e_{15}$, etc. (*v.* p. 208). Unit of T = 1°K; of P, d, e = 1 cgse unit of appropriate kind.

Pyroelectric $\delta P/\delta T$

T	B. G.*	Y. G.*	R. R.*
23	0.04	0.08	0.08
88	0.142	0.289	0.300
198	0.652	0.974	0.982
253	0.935	1.205	1.219
274	1.005	1.243	1.270
293	1.060	1.281	1.313
(293)	1.057†	1.275†	1.324†
352	1.170	1.337	1.404
372	1.187	1.350	1.426
408	1.217	1.381	1.460
488	1.268	1.490	1.544
578	1.381	1.669	1.723
648	1.525	1.865	1.943

L. G.‡ (94)

T	20.5	79	194	273	313.5	291
$\delta P/\delta T$	0.037	0.20	0.66	0.96	1.10	1.13§

Piezoelectric Constants‖

A_{15}	11.04				B_{15}	7.40
A_{22}	−0.69	−0.94			B_{22}	−0.53
A_{31}	0.74	0.96			B_{31}	3.09
A_{33}	5.78	5.4	5.4	5.6	B_{33}	9.60
Lit.	(89, 115)	(94)	(113)	(71)	Lit.	(89, 115)

* B. G. = blue-green, Y. G. = yellow-green, R. R. = rose-red. Data from (1).

† Data from (47).

‡ L. G. = light-green, data from (94). With darker specimens he found values only 83 % of these; discussed in (118).

§ From (86) for 5 green Brazilian specimens: $\delta P/\delta T = 1.13–0.0104(T - 291)$.

‖ Vary but little with changes in pressure and temperature; between 20°C and the temperature of liquid air (62) and for pressures up to 22 megabarye (71), the variation of d_{33} lies within the limits of experimental error. From theoretical considerations, Keys (54) concludes that, for tourmaline, the adiabatic piezoelectric constants, corresponding to suddenly applied stress, are 1.5 times as great as the usual isothermal ones. $d_{15} = A_{15} \times 10^{-8}$, etc.; $e_{15} = B_{15} \times 10^4$, etc.

TABLE 5.—QUARTZ: PYRO- AND PIEZOELECTRIC CONSTANTS

For information regarding all properties of SiO_2, *v.* (101)

The *z*-axis coincides with the crystallographic *c*-axis of 3-fold symmetry, the *y*-axis is ⊥ to a face of the hexagonal first order prism, and, in dextro crystals, the + direction of the *x*-axis is outward through one of the faces (commonly denoted by *s*) of the trigonal pyramid; in levo crystals, the direction of the *x*-axis with reference to the *s*-faces is reversed; in each case, the + direction of the *y*-axis is such as to form a right-handed system of orthogonal axes. At 573°C, ordinary SiO_2 (trigonal, trapezohedral), known as "α-quartz," becomes transformed to "β-quartz" (hexagonal, trapezohedral) and loses its pyro- and piezoelectric properties (11, 37, 77, 101). Owing to its crystal form, SiO_2 can have no "true" pyroelectric properties; $\delta P/\delta t$ is approximately proportional to the absolute temperature (73), and at room temperature is about half as great as the value for tourmaline (113). Twinning is common; dextro and levo crystals have equally strong electrical properties; hence, specimens which are completely twinned are not piezoelectric.

Quartz is not electrically excited by hydrostatic pressure. The value of d_{11} is probably unchanged by pressure parallel to *x*-axis; Nachtikal (71) found it to decrease by 0.16% per megabarye, but Röntgen and Joffé (95) found it was not changed by 0.4% by a pressure of 18 megabarye, and according to Karcher (53) it remains constant to within 0.1% for pressures ≤ 3450 megabarye.

At room temperatures d_{11} is practically independent of temperature. There is some evidence that it increases by about 20% as *t* goes from room temperature to 60°C, and then with a further increase in *t* it gradually decreases until at 573°C it vanishes (26.5, 79, 82, 86, 101). On cooling it reappears. On cooling from +17 to −193°C, d_{11} decreases by 1.2%; cooling from −193 to −253°C causes a change of less than 0.2% (73). Ze (127) reports that the piezoelectric deformation of quartz reaches a saturation value at a field intensity of about 520 cgse units. In the following, the best values are printed in bold-face. Unit of d_{11} and d_{14} = 10^{-8} cgse; of e_{11} and e_{14} = 10^4 cgse.

d_{11}	−6.32	−6.3	−6.45	−6.27	−6.54	−6.3	−6.31	**−6.90**
Lit.	(21,25)	(26)	(89)	(80)	(71)	(113)	(47)	(22)

d_{11}	**−6.94**	−6.4	d_{14}	**+1.7**	+1.45	+1.93	e_{11} = −5.10
Lit.	(95)	(127)	Lit.	(101)	(89)	(80)	e_{14} = −1.35

Piezoelectric Resonators.—From the density (2.654 g cm^{-3}) and the elastic constants (117) of quartz, the natural frequencies (ν) of compressional vibrations parallel to the edges of a quartz parallelepiped cut with its edges *a*, *b*, *c* parallel to the crystal axes *x*, *y*, *z*, are $\nu_x = 2.70 \times 10^5/a$, $\nu_y = 2.70 \times 10^5/b$, and $\nu_z = 3.08 \times 10^5/c$ cycle per sec if the lengths of the edges are *a* cm, *b* cm, and *c* cm. In each case the wave-length of the elastic wave in the crystal is twice that of the corresponding edge. Through the agency of d_{11}, the vibrations along *x* and *y* may be directly excited by a high-frequency electric field applied parallel to *x*. Also, through the same d_{11}, a transverse, or shear, mode of vibration may be excited by a high-frequency field parallel to *y*, the fundamental frequency being $\nu_{xy} = 1.79 \times 10^5/b$ cycle per sec. This vibration depends upon the rigidity of quartz for torsion about the *z*-axis. In all of these values for the frequency the effect of sectional area is ignored, but the computed frequencies agree fairly well with those observed; *v. also* (16, 26, 81, 95, 117).

TABLE 6.—ROCHELLE SALT ($KNaC_4H_4O_6.4H_2O$): PYRO- AND PIEZOELECTRIC CONSTANTS

Axes *x*, *y*, *z* coincide, respectively, with crystallographic axes *a*, *b*, *c*. Electrical properties are complicated and are greatly affected by changes in temperature and humidity, and by the past history of the specimen; great differences between individual specimens (29, 52, 72, 110, 111, 112). Valasek (110, 111, 112) thinks it has "true" pyroelectric properties although the crystal form indicates that they can not exist; his computations (110) indicate a permanent electrical polarization of the order of 50 cgse units; *v. also* (23). Rochelle salt (potassium sodium tartrate) is not electrically excited by hydrostatic pressure; its d_{14} is the largest known piezoelectric constant; *v.* especially (72). Unit of d_{14}, d_{25}, and d_{36} = 10^{-6} cgse. Note: In other tables the unit, or common factor, is 10^{-8}.

t	−70	−50	−30	−20	−10	0	10	20	30	40	°C
d_{14}	0.17	0.17	0.65	10.8	60.7	67.5	74.2	81.0	10.8	4.1	(112)

The maximum is much greater than that recorded by any other observer. Later observations (112.5) indicate that with increasing *t*, d_{14} increases rapidly from a very low value to about 23 at −20°C, increases slightly from −20 to +25°C, and then decreases rapidly. Between −60 and +30°, d_{25} and d_{36} increase linearly with *t*, their rates being, respectively, 6.8×10^{-9} and 3.1×10^{-10} cgse unit per 1°C (112.5).

Near 20°C, Pockels (80) finds d_{14} = 3.40 to 11.80; d_{25} = −1.65, and d_{36} = 0.35.

From these data and the elastic constants (66.5) it is found that $e_{14} = 56 \times 10^4$ to 194×10^4, $e_{25} = -5.33 \times 10^4$, and $e_{36} = 4.34 \times 10^4$ cgse units.

From the density (1.767 g cm^{-3}) and the elastic constants (66.5) the velocity of compressional waves in a bar of Rochelle salt cut with its length perpendicular to the x-axis and at 45° with the y and z axes is found to be 3.98 × 10^5 cm/sec. Hence, natural frequency (ν) of such vibrations in a bar a cm long is 1.99 × $10^5/a$ cycle per sec; experimental values may be expected to differ rather widely from this value (17).

TABLE 7.—PIEZOELECTRIC CONSTANTS OF TARTARIC ACID ($C_4H_6O_6$) AND OF CANE SUGAR ($C_{12}H_{22}O_{11}$)

Room temperature; precision about 3%; system = monoclinic polar. $d_{14} = A_{14} \times 10^{-8}$; etc. Unit of d = 1 cgse.

Formula	A_{14}	A_{15}	A_{24}	A_{25}	A_{31}	A_{32}	A_{33}	A_{36}	Lit.
$C_4H_6O_6$	−24	28.3	28.5	−36.5	1.95	5.9	6.4	3.8	(103)
$C_{12}H_{22}O_{11}$	1.27	−12.6	−7.2	3.75	2.21	4.4	−10.2	−2.62	(51)

TABLE 8.—PYROELECTRIC EFFECT: VARIATION WITH TEMPERATURE (1)

T = absolute temperature, °K. Unit of $\delta P/\delta t$ = 1 cgse unit

T	23	88	198	253	274	293	293*	352
Formula	$\delta P/\delta t$							
$Sr(HC_4H_4O_6)_2.4H_2O$†	0.04	0.12	0.45	0.64	0.69	0.728	0.73	0.825
$NaLiSO_4$	0.12	0.29	0.88	1.63	2.03	2.26	2.31	2.74
$C_4H_{12}N_2O_6$‡	0.15	0.31	1.18	2.41	2.58	2.84	2.84	3.42
$KLiSO_4$		0.69	2.50	4.09	4.51	4.85	4.88	5.35
$Na_3Li(SeO_4)_2.6H_2O$	0.35	0.93	2.94	4.58	5.07	5.38	5.38	6.37
$K_2C_4H_4O_6.\frac{1}{2}H_2O$†	0.39	1.00	3.32	5.10	5.60	5.96	5.98	6.89
$Li_2SeO_4.H_2O$	0.92	2.30	9.87	14.54	16.00	17.17	17.14	19.35
$Li_2SO_4.H_2O$	1.21	3.81	12.24	18.42	20.45	23.27	23.18	26.90

* (47). † Tartrate. ‡ Ammonium tartrate.

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(For a key to the periodicals see end of volume)

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THERMOELECTRICITY

A. E. Caswell

If two metallic conductors, M and R, are connected in series so as to form a closed circuit, and if one junction is kept at the temperature, 0°C and the other at the temperature, $t (t \neq 0)$, there will be a *thermo emf* ${}_ME_R$ around the circuit. By convention, ${}_ME_R$ is regarded as positive if the current so produced flows from M to R at the junction which is at 0°C. ${}_RE_M = -{}_ME_R$; ${}_ME_R + {}_RE_S = {}_ME_S$. ${}_MQ_R \equiv \partial_ME_R/\partial t$ is called the *thermoelectric power* of M with respect to R. As a current I passes through a junction from R to M an amount of heat $({}_MP_R)I = T({}_MQ_R)I$ is absorbed per second; ${}_MP_R$ is the *Peltier coefficient* of M with respect to R, and T is the absolute temperature corresponding to t. If ${}_MQ_R$ is negative, so is ${}_MP_R$, and heat is evolved when current flows from R to M. The equations are valid for any consistent system of units; in particular, if E is expressed in volts and I in amperes, the heat is expressed in joules. If, in an unequally heated homogeneous conductor, a current, I, flows from a point where the temperature is t_2 to another where it is t_1, $t_2 > t_1$, an amount of heat $H = \int_{t_1}^{t_2} I\sigma dt$ will be absorbed per second, apart from the usual Joule heating effect. σ is the *Thomson coefficient* of the metal in question; it may be either positive or negative. Denoting by a subscript the metal to which σ refers, $\sigma_M - \sigma_R = -T\,(\partial^2{}_ME_R/\partial t^2)$.

All four quantities, ${}_ME_R$, ${}_MQ_R$, ${}_MP_R$ and σ_M are profoundly affected by anything which alters the structure of the metals to which they refer. They are greatly affected by impurities, heat treatment, drawing, rolling, pressure, tension and magnetization. Only very rarely will identical thermoelectric curves be found for two couples formed from the same pair of metals.

For a bar cut from a crystal, the value of Q will, in general, depend upon the direction which the length of the bar makes with the axis of the crystal. When Q does depend upon this direction, the bar, unless cut parallel to one of the principal thermoelectric axes, exhibits another distinct thermoelectric property, in virtue of which the longitudinal passage of an electric current through the bar is accompanied by an absorption of heat at one side of the bar and an evolution of heat at the opposite side, the two sides being kept at the same, or essentially the same, temperature. This is known as the *transverse Peltier effect.* (For a rectangular bar of Bi cut with its length at 45° to the axis of the crystal, distance between sides which became unequally heated = 1.55 mm, distance between other two sides = 2.64 mm, it was observed that $\Delta t = 0.267$°C per ampere of longitudinal current, the bar being exposed to the air and at room temperature (16).) Conversely, a difference in temperature of the two sides gives rise to a longitudinal emf.

TABLE 1.—THERMO EMF AND THERMOELECTRIC POWER OF ELEMENTARY SUBSTANCES

${}_ME_R = at + \frac{1}{2}bt^2(10)^{-2} + \frac{1}{3}ct^3(10)^{-5} + d$; one junction at 0°C.
${}_MQ_R = d({}_ME_R)/dt = a + bt(10)^{-2} + ct^2(10)^{-5}$.

${}_MP_R = T({}_MQ_R)$ = Peltier coefficient; difference in the Thomson coefficients is $(\sigma_M - \sigma_R) = Td({}_MQ_R)/dt$; T = absolute temperature corresponding to temperature t. The tabulated coefficients apply for all values of t between t_1 and t_2. For other notation, *see* introduction.

The numbers in the "Error" column indicate the possible departures (±) of observed value of E from that calculated by means of the coefficients; unit is 1%, unless another is indicated. The expression $\left.\begin{matrix}-0.38\\-0.53\end{matrix}\right\}$ indicates that the quantity varies from −0.38 to −0.53. Unit of $E = 1\mu v = 10^{-6}$ volt; t_1, t_2 = centigrade temperature, °C.

M	R	t_1	t_2	a	b	c	Error	Lit.
Ag^e	Pb	−200	+100	+2.947	+0.6782	−0.186	1	(31)
Ag	Pb	0	+200	+3.3383	+0.847		1.5	(59)
Ag^u	Pb	0	+100	+2.50	+1.15		1	(76)
Ag	Pt	0	+900	+3.04	+2.01		1.5	(65)
Al^b	Pb	−200	+100	−0.4717	+0.2718	−2.386	1	(31)
Al^h	Pb	0	+200	−0.4960	+0.1734		1.5	(59)
Al^c	Pb	0	+100	$\left\{\begin{matrix}-0.38\\-0.53\end{matrix}\right.$	$\left.\begin{matrix}-0.01\\+0.21\end{matrix}\right\}$	−2.82		(76) (17)
Al	Pt	0	+800	−0.7982	−0.9072	−0.6717	1.5	(65)
Au	Pb	−260	0	+2.90	+0.68		1.5	(80)
Au	Pb	0	+200	+2.90	+0.934		1.5	(17, 59, 76)
Bi	Pb	−200	+100	−81.845	+0.599	+162.5	1	(31)
Bi^c	Pb	−200	+100	−43.688	−46.47	−38.72	1	(31)
Bi^e	Pb	0	+100	−74.42	+3.2		1.5	(17)
Bi	Pt	0	+268	−61.95	+4.502	+26.82	1.5	(65)
Bi	Pt	+300	+800	+15	d = −17 900		1.5	(65)
Bi^w	Cu	+20	+100	−55.0	−3.12	(0.0°)*	1.0	(17)
Bi^w	Cu	+20	+100	−56.6	−2.50	(5.5°)*	1.0	(17)
Bi^w	Cu	+20	+100	−59.0	−10.00	(10.0°)*	5.0	(17)
Bi^w	Cu	+20	+100	−61.4	−6.25	(17.7°)*	1.0	(17)
Bi^w	Cu	+20	+100	−61.1	−8.75	(21.1°)*	1.0	(17)
C^f	Pb	−200	+100	+11.056	+3.578	+5.379	1	(31)
C	Pt	0	+560	−6.0072	+16.92	−0.2274	2	(53)
Ca	Cu	0	+100	−9.35	−3.1		1	(60)
Ca^d	Pb	0	+400	−8.20	−2.9			(77)
Cd	Pb	−200	+100	+3.059	+2.856	+9.00	1	(31)
Cd^h	Pb	0	+200	+2.619	−1.787		1.5	(59)
Cd^g	Pb	0	+100	+2.85	+3.89		1	(76)
Cd	Pt	0	+320	+0.390	+0.38		0.5	(65)
Cd	Pt	+320	+700	+1.5	d = −164		0.5	(65)
Ce^o	Cu	0	+200	+4.39	−1.26		2	(44)
Co^i	Cu	0	+280	−20.51	−5.4		2	(64)
Co	Cu	+340	+550	−24.75	−2.7		2	(64)
Co	Cu	+580	+900	−62.6	+4.34	(+10 310)†		(64)
Co	Cu	0	+280	−23.24	−8.26		1.5	(66)
Co	Pt	0	+1 200	−10.7	−5.70	+7.50	2	(68)
Cs	Pt	−200	−75	+4.66^p	+5.49^p			(11)
Cs	Pt	−75	+5.8	+3.14	+3.453		(?)	(11)
Cs	Pt	+27.4	+300	+15.73^p	−4.93^p			(11)
Cs	Pb	−183	0	+0.66	−0.10			(19)
Cs	Pb	+28	+100	+7.735	−3.34			(19)

TABLE 1.—(*Continued*)

M	R	t_1	t_2	a	b	c	Error	Lit.
Cu^j	Pb	−270	+200	+2.705	+0.7866	+1.773	1	(31, 59, 62, 80)
Cu^k	Pb	0	+100	+2.76	+1.22		1	(76)
Cu	Pt	0	+900	+3.130	+2.460		1	(65)
Fe	Pb	−260	−200	−51.34	−20.4	(−2 912)†	0.25	(80)
Fe^m	Pb	−230	+100	+16.65	−2.966	−26.75	1	(17, 31, 80)
Fe	Pt	0	+1 000	*v.* Table 2				
Fe^e	Cu	0	+700	+13.7	−7.80	+6.60	1	(18)
Ge	Pt	−200	+125	+302.5	+72.5		1	(11)
Ge	Pt	+135	+275	−219‡	+766	−2 391		
Ge	Pt	+275	+500	+1 422§	−702	+762		
Ge	Pt	+500	+700	−362	+31.2	(+204.9)‖		(11)
Hg	Pb	0	+200	−8.8103	−3.333		1.5	(59)
In	Pb	0	+100	+2.40	+0.190			(33.1)
Ir	Pt	+250	+1 500	−7.282	−1.108	(+248)‖		(45)
Ir^h	Pb	−80	+100	+2.44	−0.28		1	(19)
K	Pb	−183	0	−11.33	−3.76		1	(19)
K	Pt	−200	−113	−4.64^p	+2.41^p			(11)
K	Pt	−113	+53	−8.09	−0.59		(?)	(11)
K	Pt	+62.5	+300	−5.41^p	−0.017^p			(11)
Li	Pt	−200	+50	+14.37	+8.76			(11)
Li	Pt	+50	+168	+16.71^p	+4.08^p		(?)	(11)
Li	Pt	+183	+300	+20.57^p	+5.39^p			(11)
Mg	Pb	−200	+100	−0.2010	+0.2572	−1.677	1	(31)
Mg^h	Pb	0	+200	−0.120	+0.193		1.5	(59)
Mg	Pt	0	+700	+5.0	+1.444		1	(68)
Mo	W	0	+1 060	+4.61	+0.872		4	(60)
Mo	W	+950	+2 250	+24.5¶	−188.6		5.0	(57.1)
Mo	Pb	0	+100	+5.892	+4.334	−7.50	1.5	(17)
Mo	Pt	0	+1 200	+13.0	+2.96		2.5	(68)
Na	Pt	−200	+8.1	−0.882	+4.104			(11)
Na	Pt	+8.1	+84.7	−0.482^p	−0.833^p		(?)	(11)
Na	Pt	+97	+300	+3.222^p	−2.094^p			(11)
Na	Pb	−183	0	−4.16	−1.44			(19)
Ni^n	Pb	−200	+100	−16.325	−5.346	+5.703	1	(31)
Ni^h	Pb	0	+200	−19.067	−3.022		1.5	(59)
Ni	Pb	−260	0	−17.633	−5.016	+1.137	0.02	(80)
Ni	Pt	0	+313	−2.891	+0.622		0.5	(65)
Ni	Pt	+313	+900	+0.484**	−0.366	+0.1616	0.5	(65)
Ni	Pt	0	+1 200	−17.12	+2.46	−2.193	2	(68)
Pd	Pb	−200	+100	−7.409	−3.922	+12.65	1	(31)
Pt^h	Pb	−200	+300	−3.038	−3.248	+8.409	1.5	(17, 31, 59)
Pt^q	Pb	0	+100	−1.788	−3.460	+12.6	1	(17)
Pt	Pb	−260	0	−6.677	+0.1528		0.5	(80)
Rb	Pt	−200	−25	−3.537^p	+1.851^p			(11)
Rb	Pt	−25	+23.2	−4.332	−1.328		(?)	(11)
Rb	Pt	+37.2	+300	+2.141^p	−5.76^p			(11)
Rb	Pb	−183	0	−8.26	−3.02			(19)
Rb	Pb	+38	+100	−0.28^p	−6.00^p			(19)
Rh^h	Pb	−78	+100	+2.17	+0.05			(19)
Rh	Pt	0	+1 300	+6.27	+1.612	+0.1797	2.5	(45)
Sb	Pt	0	+630	+46.24	+6.362	−14.33	2	(65)
Sb	Pt	+650	+711		+2 100^p			(65)
Sb^r	Pb	0	+100	+35.58	+14.50		1.5	(41, 76)
Se^v	Pb	+10	+100	b = +99 030^p to 114 000^p				(46.1)
Si	Pb	−200	+350	−408.2	−46.96	+351.0	3	(79)
Sn	Pb	−260	0	−0.11	+0.264		3 mcv.	(80)
Sn	Pb	−200	+100	+0.0684	+0.0038	−0.266	1%	(31)
Sn	Pb	0	+100	−0.111	+0.040		1	(76)
Sn	Pb	0	+100	+0.230	−0.134		1	(17)
Sn	Pb	0	+200	−0.168	+0.187		1.5	(59)
Sn	Pt	0	+415	+2.870	+2.3		0.5	(65)
Sn	Pt	+415	+600	+13.0	d = −2 200		0.5	(65)
Ta	Cu	−200	+100	−3.358	−1.343		3 mcv.	(27)
Ta^s	Pt	0	+400	+2.20	+2.46		2%	(64)
Ta	Pt	0	+1 200	+2.0	+2.64		3	(68)
Te	Cu	Qu$<_{352}$, Q_{18} = +434††						(41)
		An$<_{352}$, Q_{18} = +229††						(41)
		Ht$>_{353}$, Q_{18} = +160††						(41)
Te^w	Cu	+20	+100	+191.2	−275.0	(0.0°)§§	1.0	(17)
Te^w	Cu	+20	+100	+148.7	−168.9	(7.5°)§§	1.0	(17)
Te^w	Cu	+20	+100	+277.2	−361.2	(12.5°)§§	1.0	(17)
Tl^u	Pb	0	+100	+2.14	−0.77		1	(76)
Tl	Pb	0	+100	+1.659	−0.268	−1.68	1	(17)
Tl	Pt	0	+310	+5.18	+1.34		1	(65)
Tl	Pt	+310	+404	−156‡‡	+70.66	−111.9	1	(65)
W	Pb	0	+100	+1.594	+3.41		1	(17)

TABLE 1.—(*Continued*)

M	*R*	t_1	t_2	a	b	c	Error	Lit.
W	Cu	−200	+ 300	− 1.080	+ 2.334	+ 2.375	5 mcv.	(27)
W^t	Cu	0	+ 630	− 1.12	+ 1.695		2%	(64)
W	Pt	0	+1 200	+ 9.4	+ 3.68		2	(68)
W	Ta	+950	+2 430	+ 5.21‖‖	+ 590		2.0	(57.1)
Zn	Pb	−260	0	+ 3.096	+ 3.191	+ 10.99	1	(80)
Zn^w	Cu	+ 20	+ 100	− 0.919	+ 0.28	(35.0°)§§	1.0	(17)
Zn^w	Cu	+ 20	+ 100	− 1.012	+ 0.93	(46.5°)§§	1.0	(17)
Zn^w	Cu	+ 20	+ 100	− 0.725	+ 0.75	(48.0°)§§	1.0	(17)
Zn^w	Cu	+ 20	+ 100	− 0.400	+ 0.59	(57.0°)§§	1.0	(17)
Zn^w	Cu	+ 20	+ 100	− 0.200	+ 0.75	(60.0°)§§	1.0	(17)
Zn^w	Cu	+ 20	+ 100	+ 0.154	+ 0.82	(80.0°)§§	1.0	(17)
Zn^w	Cu	+ 20	+ 100	+ 0.135	+ 0.97	(83.0°)§§	1.0	(17)
Zn^w	Cu	+ 20	+ 100	+ 0.232	+ 0.97	(86.5°)§§	1.0	(17)
Zn^t	Pb	−200	+ 100	+ 2.607	+ 1.074	+ 1.39	1	(31)
Zn	Pb	0	+ 100	+ 3.047	− 0.99		1.5	(17)
Zn^c	Pb	0	+ 250	+ 3.181	− 0.113		1.5	(59)
Zn	Pt	0	+ 450	+ 5.74	+ 3.30		1.5	(31, 59, 65)
Zn	Pt	+450	+ 700	− 17	d = +1 820		1.5	(65)

* Angle between basal cleavage plane and direction of current.

† Value of d; c = 0.

‡ d = 26 716.

§ d = −87.46.

‖ Value of d; c = 0.

¶ d = −12 400.

** d = −600.

†† Qu<$_{352}$, [An<$_{352}$] = quenched [annealed] from below 352°C; Ht>$_{353}$ = after heating above 353°C; Q_{18} = Q at 18°C.

‡‡ d = +12 420

§§ Angle between crystal axis and direction of current.

‖‖ d = 1 320.

[a] Annealed. [b] 99% pure. [c] Commercial. [d] 99.57% pure. [e] Electrolytic. [f] Filament of incandescent lamp. [g] Cold-drawn and hammered. [h] Heraeus made. [i] 99.8% Co, 0.2% Si, traces Fe. [j] Electrolytic, cold-drawn, annealed in hydrogen. [k] Pure "Swedish," hard-drawn, used for gold refining. [m] Very soft, annealed transformer Fe. [n] Deposited from nickel carbonyl. [o] 97.7% Ce, 1.2% Fe, remainder cerium oxide and cerium carbide. [p] Applies to equation for *Q* only. [q] Baker's platinum. [r] Used in cast form, solid rods soldered end to end. [s] Slight traces of carbon. [t] Traces of Fe. [u] 97.9% Tl, 1.5% Pb, traces of Cu and As. [v] Se in darkness; in light sufficient to increase its conductivity 600%, *Q* is decreased by 6%. [w] Single crystal.

TABLE 2.—THERMOELECTRIC POWER (${}_{Fe}Q_{Pt}$) OF COUPLES OF PURE IRON AND PLATINUM (22)

The pure iron contained 99.968 Fe, 0.009 C, 0.009 S, 0.001 P, 0.006 Si, 0.001 Mn and 0.006 Cu; the platinum was purest Heraeus Pt. For the Fe, the A_1 transformation point near 700°C, due to C, is absent; A_2 is at 768°C, Ar_3 and Ac_3 are at 900 and 910°C, respectively. Unit of $Q = 1\mu v/°C = 10^{-6}$ volt/°C; t = centigrade temperature, °C.

t	${}_{Fe}Q_{Pt}$	t	${}_{Fe}Q_{Pt}$	t	${}_{Fe}Q_{Pt}$
0	+19.5	775	+18.1	Temp. rising	
100	+18.1	800	+18.4	1000	+12.6
200	+15.4	880	+19.4	Temp. falling	
300	+11.7	Temp. rising		930	+11.1
400	+ 9.5	900	+19.7	920	+10.9
500	+ 9.1	910	+19.4	910	+10.8
600	+10.8	920	+16.6	900	+17.5
700	+14.3	930	+11.4		

TABLE 3.—THERMOELECTRIC POWER (Q) AND THERMO EMF (E) OF ALLOYS (MAINLY BINARY ALLOYS)

For list of commercial alloys and miscellaneous mixtures, *see* end of table. $Q = a + bt(10)^{-2} + ct^2(10)^{-5}$; $E = at + \frac{1}{2}bt^2(10)^{-2} + \frac{1}{3}ct^3(10)^{-5} + d$, one junction at 0°C; E can not be obtained from Q unless the value of d is known, but d is generally zero if no transformation point occurs between 0°C and t, °C. "$t_1\ t\ t_2$" denotes that the coefficients apply if t lies between t_1 and t_2. Unit of $Q = 1\mu v/°C = 10^{-6}$ volt/°C; t = centigrade temperature, °C.

Ag-Al; 0° t 100°; Q_{Pb} (18)

Vol. % Ag*	Annealed		Quenched	
	a	b	a	b
0.00	−0.07	−0.02	−0.04	−0.06
4.98	+0.67	−0.22	+0.43	−0.35
10.1	+0.74	−0.16	+0.70	−0.19
20.1	+0.93	+0.32	+1.05	+0.13
30.3	+1.24	+0.63	+1.39	+0.44
39.7	+1.58	+0.68	+1.84	+0.53
50.6	+2.24	+0.81	+2.75	+0.95
56.1	+2.90	+1.15	+3.25	+1.22
58.0	+3.01	+1.20	+3.56	+1.24
60.9†	+3.67	+2.13	+4.03	+1.54
63.5	+2.75	+0.96	+2.88	+0.81
67.4	+1.74	+0.56	+1.80	+0.58
69.8	+1.37	+0.34	+1.53	+0.22
73.2‡	+0.95	+0.37	+1.36	+0.25
75.4	+1.08	+0.40	+1.23	+0.29
80.0	+2.23	+0.55	+2.15	+0.64
90.3	+1.83	+0.35	+1.76	+0.48
95.1	+1.51	+0.47	+1.46	+0.40
100.0	+2.51	+0.76	+2.44	+0.72

* Electrolytic Ag. † Ag_3Al_2. ‡ Ag_3Al.

Ag_3Al_2-$AlCu_3$; 0° t 100°; Q_{Pb} (18)

Vol. % Ag_3Al_2	Annealed		Quenched	
	a	b	a	b
0	−1.36	+0.37	+1.48	+0.77
11.6	−4.18	−0.91	−3.79	+0.11
31.3	+3.71	+2.39	−2.93	+0.31
50.2	+6.94	+1.75	+9.56	+2.47
69.1	+3.99	+1.30	+6.27	+1.82
92.4	+2.78	+1.18	+3.15	+0.97
100.0	+3.67	+2.13	+4.03	+1.54

Ag-Au; 0° t 100°; Q_{Cu} (69)

Wt. % Au	a	b	Wt. % Au	a	b
0	+0.20	0.00	60	−2.13	−1.34
5	−1.34	−0.53	80	−2.16	−0.94
20	−2.70	−0.40	95	−0.84	−0.32
40	−2.40	−1.20	100	−0.00	−0.00

Ag-Cd; 0° t 100°; Q_{Cu} (71)

At. % Cd	a	b	At. % Cd	a	b
0.0	−0.31	+0.04	11.9	−1.41	−0.30
4.0	−1.32	−0.23	16.3	−1.42	−0.38
8.8	−1.42	−0.30	25.7	−1.23	−0.29

Ag-Hg; *see* **Hg**

Ag-Pd; 0° t 900°; Q_{Pt} (39)

Wt. % Ag	a	b	c
0	− 2.61	−0.444	−1.296
10	− 6.89	−2.778	+0.185
20	−11.44	−5.444	+2.037
30	−16.56	−7.444	+3.518
40*	−26.78	−6.667	+3.704
50	−20.333	−4.333	+1.667
60	−10.55	−1.889	−0.926
70	− 4.72	−0.333	−1.481
80	− 1.17	−0.278	−0.278
90	+ 0.22	+2.000	−0.741
100	+ 5.67	+2.667	−0.000

* Ag_2Pd_3.

Ag-Pt; 0° t 900°; Q_{Pt} (39)

Wt. % Pt	a	b	Wt. % Pt	a	b
10	+0.50	+1.00	30	−3.375	−0.938
25	−1.50	−0.624	33	−4.25	−1.00

Ag-Sb; t = 18°; Q_{Cu} (41); error = ±4.5%

Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}
10	−1.7	29	− 6.8	70	+14.33
15	−1.2	30	− 5.55	80	+17.63
20	−0.91	31	− 4.0	90	+20.5
25	−2.32	35	+ 1.32	95	+22.5
27	−2.9	40	+ 2.98	100	+32.0
27.07	−4.8	50	+ 8.15		
28*	−7.65	60	+12.12		

* Ag_3Sb.

Ag-Sn; 0° t 100°; Q_{Cu} (10); for 4 Wt. % Sn, a = − 8.21, b = +3.39

Ag-Tl; 0° t 100°; Q_{Cu} (10)

Wt. % Tl	a	b	Wt. % Tl	a	b
2.73	+2.95	−0.81	4.76	+12.24	−0.108

Al-Bi; 0° t 100°; Q_{Pb} (18)

Vol. % Bi*	Annealed		Quenched	
	a	b	a	b
0	− 0.07	−0.02	− 0.04	−0.06
1.89	− 0.36	−0.01	− 0.25	−0.05
4.83	− 0.85	−0.12	− 0.46	−0.01
10.0	− 0.92	−0.20	− 0.54	−0.02
30.0	− 9.27	−2.05	− 9.06	−2.09
50.0	−21.9	−2.14	−22.5	−2.14
70.0	−32.6	−3.60	−36.8	−3.36
90.0	−45.7	−0.12	−55.1	−3.02
94.6	−52.7	−1.24	−58.6	−3.48
97.9	−57.8	−1.46	−65.6	−2.01
100.0*	−58.7	−3.26	−55.7	−0.34

* Electrolytic.

Al-Cu; 0° t 100°; Q_{Pb} (18)

Vol. % Cu	Annealed		Quenched	
	a	b	a	b
0	− 0.07	−0.02	− 0.04	−0.06
1.18	+ 0.29	+0.23	+ 0.44	+0.07
2.78	+ 0.37	+0.58	+ 0.62	+0.22
6.41	+ 0.27	+0.45	+ 0.50	+0.15
10.6	+ 0.09	+0.27	+ 0.34	+0.06
16.3	+ 0.03	+0.20	+ 0.12	+0.03
22.1	− 0.24	−0.24	+ 0.06	−0.47
24.1	− 0.20	−0.40	− 0.05	−0.41
26.2*	− 0.28	−0.42	− 0.11	−0.41
31.6	+ 1.44	+0.61	+ 1.32	+0.48
37.9	+ 3.65	+1.38	+ 3.30	+1.26
41.7†	+ 3.80	+1.55	+ 3.96	+1.46
47.3	+ 3.48	+1.32	+ 3.30	+1.14
50.1	+ 2.72	+1.15	+ 2.98	+1.00
51.7‡	+ 2.81	+1.20	+ 2.76	+0.96
52.6	+ 6.64	+1.34	+ 5.83	+1.60
54.4	+11.80	+2.65	+11.25	+2.34
58.8	+ 6.07	+1.00	+ 6.10	+1.58
64.7	− 2.32	+0.23	− 1.22	+0.50
68.3§	− 1.36	+0.37	+ 1.48	+0.77
74.3	+ 1.78	+0.74	+ 2.33	+0.79
80.3	+ 2.06	+0.71	+ 2.27	+0.73
86.0	+ 2.15	+0.68	+ 2.17	+0.69
94.0	+ 2.24	+0.66	+ 2.24	+0.66
100.0	+ 2.88	+0.98	+ 2.88	+0.98

* Al_2Cu. † AlCu. ‡ Al_2Cu_3. § $AlCu_3$.

Al-Cu; 0° t 820°; Q_{Cu}* (64)

Wt. % Cu*	a	b	Wt. % Cu*	a	b
6.0	−2.21	−0.680	94.0	−1.78	−0.040
90.0	−1.21	−0.104	95.0	−2.53	−3.20
92.5	−1.59	−0.090	97.0	−2.31	−3.00

* Electrolytic.

Al-Fe; 0° t 100°; Q_{Pb} (18)

Vol. % Fe*	Annealed		Quenched	
	a	b	a	b
0	−0.07	−0.02	−0.04	−0.06
4.85	−0.65	−0.53	−1.07	−0.39
9.90	−1.46	−1.37	−2.04	−1.26
14.9	−2.13	−2.03	−2.45	−1.90
19.1	−2.65	−3.14	−2.85	−2.86
25.7			−4.17	−1.98

* Swedish Fe; 0.08 % C.

Al-Mg; 0° t 100°; Q_{Pb} (18)

Vol. % Mg*	Annealed		Quenched	
	a	b	a	b
0.0	−0.07	−0.02	−0.04	−0.06
5.68	+0.84	−0.39	+1.04	−0.59
10.28	+1.12	−0.58	+1.11	−0.58
20.7	+0.85	−0.55	+0.91	−0.58
25.4	+0.72	−0.70	+0.75	−0.56
30.3	+0.21	−0.42	+0.25	−0.37
39.5	−0.40	−0.40	−0.82	−0.28
41.2	−0.42	−0.55	−0.76	−0.43
46.0	−0.56	−0.60	−1.36	−0.37
51.7	−0.95	−0.82	−2.49	−0.56
58.5†	−4.19	−1.08	−4.56	−0.88
62.8	+1.68	−1.53	+1.57	−1.50
64.3	+3.51	−1.18	+3.48	−0.99
65.3	+3.53	+0.86	+3.43	+0.60
67.8‡	+1.22	+0.30	+1.01	+0.36
70.1	−0.05	+0.10	−0.13	+0.23
73.9	−0.33	+0.09	−0.99	−0.02
80.7	−0.78	−0.05	−1.52	−0.16
89.9	−1.64	−0.18	−1.86	−0.22
95.3	−1.64	−0.18	−1.46	−0.55
100.0	+0.18	−1.02	+0.24	−0.83

* 99.2 % Mg, 0.3 % Fe, 0.5 % Si by Wt. † AlMg. ‡ Al_2Mg_3.

Al*-Mg;† 0° t 420°; Q_{Cu} (60)

Wt. % Al*	a	b	c
0	−2.656	−0.7082	
10‡	−6.423	+1.196	− 4.961
87.5‡	−2.057	−0.7871	
90‡	−1.780	−0.980	
90‡§	−2.132	−0.836	
100‖	−4.495	+2.408	−12.877

* 99.67 % Al, 0.16 % Si, 0.15 % Fe, 0.02 % Cu. † Pure Mg. ‡ Cold-drawn. § Contains 8 % Mg and 2 % Ni. ‖ Heated red-hot and cooled in air.

Al-Mn; 0° t 100°; Q_{Pb} (18)

Vol. % Mn*	Annealed		Quenched	
	a	b	a	b
0.0	− 0.07	−0.02	−0.04	−0.06
2.40	− 5.04	−0.46	−5.17	−0.80
5.01	− 4.93	−0.91	−4.68	−0.97
8.99	− 4.81	−0.71	−4.62	−1.12
15.1	− 4.53	−0.58	−4.47	−1.08
19.8†	− 0.56	−1.48	−1.62	−1.66
24.1	+27.3	+2.59	+3.44	−0.21

* 96.8 % Mn, 1.8 % Al, 0.9 % Si, 0.5 % Fe, by Wt. In computing Vol. % of alloy, an allowance was made for the Al in the Mn. † Al_3Mn.

Al-Ni; 0° t 100°; Q_{Pb} (18)

Vol. % Ni*	Annealed		Quenched	
	a	b	a	b
3.81	−0.56	−0.07	−0.50	−0.10
8.12	−0.75	−0.10	−0.68	−0.27
11.7	−1.30	−0.15	−1.21	−0.32
18.4†	−1.35	−0.22	−0.83	−0.73
19.8	−0.91	−0.36	−0.80	−0.76
60.7	−0.93	−0.31	−4.57	−3.39
66.4	+6.02	+0.39	+6.07	−0.05
70.3	+10.4	−0.24	+10.3	−0.45
79.3	−5.30	−1.39	−4.93	−3.50
90.0	−17.3	−4.94	−14.9	−7.98
94.9	−16.8	−5.62	−16.9	−6.96
100.0	−16.2	−5.95	−16.2	−5.95

* No trace of Fe. † Al_3Ni.

Al-Ni; 0° t 1200°; Q_{Pt} (68)

Wt. % Al	a	b
5	−5.671	−0.6218

Al-Pb; 0° t 200°; Q_{Cu} (64)

Wt. % Al	a	b	Wt. % Al	a	b
0	−2.58	+0.02	96.0	−1.25	−1.00
92.0	−1.19	+0.07	100.0	−1.62	−0.59
94.0	−1.41	+0.06			

Al-Sb; 0° t 400°; Q_{Cu} (64)

Wt. % Sb	a	b	c
0.0	−1.030	−2.243	+8.665
60.0	−0.816	−0.598	+2.607
62.0	−0.233	−0.726	+2.492
65.0	−0.781	−0.968	+3.626
70.0	−0.306	−1.083	+3.715
100.0	−34.50	−4.941	+48.38

Al-Sn;* 0° t 100°; Q_{Pb} (18)

Vol. % Sn	Annealed		Quenched	
	a	b	a	b
5.03	−0.40	+0.25	−0.34	+0.46
10.1	−0.41	+0.23	−0.47	+0.48
19.9	−0.51	+0.38	−0.54	+0.54
29.2	−0.54	+0.53	−0.60	+0.66
40.2	−0.54	+0.53	−0.51	+0.64
49.8	−0.54	+0.56	−0.50	+0.64
51.4	−0.51	+0.48	−0.45	+0.55
59.4	−0.52	+0.54	−0.43	+0.61
62.0	−0.36	+0.45	−0.45	+0.55
69.8	−0.47	+0.48	−0.38	+0.61
80.0	−0.30	+0.53	−0.28	+0.58
90.5	−0.17	+0.48	−0.18	+0.53
95.0	−0.14	+0.42	−0.14	+0.42
100.0	−0.14	+0.42	−0.14	+0.42

* Al is soluble in Sn in all proportions.

Al*-Zn;† 0° t 100°; Q_{Pb} (18)

Vol. % Zn	Annealed		Quenched	
	a	b	a	b
4.60	+0.41	+0.07	+0.55	+0.29
9.50	+0.53	+0.32	+0.78	+0.40
19.3	+0.71	+0.44	+0.88	+0.47
29.0	+0.98	+0.52	+1.01	+0.58
39.3	+1.19	+0.66	+1.17	+0.69
49.6	+1.40	+1.00	+1.43	+1.04
60.0	+1.56	+1.05	+1.64	+1.13
68.7	+1.68	+1.20	+1.83	+1.30
78.4	+1.83	+1.26	+1.85	+1.31
89.0	+2.02	+1.54	+2.13	+1.50
95.0	+2.09	+1.69	+2.60	+1.56
100.0	+1.84	+1.59	+1.62	+1.36

* 99.7 % Al, 0.1 % Fe, 0.2 % Si, by Wt.
† Al is soluble in Zn in all proportions.

Au-Cd; 0° t 100°; Q_{Cu} (71)

At. % Cd	a	b	At. % Cd	a	b
0.0	−0.17	−0.03	8.7	−1.81	−0.50
5.4	−1.52	−0.19	17.2	−2.39	−0.48

Au-Cu; 0° t 150°; Q_{Cu} (69)

Wt. % Cu	a	b	Wt. % Cu	a	b
10.0	−0.40	−0.80	60.0	−0.83	−0.80
20.0	−0.84	−0.82	80.0	−0.59	−0.68
40.0	−0.88	−0.78	95.0	+0.25	−0.70

Au-Pd; 0° t 1000°; Q_{Pt} (39)

Wt. % Au	a	b	c
10.0	−7.944	−1.111	−0.185
20.0	−11.722	−1.556	+0.185
30.0	−12.722	−3.111	+1.296
40.0	−14.333	−5.222	+2.778
50.0	−21.777	−5.556	+3.704
60.0*	−26.444	−6.778	+5.370
70.0	−26.000	−0.444	−1.111
80.0	−4.111	−1.000	−0.185
90.0	−1.000	+1.000	−0.556
100.0	+6.777	+2.556	−0.926

* AuPd.

Au-Pt; Q_{Pt} is negative and on repeated or continued heating increases continually in absolute value, not becoming constant even after 2 hr at 900°C; its absolute value increases with the Pt content (39).

Au-Sb; t = 18°; Q_{Cu} (41)

Wt. % Sb.	50	55*	60
Q_{Cu} (18°).	−1.07	−17.0	−0.31

* $AuSb_2$.

Au-Zn; 0° t 100°; Q_{Cu} (71)

At. % Zn	a	b	At. % Zn	a	b
0.0	−0.17	−0.03	10.1	−2.25	−0.53
4.9	−1.85	−0.01	18.3	+0.33	+0.58

Bi-Cd; 0° t 125°; Q_{Cu} (69)

Wt. % Cd	a	b	Wt. % Cd	a	b
0.0	−105.50	+54.00	40.0	−31.04	+15.08
5.0	−77.50	+39.60	70.0	−12.34	+5.08
10.0	−68.27	+37.34	90.0	−5.47	+2.14
25.0	−47.13	+25.06	100.0	+1.56	+0.48

Bi-Hg; *see* **Hg**

Bi-Pb; t_1 t t_2; E_{Cu} (28)

Wt. % Pb	t_1	t_2	a	b	d
10.0	0	200	−8.25	−15.50	0
	241	450	−17.05	+3.30	−2000
20.0	0	110	+2.50	0.00	0
	110	200	−11.50	−17.0	0
	200	450	0	−1.50	−1000
30.0	0	120	+10.00	0.00	0
	126	450	−2.083	−0.834	+1250

Bi-Pb.—(*Continued*)

Wt. % Pb	t_1	t_2	a	b	d
40.0	0	110	+ 2.50	0.00	0
	110	450	− 6.365	+ 0.230	+1000
50.0	0	450	− 1.975	− 0.825	0
60.0	0	450	− 2.750	− 0.750	0

Bi-Pb; 0° t 150°; Q_{Pb} (6)

Vol. % Bi	a	b	Vol. % Bi	a	b
5.5	−0.0	+0.50	91.5	+ 2.00	−1.00
12.0	−0.0	+0.50	94.5	+ 0.50	−0.50
22.5	−0.30	+1.00	100.0	−30.00	−5.00
82.5	+2.50	−1.00			

Bi-Sb; t = 18°; Q_{Cu} (41)

Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}
2.0	−71.5	30.0	−42.0	70.0	+ 7.55
5.0	−74.7	40.0	−19.0	80.0	+15.5
10.0	−77.7	50.0	−11.0	85.0	+18.0
15.0	−63.7	55.0	− 3.8	90.0	+23.5
20.0	−53.3	60.0	− 1.95	95.0	+26.7

Bi-Sb; Q_{Cu} (38)

t =	−190°C	−77°C	0°C	+100°C
Wt. % Sb	Q_{Cu}			
0	− 30	− 75	−72	−64
9	−153	−103	−87	−77
11	−156	− 98	−84	−74
13	−130	− 95	−83	−73
20	−110	− 83	−71	−60
50	− 15	− 21	−21	−14
70	+ 3.4	+ 6.3	+ 8.6	+13
100	+ 12	+ 29	+36	+45

Bi-Sn; 0° t 100°; Q_{Cu} (24)

Wt. % Sn	a	b	Wt. % Sn	a	b
0.0	−40.20	−50.0	3.72	+29.4	−24.0
1.0	+ 6.77	−33.5	6.36	+39.4	−26.0
2.0	+26.0	−46.5	9.93	Q = +38.0 if t = 20.7°	

Bi-Sn; t_1 t t_2; E_{Cu} (28)

Wt. % Sn	$t_1 = 0, t_2 = 130$	$t_1 = 150, t_2 = 450$	
	a	a	d
10	+32.4*	−4†	+5300†
20	+27.6	−2.39‡	+4300‡
30	+18.0	−3.38	+2790
40	+13.35	−3.79§	+2190§
50	+10.0	−3.38	+1770
60	+ 3.75	−0.0042	+ 420
70	+ 1.80	−0.00518	+ 270

* t_2 = 125. † t_1 = 200. ‡ t_1 = 210. § t_1 = 130.

Bi-Sn; t = 30.7°; Q_{Pb} (48)

Wt. % Bi	Q_{Pb}	Wt. % Bi	Q_{Pb}	Wt. % Bi	Q_{Pb}
50.0	+ 8.75	90.0	+45.09	99.25	+12.96
60.0	+12.55	95.0	+45.62	99.62	+ 0.41
70.0	+20.14	97.5	+41.34	100.0	−64.66
80.0	+28.26	98.75	+33.48		

Bi-Te; t = 18°; Q_{Cu} (41)

Wt. % Bi	Q_{Cu}	Wt. % Bi	Q_{Cu}	Wt. % Bi	Q_{Cu}
2.0	+127.0	35.0	− 77.3	53.0	+62.0
5.0	+ 71.1	40.0	− 90.1	55.0	+27.7
10.0	+ 58.4	42.0	− 99.0	60.0	−18.3
13.9	+ 33.0	45.0	− 89.0	70.0	−21.8
15.0	+ 20.0	49.0	− 36.0	80.0	−16.2
20.0	− 9.83	50.0	+ 52.0	85.0	−11.0
25.0	− 37.0	52.0	+ 93.3	95.0	− 3.5
30.0	− 54.0	52.14*	+121.8	100.0	−57.4

* Bi_2Te_3.

Cd-Hg; 0° t 100°; Q_{Cu} (10); *see also* Hg-Metal

Wt. % Hg	a	b	Wt. % Hg	a	b
5.14	−4.33	+5.16	10.0	−3.62	+5.65

Cd-Pb; 0° t 100°; Q_{Pb} (6)

Vol. % Cd	8.0	15.0	73.8	85.0
a	+1.05	+1.75	+2.10	+2.60
b	+2.9	+3.4	+4.1	+3.9

Cd-Sb; 0° t 150°; Q_{Pb} (6)

Vol. % Sb	a	b	Vol. % Sb	a	b
6.6	+ 5.0	+ 4.0	58.5	+235.0	+48.0
25.8	+20.0	+13.0	66.5	+420.0	+63.0
41.0	+70.0	+19.0	72.0	+235.0	+46.0

Cd-Sb; Q_{Cu}*

Wt. % Sb	18°C (41)	50°C (8)	Wt. % Sb	18°C (41)	50°C (8)
	Q_{Cu}			Q_{Cu}	
0	+0.38		51.7	+305.0	
33.3		+ 4.48	66.7		+87.20
50.0		+134.2	100	+ 32.0	

* For 50 atom %, Q_{Cu} varies rapidly with composition and is much affected by unhomogeneous structure; mean value between 18 and 55°C may amount to +543 (35, 35.1).

Cd-Sn; 0° t 150°; Q_{Cu} (69)

Wt. % Cd	a	b	Wt. % Cd	a	b
0.0	−2.73	−1.34	70.0	−0.30	+1.60
10.0	−2.60	−0.34	90.0	−0.40	+3.20
30.0	−1.66	−0.28	100.0	−0.06	+3.72
50.0	−1.33	+1.06			

Cd-Zn; 0° t 150°; Q_{Cu} (69)

Wt. % Cd	a	b	Wt. % Cd	a	b
0.0	+0.20	0.00	70.0	−0.56	+4.04
10.0	−0.267	+0.53	90.0	−0.63	+4.22
30.0	−0.99	+2.58	100.0	−0.06	+3.72
50.0	−0.54	+2.68			

Co-Cu; t = 50°; Q_{Cu} (66)

Wt. % Co	Q_{Cu}	Wt. % Co	Q_{Cu}	Wt. % Co	Q_{Cu}
1.5*	+30.8	13.9	+29.1	70.3	+18.5
1.9	+32.1	23.6	+26.5	80.5	+17.6
3.1	+33.0	34.4	+25.9	90.4	+16.7
4.1*	+32.1	46.6	+20.8	100*	+27.37
6.7	+31.5	59.4†	+19.4		

All alloys contain traces of Fe and Ni. Q was measured after heating to 160°C.

* For 0° t 100°:

Co	1.5	4.1	100 %
a	+30.52	+31.03	+23.24
b	+0.776	+0.416	+ 8.26

† Contains 0.6% Fe.

Co-Fe; *see* Fe alloys

Co-Ni; 0° t 1200°; Q_{Pt}(68)

Wt. % Co	a	b	c
10	−28.39	+9.944	−6.546

Cr-Fe; *see* Fe alloys

Cr-Ni; 0° t 1200°; E_{Pt} (68)

Wt. % Cr	a	b	c
4.0	+22.43	+1.531	−1.914
5.0	+21.304	+1.716	−4.038
8.0	+28.47	+1.325	−1.492
10.0	+30.3	0.0	0.0
12.0	+19.9*	+2.8	
12.0	+31.28†	d = −1700	
16	+11.00‡	+7.70	−8.655
16	+30.22§	d = −3830	

* 0° t 200°. † 200° t 1200°. ‡ 0° t 600°. § 600° t 1200°

Cu-Hg; *see* **Hg**

Cu-Mn-Ni; 0° t 100°; E_{Pb} (17) manganin (84Cu, 12Mn, 4Ni) (?); a = +1.366, b = +0.0828, c = +3.36.

Cu-Mn-Ni-Fe;* t = 25°; Q_{Cu} (47)

Wt. %				Q
Cu	Mn	Ni	Fe	
88.02	9.93	1.71	0.24	+4
87.24	10.26	1.77	0.52	+5
88.20	8.84	1.78	0.93	+3
83.60	12.03	3.41	1.04	+8
84.72	12.83	2.08	0.73	+4

* All specimens annealed.

Cu-Ni; 0° t 100°; Q_{Cu} (71)

At. % Ni	a	b	At. % Ni	a	b
5.4	−17.67	−4.55	66.4	−32.12	−2.47
10.8	−22.42	−6.69	69.6	−32.76	−1.58
21.4	−28.11	−7.73	73.0	−34.02	−1.48
32.1	−32.93	−7.71	74.5	−33.01	−0.71
41.9	−35.10	−7.74	74.7	−30.43	−2.36
50.9	−39.41	−8.66	82.8	−33.65	−1.66
55.1	−33.17	−6.75	88.3	−31.08	−3.84
62.8	−32.56	−5.95	100.0	−25.56	−3.40

For 3.94 Wt. % Ni, a = −15.14, b = +10.2; for 17.3 Wt. % Ni, a = −24.9, b = −13.2 (10).

Constantan = 60% Cu, 40% Ni; 0° t 400°, a = −38.105, b = −8.884, c = +8.568; error in E = ±1% (2).

Cu-Ni; t_1 t t_2; E_{Pt} (68)

Wt. % Cu	t_1	t_2	a	b	c
0.0	0	1200	−17.12	+2.460	−2.193
10.0	0	400	−30.85	+4.250	
	400	1200	−21.71		
30.0	0	300	−36.87	+4.712	
	300	1200	−39.37	d = +2980	
50.0	0	350	−53.23	+4.756	
	350	1200	−50.64	d = +1700	
70.0	0	400	−44.73	−0.978	
	400	1200	−49.80		

Cu-Ni; t = 50°; Q_{Pb} (34)

Wt. % Ni	Q_{Pb}	Wt. % Ni	Q_{Pb}	Wt. % Ni	Q_{Pb}
10.0	−22.0	41.8	−38.8	62.8	−31.5
15.5	−27.3	46.0	−38.8	89.3	−25.1
20.0	−29.0	49.0	−35.4	93.5	−23.0
24.5	−29.4	50.7	−35.8	100.0	−20.2
30.0	−33.3	56.0	−34.2		

Cu-Ni-Zn; −200° t +100°; E_{Pb}, German silver (commercial) (31); a = −10.861, b = −3.294, c = +1.893.

Cu-P; t = 18°; Q_{Cu} (41)

Wt. % P	Q_{Cu}	Wt. % P	Q_{Cu}	Wt. % P	Q_{Cu}
1.88	+0.06	6.20	+1.40	13.97	+6.30
4.03	+0.435	8.75	+2.10	14.16*	+6.85
4.08	+0.48	12.70	+5.20	14.29	+4.30
5.75	+1.30	13.62	+6.00	14.56	+4.00

* Cu_3P.

Cu-Sn; −80° t 100°; Q_{Pb} (56)

Vol. % Sn	a	b	Vol. % Sn	a	b
0	+3.57	+1.01	55	+2.07	+0.80
5	+0.81	+0.20	60	+2.43	+0.76
10	+0.66	+0.21	65	+2.45	+0.70
15	+1.17	+0.12	70	+1.30	+0.68
20	+1.25	+0.23	75	+1.47	+0.66
25	+0.86	+0.28	80	+1.06	+0.70
30	+0.49	+0.37	85	+0.41	+0.46
35	+2.13	+0.39	90	+0.31	+0.46
40	+1.54	+0.73	95	−0.10	+0.185
45	+1.58	+0.89	100	−0.13	+0.25
50	+2.18	+0.89			

Cu-Sn; 0° t 100°; Q_{Cu}; for 5 Wt. % Sn, a = −3.46, b = +0.322 (10).

Cu-Zn;* −78° t 100°; Q_{Pb} (61)

Vol. % Zn	a	b	Vol. % Zn	a	b
0.0	+2.350	+1.38	59.5†	−0.062	+0.40
3.15	+0.707	+1.01	63.2	−1.082	+0.79
9.3	+0.608	+0.81	68.4	+0.639	+2.20
14.2	+0.710	+0.56	73.6‡	+3.330	+2.45
18.15	+0.740	+0.50	79.3	+2.195	+1.36
22.8	+0.702	+0.39	80.15	+1.407	+0.97
31.5	+0.602	+0.59	85.5	+1.821	+1.13
33.7	+0.699	+0.69	90.4§	+4.716	+1.75
39.3	+0.602	+0.59	93.7	+4.279	+1.54
41.7	+0.249	+0.60	95.0	+4.288	+1.72
47.7	+0.476	+0.44	98.8	+3.220	+1.69
53.2	+0.490	+0.62	100.0	+2.609	+1.49
53.4	+0.539	+0.73			

* Electrolytic Cu; Zn free of As and Pb. † CuZn. ‡ $CuZn_2$. § $CuZn_6$.

Alloys of less than 45% Zn were annealed for 36 hr at temperature about 30° below transformation point; other alloys annealed at 650°C.

Cu-Zn; 0° t 100°; E_{Pb}, brass (commercial) a = +0.140, b = +0.5166 (59).

Fe-C Steel; *see* Tables 4, 5

Fe-Co;* t = 100°; E_{Cu} (37)

Wt. % Co	10.0	20.0	30.0
E_{Cu}	− 0.64	− 3.70	− 3.50

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Cr;* t = 100°; E_{Cu} (37); *see also* Table 4

Wt. % Cr	E_{Cu}	Wt. % Cr	E_{Cu}	Wt. % Cr	E_{Cu}
10.0	+1.20	20.0	+0.43	29.5	+0.31
18.0	+1.04	23.5	+0.32		

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Cr-Ni;* t = 100°; E_{Cu} (37)

Wt. %				E_{Cu}
Cr	Ni	Si	C	
4.0	17.0	0	0	−0.12
10.0	20.0	0	0	−0.46
10.0	55.0	0	0	0.00
15.0	60.0	0	0	+0.07
20.0	55.0	0	0	+0.07
25.0	55.0	0	0	−0.08
7.0	75.5	0.03	0.22	+0.20
13.1	70.6	0.02	0.17	+0.20
13.1	70.6	0.02	0.20	+0.17
11.0	84.0	0.40	0.034	+1.49
15.6	80.4	0.58	0.23	+0.76

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Cr-Mn-Ni;* t = 100°; E_{Cu} (37)

Wt. %					E_{Cu}
Cr	Mn	Ni	Si	C	
0.31	6.6	58.3	1.0	0.16	−0.94
0.11	12.0	82.8	1.058	0.068	−1.11
0.11	6.2	88.5	0.061	0.065	−1.60
31.9	0.20	57.7	0.30	0.40	−0.08
22.7	0.30	69.0	0.25	0.20	+0.24

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Cr-Mn-Ni; t_1 t t_2; E_{Pt} (60) nichrome (16Cr, 22.5Fe, 3Mn, 58.5Ni approximately)

t_1	t_2	a	d	t_1	t_2	a	d
0	420	+25.0		500	1082	−34.9	+6994

Fe-Mn; *see* Table 4

Fe-Mn-Ni;* t = 100°; E_{Cu} (37)

Wt. %		E_{Cu}	Wt. %		E_{Cu}
Mn	Ni		Mn	Ni	
3.0	10.0	−1.09	6.0	17.5	−0.73
2.0	12.0	−1.02	2.0	22.0	−1.84
2.0	17.0	−1.50	6.0	44.0	−0.59
3.0	17.0	−0.79			

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Mo; *see* Table 4

Fe-Ni;* t = 100°; E_{Cu}(37); *see also* Table 4

Wt. %			E_{Cu}	Wt. %			E_{Cu}
Ni	Si	C		Ni	Si	C	
0	0	0	+0.86	81.2	0.014	0.19	−2.45
17.0	0	0	−0.64	93.0	0	0	−1.90
20.0	0	0	−0.55	94.6	0.64	0.11	−1.40
30.0	0	0	−0.52	96.3	0.35	0.12	−2.00
33.5	0.16	0.25	−0.48	100.0	0	0	−2.38

* Annealed by heating with electric current for 15 min; not over 2 % difference between hard-drawn and annealed wires.

Fe-Ni; t = 48°; Q_{Cu} (49)

Wt. % Ni	Q_{Cu}*	Wt. % Ni	Q_{Cu}*	Wt. % Ni	Q_{Cu}*
4.0	+ 2.32	21.0	+23.5	45.0	+29.0
7.0	+ 7.32	22.11	+21.0	47.08	+31.9
13.0	+16.9	26.4	+16.7	90.0	+17.9
14.0	+17.2	35.09	+ 9.79		
18.0	+21.0	40.0	+22.4		

* If diameter of wire > 0.12 cm, Q is somewhat greater.

Fe-Ni; t_1 t t_2; E_{Pt} (68)

Wt. % Fe	t_1	t_2	a	b
10	0	750	−27.66	+7.326
	750	1200	+20.612*	

* d = −15 600.

Fe-Si; *see* Table 4

Fe-Ti; at 50°C, Q_{Cu} = −140 (52)

Fe-W; *see* Table 4

Hg-Metal; 20° and t; E_{Hg} (33)

Metal	At.*	80°	100°	180°
Ag	1	+ 1.0	+ 1.2	+ 2.6
Bi	1	+ 59.6	+ 84.5	+203.6
Cd†	1	+ 7.9	+ 12.1	+ 28.2
Cu	1	+ 0.7	+ 0.8	+ 1.3
K	1	− 21.6	− 33.0	− 82.2
	8.47	−177.2	−273.4	−694.0
Li	0.253	− 13.9	− 22.4	− 43.4
	1	− 55.4	− 78.7	−184.8
Na	1	− 37.5	− 51.7	−117.1
	3.34	−114.2	−160.7	−389.0
Pb‡	1	+ 25.6	+ 34.6	+ 82.5
Sb	1	+ 5.1	+ 7.5	+ 21.4
Sn	1	+ 19.9	+ 26.9	+ 65.8
Tl‡	1	− 41.8	− 57.6	−138.8
Zn	1	+ 6.2	+ 9.2	+ 24.4

* Atoms of metal per 100 atoms of Hg. † *See* **Cd-Hg** for Q_{Cu}. ‡ *v. infra.*

Hg-Pb; 20° and t; E_{Hg} (33)

Wt. Pb*	80°	100°	180°
	E_{Hg}		
1.03	+ 25.6	+ 34.6	+ 82.5
2.06	+ 35.5	+ 48.9	+110.1
3.09	+ 70.8	+120.8	+239.9
6.19	+ 92.0	+154.0	+548.3
9.28	+124.3	+162.6	+629.2
12.38	+ 94.2	+151.4	+529.9
15.47	+ 87.3	+148.2	+439.5
18.57	+ 96.6	+170.9	
24.77	+113.5	+179.6	+591.0
49.53	+147.2	+217.2	+656.9
98.2	+169.4	+250.3	+733.2
206	+216.5	+280.6	+746.7

* Grams Pb per 100 g Hg.; *see also* **Hg-Metal.**

Hg-Tl; 20° and t; E_{Hg} (33,

Wt. Tl*	80°	100°	180°
	E_{Hg}		
0.255	− 10.8	− 14.6	− 32.5
0.51	− 21.8	− 29.8	− 68.8
1.02	− 41.8	− 57.6	− 138.8
2.04	− 67.9	− 93.2	− 199.2
3.055	− 79.3	−111.0	− 250
4.08	− 86.6	−125.8	− 282.1
6.11	− 82.7	−114.3	− 246.8
12.22	− 44.4	− 65.3	− 120.7
24.44	+ 35.8	+ 52.2	+ 149.8
∞ †	+321.7	+445.0	+1001.1

* Grams Tl per 100 g Hg; *see also* **Hg-Metal.** † Pure Tl.

Ir-Pt;* 0° t 1200°; Q_{Pt} (39)

Wt. % Ir	a	b	c
5	+10.375	+0.250	−0.2344
10	+13.208	+0.750	−0.3906
15	+14.083	+1.063	−0.3906
20	+13.00	+1.875	−0.9375
25	+11.250	+2.250	−1.1718
30	+10.75	+2.375	−0.9375
35	+10.50	+2.375	−0.9375

* Alloy in all proportions.

Mn-Ni; t_1 t t_2; E_{Pt} (68); Wt. % Mn = 5

t_1	t_2	a	b
0	400	−2.158	+6.58
400	1200	−0.375	d = −3220

Mo-Ni; 0° t 1200°; Q_{Pt} (68)

Wt. % Mo	a	b	Wt. % Mo	a	b
4	+11.85	+1.2056	12	+27.45	+1.788
5	+14.90	+1.48	16	+27.45	+2.00
8	+21.08	+1.784	20	+23.38	+2.392
10	+24.70	+1.720			

Nichrome; *see* **Fe-Cr-Mn-Ni**

Ni-Ta; 150° t 1200°; E_{Pt} (68); for 5 Wt. % Ta, a = −0.573, d = −1914

Ni-Ti; t_1 t t_2; E_{Pt}; Wt. % Ti = 5 (68)

t_1	t_2	a	b
0	600	−7.98	+1.256
600	1200	−1.117	d = −1860

Ni-V; 0° t 1200°; Q_{Pt} (68)

Wt. % V	a	b	Wt. % V	a	b
5	+18.30	+1.72	10	+26.5	+1.56

Ni-W; 0° t 1200°; Q_{Pt} (68)

Wt. % W	a	b	Wt. % W	a	b
4	+1.428	+0.885	12	+12.26	+1.906
5	+2.90	+1.08	16	+16.38	+1.96
8	+6.91	+1.664	20	+20.22	+2.128
10	+9.70	+1.72			

Ni-Zr; 0° t 1200°; Q_{Pt} (68); for 5 Wt. % Zr, a = −12.57, b = +2.286

Pb-Sb; 0° t 150°; Q_{Cu} (69)

Wt. % Sb	a	b	Wt. % Sb	a	b
0.0	−2.83	−0.94	50.0	+ 2.11	+2.08
5.0	−1.68	−1.10	70.0	+ 2.15	+3.80
13.0	−1.54	−0.44	90.0	+ 4.23	+6.54
30.0	+0.33	+1.34	100.0	+37.53	+7.74

Pb-Sn; 0° t 150°; Q_{Cu} (69)

Wt. % Sn	a	b	Wt. % Sn	a	b
0	−2.83	−0.94	50	−2.67	−1.06
5	−2.63	−0.94	80	−3.13	−0.54
30	−2.80	−0.80	100	−2.73	−1.34

Pb-Tl; 0° t 180°; Q_{Pb} (33); for 2.03 Wt. % Tl, a = −0.0120, b = −0.0742

Pb-Zn; 0° t 180°; Q_{Pb} (33); for 0.63 Wt. % Zn, a = +0.0040, b = +0.016

Pd-Pt;* 0° t 1200°; Q_{Pt} (39)

Wt. % Pt	a	b	c
0	−3.875	−1.350	−0.234
10	+4.042	−0.563	−0.781
20	+6.792	+0.438	−1.250
30	+7.583	+0.938	−0.885
40	+7.000	+1.375	−0.938
50	+7.167	+1.188	−0.677
60	+5.833	+1.500	−0.729
70	+5.125	+1.135	−0.469
80	+4.875	+0.812	−0.469
90	+3.625	+0.395	−0.234

* Alloy in all proportions.

Pt-Rh; 0° t 1600° Q_{Pt}; *see also* Vol. I, p. 57; error in E_{Pt} may amount to ±50

Wt. % Rh	a	b	c	Lit.
1	+2.19	−0.044	+0.024	(29)
5	+5.99	+0.200	−0.060	(29)
10	+7.013	+0.640	−0.1932	(29)
10*	+7.048	+0.5896	−0.1284	(80)
15	+6.69	+1.072	−0.3276	(29)
20	+6.083	+1.380	−0.3999	(29)
30	+6.12	+1.344	−0.1092	(46)
40	+6.44	+1.344	−0.0468	(46)
100	+6.27	+1.612	−0.1797	(45)

* Le Chatelier's couple.

Pt-Rh; t_1 t t_2; E_{Pt}; Rh, Wt. % = 10; error in E may amount to ±50

t_1	t_2	a	b	c	Lit.
−253	0	+5.97	+4.28		(80)
0	+650	+5.543	+1.804	−1.965	(80)
+650	1600	+8.162	+0.338	d = −283.5	(80)
+250	1600	+8.048	+0.344	d = −310	(45)
+400	1100	+8.259*	+0.3332	d = −313.8	(21)

* Made by Heraeus; diameter = 0.4 mm.

Pt-Ru; 250° t 1500°; E_{Pt} ±5 (45); for 10 Wt. % Ru, a = +9.260; b = +0.300, d = −359

Sb-Sn; t = 30.1°; Q_{Pb} (48)

Wt. % Sb	Q_{Pb}	Wt. % Sb	Q_{Pb}	Wt. % Sb	Q_{Pb}
20	+1.07	60	+12.54	90	+ 7.77
30	+2.16	70	+12.20	95	+ 7.93
50	+6.14	80	+14.08	100	+32.67

Sb-Te; t = 18°; Q_{Cu} (41)

Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}	Wt. % Sb	Q_{Cu}
2	+139.0	35	+62.3	70	+ 2.3
5	+105.0	38.90*	+82	75	+ 1.6
10	+ 93.0	40	+34.0	80	+ 1.0
13	+ 86.5	45	+13.5	83	+ 3.5
15	+ 81.7	50	+ 9.3	90	+ 6.5
20	+ 74.0	55	+ 8.0	95	+10.0
25	+ 63.0	60	+ 4.5		
30	+ 61.2	65	+ 3.0		

* Sb_2Te_3.

SeSn; E_{Pt} is of same order of magnitude as for Se_2Sn but is of opposite sign (65)

Se_2Sn; 0° t 650°; E_{Pt} (1 ± 0.025); a = +389.5, b = +6.334 (65)

Se-Te; t = 18°; Q_{Cu} (1 ± 0.03) (41)

Wt. % Se	Q_{Cu}	Wt. % Se	Q_{Cu}	Wt. % Se	Q_{Cu}
2.0	+480	15	+680	40	+620
5	+570	20	+580	45	+580
10	+563	30	+540	50	+460

Sn-Te; t = 18°; Q_{Cu} (41)

Wt. % Sn	Q_{Cu}	Wt. % Sn	Q_{Cu}	Wt. % Sn	Q_{Cu}
10	+116.0	45	+22.3	70	−0.2
15	+ 84.0	48.28*	+26.0	80	−0.8
20	+ 71.0	49	+99.0	85	−1.35
30	+ 42.2	50	+ 6.3	90	−1.5
35	+ 34.0	55	+ 1.6	95	−1.4
40	+ 28.0	60	+ 0.7	100	−2.25

* SnTe.

Sn-Zn; 0° t 150°; Q_{Cu} (69)

Wt. % Sn	a	b	Wt. % Sn	a	b
0	+0.20	0.0	70	−1.43	−0.94
10	−0.23	−0.14	90	−2.37	−0.66
30	−1.39	+0.18	95	−2.57	−0.66
50	−1.23	−0.46	100	−2.73	−1.34

Commercial Alloys and Miscellaneous Mixtures

"Akkumulatorenlot" (75Pb, 20Hg, 5Sb), 0° t 300°, $E_{Constantan} = 4.18\ t$ (25)

Brass; *see* **Cu-Zn**

Chronin (80)

t,°C...........	− 78.5	− 170.3	− 188.8	− 252.7
E_{Pb}...........	+1277	+2435	+2612	+3025

Constantan; *see* **Cu-Ni**

Culmitz (80)

t, °C	E_{Pb}	t, °C	E_{Pb}
− 78.4	+204	−192.6	+401*
	+160*	−252.7	+596
−192.6	+476		+472*

* After annealing.

German Silver; *see* **Cu-Ni-Zn**

Kruppin (80)

t, °C................	− 78.5	−170.3	− 188.8	−252.7
E_{Pb}................	−280	−992	−1129	−920

Manganin; *see* **Cu-Mn-Ni**

Nernst filament; 980° t 1425°; Q_{Pt}; a = +405 (72)

Nichrome; *see* **Fe-Cr-Mn-Ni**

Nickelin (80)

t, °C	E_{Pb}	t	E_{Pb}
− 78.4	−1256	−192.6	−2416*
	−1259*	−252.7	−2650
−192.6	−2406		−2600*

* After annealing.

Piano wire; *see* Table 4

Platinoid; −200° t 100°; E_{Pb}; a = −10.620, b = −2.766, c = +3.171 (31)

Resistin (80)

t, °C................	− 78.5	−170.3	−188.8	−252.7
E_{Pb}................	+331	+652	+713	+895

Steel; *see* **Al-Fe, Fe,** and Tables 4, 5

TABLE 4.—MEAN THERMOELECTRIC POWER (E/t) BETWEEN 0 AND t°: STEELS, t = −78.5 AND +100° (32)

For other alloys of Fe, *see* Tables 3, 5. $E = \mathrm{a}t + \frac{1}{2}\mathrm{b}t^2(10)^{-2} + \frac{1}{3}\mathrm{c}t^3(10)^{-5}$; $Q = \mathrm{a} + \mathrm{b}t(10)^{-2} + \mathrm{c}t^2(10)^{-5}$. An. = annealed; Qu. = quenched; "$t_1\ t\ t_2$" denotes that t lies between t_1 and t_2. Except where the contrary is indicated, one junction is at 0°C and the other at t, °C. Steels of low C content were annealed in magnesia; those of about 0.8% C, in turnings of pig iron. Mean error in all cases = *ca.* 30μv(= 30 microvolt). Unit of E = 1μv = 10^{-6} volt; of Q and E/t = 1μv/°C = 10^{-6} volt per 1°C; t = centigrade temperature, °C.

Symbol	Composition in %						E_{Pb}/t					
							Annealed		Quenched		Ingot	
	C	Mn	P	S	Si	Al	−78.5°	+100°	−78.5°	+100°	−78.5°	+100°
	Al steels; *see also* Table 3; An. from 900°C, cooling 8.75 hr; Qu. at 1000°C in water at 14°C*											
1A2	0.17	Tr.	0.008	0.022	Tr.	2.04	− 7.65	−12.65	− 8.26	−11.50		
1A3	0.13	Tr.	0.016	0.013	0.10	3.04	−11.93	−12.65	−11.93	−10.05		
1A7	0.08	0.05	0.020	0.017	0.18	7.20	−16.92	−12.65	−17.32	−10.05		
8A5	0.81	0.12	0.024	0.024	0.22	4.6	−10.20	−14.65	−13.86	−16.30		
8A7	0.66	0.14	0.025	0.050	0.26	7.0	−11.52	−16.05	−15.90	−16.30		
8A10	0.67	0.09	0.034	0.024	0.11	9.1	−15.40	−16.05	−14.90	−16.30		
8A15	0.86	0.40	0.032	0.018	0.23	14.9	− 8.77	−13.15	−13.03	−14.05		
	C steels; *see also* Tables 3, 5; An. from 900°C, cooling 8.5 hr; Qu. at 950°C in water at 15°C*											
H1	0.07	0.03	0.005	0.013	0.00		+11.93	+ 8.55	+12.59	+ 8.73		
H2	0.24	0.03	Tr.	0.015	0.03		+11.11	+ 7.65	+ 9.99	+ 6.93		
H3	0.44	0.08	Tr.	0.016	0.05		+ 9.68	+ 6.20	+ 5.20	+ 3.46		
H4	0.79	0.09	0.006	0.009	0.00		+ 8.05	+ 5.40	+ 0.92	− 1.32		
H5	1.12	0.06	Tr.	0.022	0.02		+ 6.02	+ 4.10	− 5.25	− 5.70		
H6	1.58	0.09	Tr.	0.016	0.04		+ 6.73	+ 4.15	− 6.52	− 5.80		

For H1 to H5, coefficients of Q_{Cu} are: 0° t 700°, a = A, b = −0.563A, c = +0.5A, where $\mathrm{A} \equiv 18.8 - 10.5C + 4.1C^2$, carbon content = C%; $t_2\ t\ t_3$, a = −5.9 − 0.01bt_2, b = −0.38; $t_3\ t$ 1000°, a = −10.5 − 0.01bt_3, b = −2.8; t_2, t_3 = temperatures of transformations A_2, A_3 (18). For pure Fe, t_2 = 730°, t_3 = 950°; increasing C decreases both; with more than 0.4% C they coincide at *ca.* 700° (18). For piano wire, coefficients of E_{Pb} −200° t 100° are: a = +10.763, b = −1.5586, c = −18.762 (31).

						Cr						
	Cr steels; *see also* Table 3; An. from 1000°C, cooling 7 hr; Qu. at 1000°C in water at 11°C*											
1C1	0.06	Tr.	0.016	Tr.	0.70	1.20	+17.87	+16.93	+ 6.83	+16.4	+17.43	+16.6
1C2	0.08	0.08	0.015	Tr.	0.12	1.89	+15.72	+16.65	+14.78	+15.20	+15.51	+16.6
1C3	0.28	0.15	0.010	Tr.	0.05	2.66	+17.28	+18.11	+14.88	+21.50	+14.99	+17.10
1C7	0.07	Tr.	0.010	0.014	0.12	7.84	+ 9.94	+14.92	+ 9.99	+13.50	+ 8.67	+12.70
1C10	0.42	Tr.	0.010	Tr.	0.35	9.80	+12.40	+14.74			+ 6.97	+ 5.82
1C12	0.14	Tr.	0.016	0.015	0.21	13.60	+ 6.63	+10.56	+ 5.20	+ 7.65	+ 6.27	+ 8.73
1C25	0.24	0.10	0.022	0.013	0.26	25.31	+ 6.38	+ 9.01	+ 6.40	+ 5.09	+ 4.25	+ 6.28
1C30	0.46	Tr.	0.024	0.006	0.37	31.75	+ 4.37	+ 6.55	+ 5.09	+ 7.86	+ 6.03	+ 9.55
8C1	0.97	0.24	0.013	0.016	0.22	0.92	+ 9.93	+ 8.92	+ 3.97	+ 3.64	+ 9.70	+ 8.83

TABLE 4.—(*Continued*)

Symbol	Composition in %						E_{Pb}/t					
							Annealed		Quenched		Ingot	
	C	Mn	P	S	Si	Cr	−78.5°	+100°	−78.5°	+100°	−78.5°	+100°
	Cr steels; *see also* Table 3; An. from 1000°C, cooling 7 hr; Qu. at 1000°C in water at 11°C*											
8C2	0.89	0.10	0.020	0.033	0.28	2.14	+10.41	+9.64	+3.59	+4.20	+9.70	+9.00
8C5	0.79	Tr.	0.016	0.023	0.42	4.57	+12.40	+12.56	+7.13	+5.91	+12.53	+12.90
8C7	0.84	0.05	0.018	0.031	0.41	7.27	+11.82	+13.45			+10.40	+11.90
8C10	0.52	0.13	0.024	0.005	0.62	9.85	+11.70	+14.48	+5.08	+3.58	+2.83	+3.63
8C12	0.96	0.05	0.013	0.047	0.41	11.52	+10.60	+13.60	+7.03	+9.70	+9.60	+11.90
8C20	0.90	0.05	0.010	0.007	0.74	18.65	+5.09	+7.95	+3.31	+4.64	+0.83	−1.55
8C25	0.82	0.05	0.016	0.008	0.58	26.54	+3.36	+5.91	+2.04	+4.64	+2.90	+5.37
8C30	0.92	0.05	0.021	0.012	0.47	32.46	+6.97	+6.30	+4.40	+5.55	+4.95	+6.28
	Mn steels; An. from 900°C, cooling 5 hr; Qu. at 1000°C in water at 14°C*											
8M0.5	0.87	0.40	0.020	0.024	1.35		−0.30	−3.10		−2.00		
8M1	0.84	1.03	0.024	0.015	0.57		−0.71	−2.80	−5.50	−6.65		
8M3	0.93	3.08	0.015	0.010	1.44		−2.65	−4.70				
8M12	0.96	12.09	0.011	0.013	0.87		−9.78	−11.80	−10.20	−6.65		
	1.2	5.0	Ni = 25.0	Hadfield's Mn steel; for E_{Fe}, 0° t 310°, a = +21.8, b = −5.8; for 310° < t < 1100°, E_{Fe} = +3975 ± 50 (5)								
	(?)	12	(?)	Hadfield's Mn steel; for E_{Pb}, −200° t +100°; before annealing, a = −5.591, b = −0.5152, c = +0.390; after An. from 600°, a = −5.067, b = −0.3582, c = +2.337 (31)								
						Mo						
	Mo steels; An. from 900°C, cooling 8.75 hr; Qu. at 1000°C in water at 14°C*											
1Mo0.5	0.19	0.07	0.018	0.009	0.12	0.45	+10.20	+8.35				
1Mo1	0.16	0.10	0.018	0.032	0.11	1.00	+11.01	+7.70	+10.20	+8.00		
1Mo2	0.14	0.17	0.021	0.009	0.12	2.20	+10.90	+7.80	+10.30	+7.92		
1Mo5	0.29	0.50	0.026	0.039	0.12	4.50	+8.77	+6.30	−12.23	+3.98		
8Mo0.5	0.78	0.26	0.021	0.032	0.21	0.50	+4.59	+3.00	−4.48	−6.50		
8Mo1	0.81	0.40	0.040	0.018	0.02	1.21	+4.79	+3.20				
8Mo2	0.81	0.30	0.016	0.034	0.017	1.98	+5.30	+4.30	+1.12	+0.10		
						Ni						
	Ni steels;† *see also* Table 3; An. from 900°C, cooling 7 hr; Qu. at 950°C in water at 18°C*											
1N2	0.07	0.02		0.006	0.07	2.23	+9.07	+6.3	+10.91	+6.2	+8.97	+6.5
1N5	0.12	0.01		0.004	0.05	5.23	−0.61	−3.5	+0.2	−3.4	−0.61	−3.2
1N7	0.12	0.12		0.005	0.05	7.13	−4.89	−7.8	−4.99	−7.6	−4.89	−7.6
1N10	0.13	Tr.		0.005	0.10	10.10	−10.8	−14.6	−11.11	−9.7	−11.21	−13.5
1N12	0.12	Tr.		0.002	0.09	12.07	−14.58	−16.9	−14.78	−17.0	−18.45	−17.4
1N15	0.11	Tr.		0.004	0.02	15.17	−19.38	−23.5	−18.75	−23.9	−20.28	−24.3
1N20	0.18	Tr.		0.004	0.02	20.40	−28.96	−30.4	−33.22	−31.3	−27.83	−30.0
1N25	0.16	Tr.		0.007	0.04	25.85	−32.0	−11.5	−33.22	−31.3	−31.08	−27.8
1N30	0.12	Tr.		Tr.	0.03	30.00	−15.08	−6.9	−14.98	−1.0	−15.49	−1.5
4N2	0.21	0.02		Tr.	0.03	1.97	+8.66	+7.0	+8.05	+5.5	+8.25	+6.3
4N5	0.20	0.02		0.03	0.04	4.90	+1.73	−2.4	+0.71	+2.0	+0.0	−2.3
4N7	0.23	0.05		Tr.	0.08	7.59	+4.18	−7.3	−3.26	−6.0	−4.38	−6.8
4N10	0.21	0.02		Tr.	0.01	9.79	+9.88	−12.6	−9.88	−11.6	−9.58	−12.9
4N12	0.22	0.02		0.002	0.01	12.29	+13.25	−15.3	−11.92	−15.7	−13.67	−16.4
4N15	0.22	Tr.		0.002	0.05	15.04	+16.61	−27.3	−16.31	−19.1	−17.63	−10.6
4N20	0.22	0.02		0.003	Tr.	20.01	+22.87	−30.6	−22.43	−23.7	−22.43	−21.5
4N25	0.23	0.02		0.003	0.08	25.06	+17.73	−7.1	−19.98	−12.7	−14.88	−3.8
4N30	0.19	0.02		0.002	0.03	27.87	+8.05	−2.3	−9.37	−0.9	−4.18	−1.9
9N2	0.80	0.10		0.005	0.10	2.30	+6.52	+4.7	+5.91	+4.6	+5.81	+4.6
9N5	0.78	0.09		0.004	0.08	4.90	+12.53	−3.0	−1.02	−2.6	−1.02	−2.6
9N7	0.81	0.12		0.003	0.10	7.09	−5.10	−6.9	−4.18	−5.9	−3.97	−5.9
9N10	1.05	0.10		0.004	Tr.	9.79	−7.34	−8.5	−7.24	−8.5	−8.15	−8.7
9N12	0.76	0.09		0.004	0.09	12.27	−7.95	−9.4	−8.87	−9.8	−10.30	−10.4
9N15	0.80	0.06		0.007	0.09	15.04	−12.13	−11.1	−10.30	−10.1	−9.38	−4.9
9N20	0.80	0.02		0.003	0.09	20.01	−12.53	−6.6	−5.10	−5.0	−6.93	−3.5
9N25	0.79	0.07		0.002	Tr.	25.06	−12.43	−6.1	−4.69	−4.9	−2.95	−2.6
9N30	0.81	0.03		0.004	0.14	29.96	−5.71	−1.8	−3.36	−2.0	−2.95	−1.9

TABLE 4.—(*Continued*)

Symbol	Composition in %						E_{Pb}/t					
							Annealed		Quenched		Ingot	
	C	Mn	P	S	Si	Ni	−78.5°	+100°	−78.5°	+100°	−78.5°	+100°
	Si steels; An. from 900°C, cooling 5 hr; Qu. at 1000°C in water at 14°C*											
1S0.5	0.21	0.72	0.117	0.061	0.41		+ 2.14	− 0.30	+ 1.12	− 0.90		
1S1	0.21	Tr.	0.024	0.020	0.93		− 2.95	− 6.10	− 1.32	− 5.00		
1S2	0.18	0.27	0.032	0.012	1.60		− 4.89	− 8.28	− 5.10	− 8.40		
1S3	0.28	0.38	0.034	0.009	5.12		− 6.93	−10.80	− 7.03	−10.40		
8S1	0.84	0.57	0.021	0.017	1.16		− 3.46	− 6.00				
8S2	0.83	0.41	0.021	0.017	1.15		− 6.93	− 9.90	− 7.85	−10.20		
8S3	0.94	1.44	0.062	0.017	5.54		− 8.36	−12.00	− 9.07	−10.70		
						W						
	W steels; An. from 900°C, cooling 8.5 hr; Qu. at 1000°C in water at 14°C*											
1T0.5	0.18	Tr.	0.013	Tr.	0.03	0.41	+ 9.18	+ 6.30	+ 8.56	+ 5.70		
1T1	0.11	Tr.	0.016	0.005	0.06	0.93	+ 8.56	+ 5.98	+ 7.85	+ 5.65		
1T2	0.11	Tr.	0.010	0.008	0.03	1.75	+ 7.75	+ 5.24	+ 6.83	+ 4.75		
1T5	0.13	Tr.	0.015	Tr.	0.03	4.96	+ 7.95	+ 6.25	+ 7.34	+ 5.20		
1T15	0.20	Tr.	0.013	0.008	0.06	14.37	+ 7.75	+ 6.40	+ 7.95	+ 7.40		
1T20	0.22	Tr.	0.011	0.013	0.14	20.71	+ 8.00	+ 6.30	+ 8.05	+ 7.25		
8T0.5	0.86	0.027	0.012	0.033	0.04	0.40	+ 1.84	− 0.08	− 1.63	− 4.15		
8T2	0.66	0.054	0.015	0.023	0.12	1.95	+ 2.55	+ 0.50	+ 1.12	− 1.70		
8T10	0.81	Tr.	0.015	0.014	0.09	9.99	+ 5.00	+ 3.00	+ 2.85	+ 1.30		
8T15	0.71	Tr.	0.015	0.023	0.12	14.74	+ 2.75	+ 0.60	+ 2.85	− 1.40		

* An. = annealed, time in furnace = 3 hr, time of cooling is as indicated. Qu. = quenched, specimen in furnace 11 or 12 min and for 2 min was at temperature indicated.

† For 1N and 4N groups, changes in heat treatment produce slight effect; maximum negative value of E occurs at *ca.* 25 % Ni in 1N and *ca.* 20 % Ni in 4N group.

TABLE 5.—THERMOELECTROMOTIVE FORCE (E) OF CARBON STEELS: EFFECT OF HEAT TREATMENT (23); *see also* Table 4

Specimens were quenched at 903 or 908°C, kept at 97 to 102°C for 48 hr, then heated (drawn) to temperature indicated and kept at that temperature for 1 to 2 hr, then allowed to cool slowly in furnace. Error in E not greater than 10μv. For all 8 specimens, the smallest negative value of E corresponds to drawing temperature of 696°C. Unit of E = 1μv = 10^{-6} volt; of admixture = 1%; temperature, °C.

Symbol	Admixture					Quenched		Drawn							
						903°	908°	100°	205°	309°	388°	495°	599°	696°	800°
	C	Mn	P	S	Si	E_{IN2} (junctions at 0° and 100°C)									
C04	0.04	0.10	0.007	0.029			− 74	− 36	− 34	− 29	− 34	− 29	− 29	− 26	− 29
M16	0.30	0.204	0.012	0.013	0.033		−310	−278	−230	−170	−136	−102	− 94	− 83	−100
H35	0.35	0.08	0.009	0.024	0.18		−575	−537	−499	−452	−437	−419	−414	−400	−413
H41	0.41	0.08	0.012	0.016	0.19		−615	−578	−529	−474	−444	−434	−429	−414	−420
H57	0.57	0.11	0.010	0.020	0.17		−707	−627	−537	−474	−444	−419	−414	−394	−417
C4	0.76	0.221	0.016	0.041	0.169	− 950		−718	−577	−474	−439	−410	−404	−350	−393
C5	0.945	0.189	0.013	0.061	0.155	−1170		−795	−608	−458	−410	−392	−376	−364	−378
C7	1.05	0.190	0.013	0.020	0.167	−1308		−916	−713	−556	−516	−509	−497	−467	−473
IN2	0.018	0.011	0.006	0.018	Cu = 0.018 = pure ingot iron = reference metal										

TABLE 6.—THERMOELECTRIC POWER (Q) OF OXIDES AND SULFIDES

R = reference metal, $Q_R = a + bt$ if t lies between t_1 and t_2. Unit of Q = 1μv/°C = 10^{-6} volt/°C; t_1, t_2 = centigrade temperature, °C.

Oxide	R	t_1	t_2	a	b	Lit.
Bi_2O_3	Pb†	500	800	+ 1 946	− 1.86	(11)
CdO	Pb†	100	1 065	− 32	− 0.030	(11)
Co_3O_4	Pb†	200	1 200	+ 629	− 0.221	(11)
Cr_2O_3	Pb†	950	1 285	− 704	+ 0.432	(11)
CuO	Pb†	170	850	− 1 029	+ 1.715	(11)
	Cu*	0	700	+ 1 190	− 0.38	(20)
Cu_2O	Cu*	0	700	+ 1 052.5	− 0.75	(20)
FeO	Cu	50	50	Q_{Cu} = + 500		(52)
Fe_2O_3	Cu	50	50	Q_{Cu} = + 60		(52)
Fe_3O_4	Pb†	170	875	− 54.6	− 0.026	(11)
	Pb†	875	1 485	− 53.2	− 0.018	(11)
	Fe*	0	700	− 427	0.00	(20)
FeS	Cu	50	50	Q_{Cu} = − 26		(52)
FeS_2	Cu	50	50	Q_{Cu} = + 200		(52)
Mn_2O_3	Pb†	200	1 200	+ 628	− 0.332	(11)
MnO_3H_2	Cu	50	50	Q_{Cu} = + 200		(52)
MoS	Cu	50	50	Q_{Cu} = + 770		(52)
NiO	Pb†	400	1 200	+ 254	− 0.065	(11)
PbO	Pb†	250	390	−48 300	+117.2	(11)
	Pb†	390	550	− 6 000	+ 9.22	(11)
	Pb†	550	850	− 3 914	+ 5.43	(11)
SnO	Pb†	0	1 200	− 90	− 0.437	(11)
U_3O_8	Pb†	65	1 265	+ 96	− 0.157	(11)
WO_3	Pb†	140	970	− 18.4	− 0.053	(11)
ZnO	Pb†	355	1 350	− 735	+ 0.259	(11)

* Error in E = ±200 microvolt. † Used Pt as reference metal, but expressed results in terms of Q_{Pb}.

TABLE 7.—EFFECT OF STRESS UPON THERMOELECTRIC PROPERTIES OF METALS

${}_sE_o$ = thermo emf around a circuit composed of two specimens of the same material, one specimen (s) is stressed, the other (o) not stressed; one junction is at 0°C and the other is at t, °C; ${}_sE_o$ is positive if the current flows from the stressed to the unstressed specimen at the junction at 0°C.

If p = hydrostatic pressure upon the stressed specimen; τ = longitudinal tension upon the stressed specimen; t = temperature (°C); f, g, h, m, n are constants depending upon the metal; then if $\tau = 0$, ${}_sE_o = \mathrm{f}pt\{1 + \mathrm{g}p(10^{-6})\}\{1 + \mathrm{h}t(10^{-3})\}$; ${}_sQ_o = \mathrm{k}p$, where $\mathrm{k} = \mathrm{f}\{1 + \mathrm{g}p(10^{-6})\}\{1 + 0.5\mathrm{h}t(10^{-3})\}$; k = f if g = 0, h = 0. If $p = 0$, ${}_sE_o = 1000\mathrm{m}\tau + \mathrm{n}\tau^2$.

The numbers in the "Error" column indicate the probable uncertainty in the value of ${}_sE_o$. Unit of $E = 1\mu\mu\mathrm{v} = 10^{-12}$ volt; of p and τ = 1 kg/cm² = 14.22 lb./in.² = 0.968 A_n; of "Error" = 10^{-6} volt; t = centigrade temperature, °C.

Symbol	Tension (17)*			Pressure (17)†				${}_sQ_o$ (78)‡
	t	m	n	f	g	h	Error	k
Ag				+ 8.34	− 6.8	+1.47	±0.02	+ 8.7
Al	50.5	+ 8.8	− 6.7	*See* Table 8				− 0.59
	76	+ 8.8	− 4.7					
Au				+ 4.40	− 8.2	+2.0	±0.01	+ 4.61
Bi				+513	+37.4	−0.06	±4	+707§
Brass	52	− 0.22	+ 0.03					
	77	− 0.13	+ 0.012					
	94	− 0.47	+ 0.05					
Cd				+ 21.3	+ 6.0	+6.3	±0.5	+ 36.3
Co				− 14.4	− 1.43	+2.07	±5%	
Constantan‖				+ 27.9	0	+0.62	±0.1	+ 28.7
Cu	95	+ 0.56		+ 2.58	− 2.2	+1.9	±0.15	+ 3.15
Fe	52	+12.0¶	−23.5	*See* Table 8				+ 12.5
	95	+22.3¶	−42			t =		
Hg**						20 − 80		+194
						106 −151		+294
						114 −167		+340
						228 −270		+478
						250 −300		+466
						304 −346		+449
						0 −100		+234
Manganin		Variable††		− 1.31	0	−1.57	±0.04	− 8.5
Mg				− 8.2	+26.0	0	±0.02	− 8.9
Mo				+ 0.099‡‡	0	+278.0−2.18t		
Ni	31	+ 3.35	− 0.60	+ 6.11	+16.5	+3.06	±0.015	+ 9.6
	51	+ 5.77	− 1.32					
	77.5	+ 8.1	− 1.75					
	94.5	+12.1	− 3.7					
Pb				+ 4.09	0	+2.9	±0.01	+ 5.6
Pd				+ 20.8	+ 1.07	+0.5	±0.1	+ 23.7
Pt				+ 13.94§§	0	+9.64 − 0.0676t		+ 18.6
				+ 14.3‖‖	+15.6	+0.87	±0.17	
Sn				*See* Table 8				− 0.95§
Tl				+ 44.4	−17.0	+2.4	±0.2	
W				+ 10.86	0	+1.61	±0.1	
Zn				+ 59.3	0	+2.23	±0.2	
							t = 43	+ 39
							t = 58	+ 57

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* For τ between 0 and τ_m; values of τ_m and of error in ${}_sE_o$ as follows:

Metal	Al	Fe	Cu	Ni	Brass	Manganin
τ_m	(?)	500	700	2000	2800	1300
Error	±5 %	±5 %	±10 %	±2.5 %	±8 %	

† Range in p 2 000 to 12 000 kg/cm²; in t is 0 to 100°C.

‡ Range in t is 0 to 100°C, in p is 1 to 300 kg/cm² (78), probable error in ${}_sQ_o$ *ca.* 1.5 %; for (74) $t \leq 400$°C, $p \leq 55$ kg/cm²; probable error in ${}_sQ_o$ *ca.* ±3 %.

§ For liquid metal, k < +4 (74).

‖ Constantan = 54 % Cu, 43.6 % Ni, 1 % Mn, 1.4 % Fe.

¶ Annealed ingot iron.

** For 20 to 80° (3, 30, 74); for 0 to 100° (78); for others (74).

†† For some samples ${}_sE_o > 0$, for other ${}_sE_o < 0$; maximum value observed was ${}_sE_o = 1.33 \times 10^{-6}$ volt.

‡‡ Error in ${}_sE_o = \pm 0.1 \times 10^{-6}$ volt.

§§ Heraeus' pure Pt; error in ${}_sE_o = \pm 0.1 \times 10^{-6}$ volt. Source of specimen for ${}_sQ_o$ is not stated.

‖‖ Baker's commercial.

TABLE 8.—EFFECT OF STRESS UPON THERMOELECTRIC PROPERTIES OF AL, FE, AND SN (17)

For explanation of symbols, *see* Table 7. Unit of $_sE_o = 1\mu v = 10^{-6}$ volt; of $p = 1$ kg/cm² = 14.22 lb./in.² = 0.968A$_n$; t = centigrade temperature, °C.

p	2 000	4 000	6 000	8 000	10 000	12 000
t	1000$_sE_o/t$, "Pure" Al					
10	−3.1	−4.8	−6.8	−7.0	− 7.6	− 6.9
20	−2.7	−4.05	−4.9	−4.9	− 4.75	− 3.4
30	−2.27	−3.33	−3.8	−2.97	− 1.87	+ 0.1
40	−1.82	−2.60	−2.58	−1.15	+ 0.75	+ 3.25
50	−1.40	−1.82	−1.26	+0.64	+ 3.16	+ 6.24
60	−0.97	−1.00	+0.08	+2.43	+ 5.47	+ 9.05
70	−0.50	−0.11	+1.47	+4.23	+ 7.69	+11.7
80	−0.025	+0.82	+2.89	+5.98	+ 9.82	+14.39
90	+0.48	+1.84	+4.32	+7.66	+11.89	+17.01
100	+1.01	+2.94	+5.77	+9.29	+13.84	+19.62

If $p < 6500$, $_sE_o(10)^6 =$

$$[-2.167p + 0.131(10)^{-3}p^2]t + [24.5\ (10)^{-3}p - 0.2(10)^{-6}p^2]t^2.$$

If $p > 6500$, $_sE_o(10)^6 = [-11.09(10)^3 + 0.497p - 14(10)^{-6}p^2] + [144.6 - 9.85(10)^{-3}p + 1.675(10)^{-6}p^2]t^2$. Mean probable error in $_sE_o$ is $\pm 10^{-8}$ volt = 0.01μv.

t	1000$_sE_o/t$, Commercial Al					
10	−1.2	−1.9	−1.7	− 2.0	− 0.6	+ 1.8
20	−0.95	−1.4	−0.95	0.0	+ 2.5	+ 5.8
30	−0.77	−0.90	−0.07	+ 1.9	+ 5.13	+ 8.83
40	−0.48	−0.25	+1.00	+ 3.70	+ 7.32	+11.60
50	−0.16	+0.52	+2.34	+ 5.40	+ 9.60	+14.40
60	+0.18	+1.40	+3.78	+ 7.33	+12.12	+17.50
70	+0.57	+2.31	+5.33	+ 9.57	+14.79	+21.04
80	+1.00	+3.25	+6.87	+11.80	+17.25	+24.70

Mean probable error in $_sE_o = \pm 10^{-8}$ volt = 0.01μv.

t	1000$_sE_o/t$, Fe, Ingot, An.*					
20	− 4	− 7.5	−14	−25	−37	−49.5
40	+ 4.2	+ 5.5	+ 5.5	+ 0.5	− 3.2	−10.2
60	+11.0	+18.0	+21.2	+21.8	+24.2	+23.3
80	+15.1	+28.5	+39.4	+48.9	+56.0	+61.1
100	+16.7	+32.5	+46.0	+58.2	+68.6	+76.8

t	1000$_sE_o/t$, Fe, Ingot, Hd.*					
20	+ 1	− 7.5	−12	−22.5	− 27	− 37
40	+ 5.8	+ 4.5	+ 5.2	− 0.5	+ 2.5	+ 0.2
60	+10.3	+17.3	+23.8	+25.7	+ 30.8	+ 36.7
80	+15.9	+30.2	+42.5	+52.5	+ 63.9	+ 76.5
100	+23.0	+44.2	+66.9	+87.0	+107.0	+128.0

t	1000$_sE_o/t$, Fe, Soft*					
20	− 1.5	− 5.5	−14.5	−25	−37.5	−56
40	+ 3.8	+ 5.5	+ 1.8	− 3.8	−10.0	−20.5
60	+ 7.7	+13.7	+15.5	+14.7	+12.5	+ 7.3
80	+12.7	+23.1	+30.9	+36.8	+39.8	+39.9
100	+23.4	+42.0	+56.8	+69.4	+82.5	+95.6

* An. = Pure American ingot iron, annealed; Hd. = same as An., but hard-drawn; soft = commercial soft iron wire. Mean probable error in $_sE_o$ is $\pm 5 \times 10^{-7}$ volt = 0.5μv.

t	1000$_sE_o/t$, Sn					
10	+0.1	−0.4	−1.4	−4.1	−8.3	−13.6
20	+0.15	0.0	−0.5	−2.25	−5.15	− 9.1
30	+0.40	+0.40	+0.37	−0.67	−2.50	− 5.13
40	+0.60	+0.82	+1.05	+0.52	−0.48	− 2.02
50	+0.76	+1.16	+1.56	+1.40	+0.96	+ 0.20
60	+0.87	+1.38	+1.85	+2.03	+1.95	+ 1.72
70	+0.91	+1.52	+2.09	+2.46	+2.61	+ 2.73
80	+0.92	+1.59	+2.20	+2.72	+3.04	+ 3.36
90	+0.91	+1.63	+2.29	+2.87	+3.29	+ 3.72
100	+0.87	+1.65	+2.32	+2.92	+3.41	+ 3.90

Mean probable error in $_sE_o$ is $\pm 2 \times 10^{-8}$ volt = 0.02μv.

TABLE 9.—EFFECT OF LONGITUDINAL MAGNETIC FIELD (H) AND OF TENSION (τ) UPON THERMOELECTRIC PROPERTIES OF METALS (12)

$_{\tau H}E_o$ = thermo emf around a circuit composed of two specimens of the same material, one specimen (τH) is subjected to tension τ and field H; for the other specimen (o), $\tau = 0$, $H = 0$; one junction is at t_1, °C and the other at t_2, °C. $_{\tau H}Q'_o = {_{\tau H}E_o}/(t_2 - t_1)$. In certain cases, $_{\tau H}Q_o = a(1 - e^{-0.001bH})$ if τ, t_1 and t_2 are kept constant. H_m is value of H at which $_{\tau H}Q_o$ is a maximum.

In general, the algebraic value of $_HQ_o$ decreases as the hardness, the intensity of magnetization, and $(t_2 - t_1)$ increase, either individually or collectively.

For the following data, t_1 = 14°C, t_2 = 100°C; probable error in $Q' = ca.\ 0.5 \times 10^{-6}$ volt/°C. Unit of Q' and a = 1mμv/°C = 10^{-9} volt/°C; of H = 1 gauss; of τ = 1 kg/cm² = 14.22 lb./in.²; of b = 1 gauss⁻¹.

Metal	H	400	450	800	∞	Maximum		a	b
	τ	$_{\tau H}Q'_o$				$_{\tau H}Q'_o$	H_m		
Co*.......	0	+ 90	+ 91	+ 96	+ 97			+ 97	−6.4
Co†.......	0	+ 60	+ 64	+ 81	+ 93			+ 93	−2.6
Fe‡.......	0	+ 80		+ 53	+ 44	+110	100		
	1620		0	− 28	− 40	+ 35	40		
Fe, C§....	0	+ 50			+ 35	+ 68	200		
Ni‖.......	0	+329	+336	+353	+355			+355	−6.5
	447	+382	+386	+390	+392			+392	−9.2
	970	+408	+424	+480	+485			+485	−4.6

* Cast. † Rolled. ‡ Pure Fe, Q' rises rapidly to a maximum, and then decreases. If $H > 200$, $_HQ_o$ for annealed Fe is 40×10^{-9} volt/°C less than $_HQ_o$ for unannealed iron. For soft Fe, $_HQ_o > 0$; for annealed steel, $_HQ_o < 0$. § Hard steel. ‖ Annealed.

TABLE 10.—EFFECT OF MAGNETIC FIELD (H) AND TENSION (τ) UPON THERMO EMF OF BIMETALLIC CIRCUITS (75)

$\Delta E/E = ({_ME'_{Cu}} - {_ME_{Cu}})/{_ME_{Cu}}$, where $_ME'_{Cu}$ = thermo emf of the M − Cu circuit when M is subjected to H and τ, $_ME_{Cu}$ = thermo emf of the same circuit when $H = 0$, $\tau = 0$; the temperatures (t_1, t_2) of the junctions are the same for $_ME'_{Cu}$ as for $_ME_{Cu}$. Probable error in $\Delta E/E = ca.$ 2% of $\Delta E/E$. The composition of each metal M is stated in the table. H_m = value of H at which $\Delta E/E$ is a maximum. Unit of H = 1 gauss; of τ = 1 kg/cm² = 14.22 lb./in.²; of composition of M = 1 wt. %.

A. Longitudinal magnetic field; t_1 = 0°C, t_2 = 100°C

M		H	200	400	800	∞	Maximum, $\Delta E/E$	H_m
Fe	Cu	τ	1000$\Delta E/E$					
100	0	0	+14.1	+10.8	+ 7.6	+ 6.0	+15.3	100
		516	+ 8.7	+ 5.25	+ 2.1	+ 0.5	+10.3	90
		1050	+ 2.85	− 0.75	− 3.9	− 6.0	+ 4.7	90
		2090	− 4.65	− 7.95	−11.4	−13.6	−13.6	∞
99.2	0.8	0	+18.6	+15.75	+12.9	+10.5	+19.2	150
		741	+13.35	+10.35	+ 7.3	+ 5.0	+14.7	110
		935	+ 8.85	+ 5.85	+ 2.48	+ 0.5	+10.5	100
		1860	+ 3.0	0.0	− 3.75	− 6.5	+ 4.6	60
98.5	1.5	0	+52.5	+43.5	+34.0	+27.0	+56.0	100
		1020	+31.5	+21.0	+10.5	+ 2.0	+36.0	100
		2040	+11.0	+ 0.5	−11.0	−20.0	+17.0	75

TABLE 10A.—(*Continued*)

M		*H*	200	400	800	∞	Maximum, $\Delta E/E$	H_m
Fe	Cu	τ	$1000\Delta E/E$					
98.0	2.0	0	+38.5	+32.5	+25.0	+21.0	+40.0	120
		1190	+25.5	+18.5	+11.0	+ 4.0	+28.5	100
		2370	+11.3	+ 4.0	− 5.8	−10.5	+15.3	75
96	4	0	+28.8	+25.0	+20.5	+17.0	+29.5	120
		1100	+21.5	+17.0	+11.8	+ 7.5	+22.5	110
		2200	+13.3	+ 8.5	+ 3.0	− 1.0	+14.9	100
94	6	0	+26.0	+21.0	+15.6	+12.0	+29.0	100
		930	+14.0	+ 8.0	+ 2.5	− 1.5	+18.0	80
		1850	+ 5.5	− 0.5	− 7.5	−13.5	+10.0	70
93	7	0	+44.5	+34.5	+25.5	+18.5	+49.3	95
		1160	+24.0	+13.0	+ 2.8	− 6.0	+31.0	90
		2310	+ 3.0	− 8.5	−20.0	−29.0	+12.0	70
Fe	Ni							
98.9	1.1	0	+24.8	+19.3	+15.8	+12.1	+27.0	100
		964	+14.0	+ 8.5	+ 3.4	+ 0.5	+16.6	95
		1920	+ 4.5	− 0.9	− 6.5	−10.0	+ 7.0	80
98.1	1.9	0	+45.0	+37.5	+29.8	+25.0	+48.0	100
		984	+26.0	+17.7	+10.0	+ 5.0	+32.0	90
		1960	+ 9.5	+ 1.5	− 7.0	−12.5	+14.0	70
93	7	0	+ 5.3	+ 5.05	+ 4.6	+ 4.1	+ 5.4	240
		963	+ 3.6	+ 3.2	+ 2.7	+ 2.1	+ 2.7	120
		1920	+ 1.95	+ 1.4	+ 0.95	+ 0.45	+ 2.25	100
88.7	11.3	0	+ 2.6	+ 3.2	+ 3.2	+ 2.9	+ 3.25	500
		931	+ 2.5	+ 2.8	+ 2.85	+ 2.5	+ 2.87	700
		1860	+ 2.1	+ 2.5	+ 2.45	+ 2.1	+ 2.5	430
0	100	0	+ 7.00	+ 8.70	+ 9.60	+ 9.75	+ 9.75	∞
		1290	+ 6.25	+10.50	+12.90	+13.30	+13.30	∞
		2610	+ 3.85	+ 9.00	+13.80	+14.75	+14.75	∞

B. Transverse magnetic field; $t_1 = 22°C$, $t_2 = 100°C$

M	$\tau = 0$		$\tau = 1370$		$\tau = 2070$	
Ni	*H*	$1000\Delta E/E^*$	*H*	$1000\Delta E/E^*$	*H*	$1000\Delta E/E^*$
100%	3000	+ 9.0	3100	+5.9	3100	+4.8
	5900	+12.5	5750	+8.6	5750	+5.7
	8500	+16.5	8400	+8.4	8400	+5.6

* Change due to *H*, τ being constant.

TABLE 11.—PELTIER COEFFICIENT: DIRECTLY OBSERVED

For all couples including constantan, *see* Table 12

When $_MP_R$ is positive, there is an absorption of heat as the current passes from *R* to *M*. When *M* is a binary alloy, the % by weight of the second component appears under the symbol of that component. The coefficients for other couples can be computed from data in Tables 1 to 6; the accuracy of values so computed probably exceeds that of those directly measured. Unit of $P = 1\mu v = 10^{-6}$ volt; of "Error" = 1% of *P*; *t* = centigrade temperature, °C.

TABLE 11.—(*Continued*)

M		*R*	*t*	$_MP_R$	Error	Lit.
Ag		Cu	0	+ 480	2	(50)
		Cu	0	− 68	2	(14)
		Cu	18	− 30	30	(24)
Ag	Pd				2	(14)
	0	Cu	0	− 68		
	10		0	− 1 593		
	20		0	− 2 215		
	30		0	− 3 240		
	40		0	− 4 960		
	50		0	− 8 650		
	60		0	− 9 980		
	70		0	− 8 500		
	80		0	− 6 150		
	90		0	− 4 290		
	100		0	− 2 380		
Ag	Sn					
	70	Cu	20	− 674	2	(14)
Al		Cu	15.8	− 695	1.5	(24)
Au		Cu	0	− 329	2	(14)
Au	Pd				2	(14)
	0	Cu	0	− 329		
	10		0	− 2 086		
	20		0	− 2 865		
	30		0	− 7 710		
	40		0	− 10 610		
	50		0	− 8 200		
	60		0	− 6 720		
	70		0	− 6 210		
	80		0	− 5 870		
	90		0	− 4 810		
	100		0	− 2 380		
Bi ⊥*		Cu	8.1	− 14 620	2–3	(51)
			20.6	− 15 730	2–3	(51)
			22.4	− 15 700	2–3	(51)
			19.75	− 14 120	2	(16)
Bi ∥		Cu	20.5	− 21 060	2	(16)
Bi(45)*		Cu	19.5	− 23 300	2	(16)
Bi†		Cu	18	− 16 130	1	(24)
		Cu	20.7	− 19 350	2	(24)
		Cu	25	− 22 300	4	(57)
Bi	Sn					
	3.75	Cu	20.7	+ 10 870	2	(24)
	6.36		20.7	+ 11 670	2	(24)
	9.93		20.7	+ 10 450	2	(24)
C		Cu	20(?)	− 2 943	3	(40)
Cd‡		Cu	0	+ 682	2	(7, 25, 50, 57)
Cu	*See* other metal in column *M*					
Cu Ni Constantan	*See* Table 12					
Cu, Ni, Zn§		Cu	20	− 7 400	2	(14)
Fe		Cu	0	+ 3 680	3	(50)
		Cu	19	+ 2 893	3	(40)
		Cu	20	+ 2 995	2	(14)
		Cu	25	+ 2 930	4	(57)
		Hg‡	18.5	+ 4 880	2	(63)
		Ni	15	+ 9 600		(7)
German silver, *see* Cu, Ni, Zn						
MoS_2		Cu	23.5	−173 500	20	(40)
Ni‡		Cu	0	− 5 070	2	(4, 7, 24, 25, 50)
Nickelin¶		Cu	20	− 5 540	2	(14)
Pd		Cu	0	− 2 380	2	(14)
		Cu	0	− 2 920	2	(14)
Pd	Pt				2	(14)
	0	Cu	0	− 2 920**		
	10		0	− 738		
	20		0	+ 51		
	30		0	+ 284		
			20	− 296		
	40		0	+ 170		
			20	− 188		
	50		0	− 79		
	60		0	− 250		
	70		0	− 545		
	80		0	− 748		
	90		0	− 1 134		
	100		0	− 1 531		
Pt		Cu	0	− 1 531	2	(14)
		Cu	0	− 370	3	(50)
		Cu	17.1	− 845	1.3	(24)
		Cu	20	− 1 070	2	(14)
Sb		Cu	25	+ 5 640	4	(57)
Si		Cu	19	+175 100	15	(40)
Zn‡		Cu	0	+ 684	3	(7, 50, 57)

* Bi ⊥, Bi ∥, Bi_{45} = current perpendicular, parallel, at 45° to axis of Bi crystal. *See also* Table 13. For *transverse* Peltier effect, *see* p. 214.

† Direction of current with reference to axis of crystal is not stated.

‡ *See* Table 12.

§ German silver, composition is not stated, it usually lies between 50Cu, 30Ni, 20Zn and 57Cu, 7Ni, 36Zn.

¶ Composition is not stated; probably 75 to 55 Cu; 18 to 32 Ni; 0 to 20 Zn.

** Compare with corresponding value for Ag-Pd, Au-Pd by same author.

TABLE 12.—PELTIER COEFFICIENT: DIRECTLY OBSERVED VARIATION WITH TEMPERATURE

Data for other couples may be derived from data in Tables 1 to 6; values so computed are probably more accurate than those directly measured. ${}_MP_R = \mathrm{u} + \mathrm{v}t + \mathrm{w}t^2$ if t lies between t_1 and t_2. Unit of $P = 1\mu\mathrm{v} = 10^{-6}$ volt; of "Error" = 1 % of P; t_1, t_2 = centigrade temperature, °C.

M	R	t_1	t_2	u	v	w	Error	Lit.
Cd	Cu	0	25	+ 682	− 7.6		2	(7, 25, 50, 57)
Constantan* (Cu, Ni)	Cd	21	570	− 8 710	−41.0	−0.020	2	(25)
	Cu	0	20	−11 340	−61.0		1	(14, 16)
	Cu	15.5	15.5	−10 210				(7)
	Fe	0	560	−12 980	−44.0	−0.051		(7, 25)
	Hg	−80.6	+20	− 8 250	−62.3	−0.32		(25)
	Pb	20	440	− 7 970	−35.1		2	(25)
	Sn	20	570	− 7 710	−34.2	−0.012	2	(25)
Cu (*see* other metal in column M)								
Fe.	Hg	18.5	182	+ 4 600	+15.6	−0.034	2	(63)
Ni.	Cu	0	445	− 5 070	−23.0	−1.24	2	(4, 7, 24, 25, 50)
Zn.	Cu	0	25	+ 684	− 9.2		3	(7, 50, 57)

* Composition is not stated; probably about 60Cu, 40Ni.

TABLE 13.—PELTIER COEFFICIENT OF BISMUTH: DIRECTLY OBSERVED EFFECT OF MAGNETIC FIELD (16)

$\Delta P = P' - P$, P' = Peltier coefficient when H = 2300 gauss, P = Peltier coefficient when H = 0; the direction of the current (‖, ⊥, ∠45°) is referred to the crystallographic *c*-axis. AB denotes the plane which includes the axis and the direction of the current. Unit of $\Delta P = 1\mu\mathrm{v} = 10^{-6}$ volt.

Direction of current	⊥	‖	∠45°
Direction of H	ΔP		
⊥AB.	−565	−1393	−2560
‖ AB, ‖ axis.	−416	− 226	− 125
‖ AB, ⊥ axis.	−264	−1393	−1286
‖ AB, ‖ current.	−264	− 226	− 753
‖ AB, ⊥ current.	−416	−1393	− 991

TABLE 14.—THOMSON COEFFICIENT (σ): DIRECTLY OBSERVED

$\sigma = \alpha + \beta t(10)^{-2} + \gamma t^2(10)^{-5}$ if t lies between t_1 and t_2; when σ is positive, there is an absorption of heat as current flows from regions of higher to those of lower temperature.

For other cases, σ may be computed by means of the relation $\sigma_M - \sigma_R = -T(\partial^2{}_ME_R/\partial t^2)$, using the data in Tables 1 to 6; probably values so computed are more accurate than those directly measured. Unit of $\sigma = 1\mu\mathrm{v}/°\mathrm{C} = 10^{-6}$ volt/°C; of "Error" = 1 % of σ; t_1, t_2 = centigrade temperature, °C.

A. Elementary substances

Symbol	t_1	t_2	α	β	γ	Error	Lit.
Ag.	− 168	− 123	− 0.112	+ 9.47	+42	2	(15)
	− 123	+ 127	− 1.17	− 0.50		2	(15)
	+ 123	+ 525	− 3.08	− 0.302		2	(55)
Al.	− 13	+ 119	− 0.04	+ 0.475		10	(15)
	+ 71	+ 322	+ 0.2685	+ 0.080		2	(25)
Au.	− 173	− 100	− 1.01	+ 0.65	+ 6.1	5	(15)
	− 100	+ 103	− 1.49	− 0.44		5	(15)
Bi*.	+ 25	+ 32.5	+ 6.76	+ 2.8		1.5	(54)
	+ 43.5	+ 43.5	+ 58			10	(24)
			+ 5.32			4	(6)
			+ 4.27				(67)
C(1)†.			− 4.6				(52)
C(2)†.	+1527	+1827	+ 3.7	+ 0.01		5	(81)
Cd.	− 163	− 83	− 2.25	− 1.5		5	(15)
	− 83	+ 107	− 5.62	− 5.99	+18.6	5	(15)
	+ 48	+ 343	− 9.00	− 1.55	− 1.5	2	(25)
Cu.	− 172	− 60	− 2.244	− 2.5	− 6.4	5	(14, 15)
	− 60	+ 127	− 1.42	− 0.74		5	(15)
	− 96.7	+ 107	− 1.50	− 0.48		2	(9)
	+ 252	+ 678	− 1.37	− 0.235		2	(55)
Fe‡.	− 51	+ 115	+ 4.00	+ 8.4		5	(9)
	+ 32	+ 182	+ 7.66	+ 4.1	+17	3	(43)
	+ 53	+ 308	+ 2.97	+ 1.85		4	(6)
	+ 48	+ 48	+ 11.3			1	(52)
	+ 49	+ 148	− 16.4	+20.8		7	(1)
	+ 91	+ 441	+ 7.785	+ 8.61	−21.4	5	(55)
Hg.	+ 50	+ 150	+ 5.065	+ 3.35	+ 1.7	5	(70)
	+ 47	+ 262	+ 1.20	+ 1.58	− 4.8	2	(25, 42)
Pb.	− 153	+ 117	+ 0.61	+ 0.221	− 0.38	3	(15)
	+ 45	+ 342	+ 0.03	− 0.47	+ 0.55	2	(25)
Pt.	− 72	+ 128	+ 9.10	− 0.475	+ 4.75	1	(9)
Si.	+ 46	+ 46	+794			10	(52)
Sn.	− 171	+ 112	− 0.09	+ 0.50		5	(15)
	+ 51	+ 266	+ 0.35	+ 0.093		1	(25)
Ta.	+1427	+1827	+ 12.5	− 2.0		5	(81)
W.	+1227	+1927	− 32.4	+ 3.5		5	(81)
	+1527	+2127	− 12.54	+ 2.0		2	(36)
Zn§.	− 173	+ 40	− 2.74	− 1.15		3	(15)
	+ 40	+ 343	− 3.112	− 0.235		2	(25)

B. Alloys and compounds

Alloy	t_1	t_2	α	β	γ	Error	Lit.
Bi-Sn‖.							
1.23	+48	+ 76	+ 62.4	+111		1.5	(54)
3.01	+30	+ 72	+ 65.0	+120		1.5	(54)
10.0	+38	+ 75	+ 75.8	+ 39		1.5	(54)
23.6	+25	+ 68	+ 33.3	+ 12		1.5	(54)
1.00	+43.5	+ 43.5	+676			10	(24)
2.00	+43.5	+ 43.5	+537			10	(24)
3.72	+43.5	+ 43.5	+207			10	(24)
6.36	+43.5	+ 43.5	+137			10	(24)
MoS_2¶.	+50	+ 50	−113			20	(52)
Constantan**.	+87	+481	+ 20.00	+ 2.554	−10.05	10	(55)
	+60	+ 60	+ 19.78			5	(58)
	+20.5	+ 20.5	+ 25.33			5	(14)
German silver**. . . .	+23	+ 23	+ 10.45			5	(14)
Manganin**.	+60	+ 60	− 2.85			5	(58)
Nickelin**.	+31	+ 31	+ 17.14			5	(14)
Piano wire**.	+28	+ 28	+ 7.7			5	(14)

* σ varies greatly from one specimen to another. *See also* Table 1.

† C(1) = 70 % graphite; C(2) = lamp filament.

‡ Exhibits thermoelectric hysteresis, sometimes as great as 25 % of mean σ. The occurrence of signs opposite to those which would be inferred from *E* is probably due to the presence of impurities.

§ Numerical value of σ increases rapidly between 40 and 100°C.

‖ σ varies from one specimen to another; the % of Sn by weight is indicated below the Sn.

¶ The current flows perpendicular to *c*-axis of the crystal.

** Composition is not stated. Possibly: Constantan = 60Cu, 40Ni. German silver between 50Cu, 30Ni, 20Zn and 57Cu, 7Ni, 36Zn. Manganin = 84Cu, 12Mn, 4Ni. Nickelin = 75 to 55Cu, 18 to 32Ni, 0 to 20Zn. Piano wire = 98.89Fe, 0.57C, 0.09Si, 0.01S, 0.02P, 0.42Mn.

LITERATURE

(For a key to the periodicals see end of volume)

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(10) Bernoulli, *8*, **33**: 690; 10. *200*, **9**: 270; 12. (11) Bidwell, *2*, **3**: 204; 14. **10**: 756; 17. **19**: 447; 22. **23**: 357; 24. (12) Bidwell, *5*, **73**: 413; 04. (13) Bordoni, *59*, **2**: 245; 11. (14) Borelius, *8*, **52**: 398; 17. **53**: 615; 17. **56**: 388; 18. (15) Borelius and Gunneson, *8*, **65**: 520; 21. (16) Borelius and Lindh, *8*, **51**: 607; 16. **53**: 97; 17. (17) Bridgman, *65*, **53**: 269; 18. **61**: 101; 26. *2*, **9**: 269; 17. (18) Broniewski, *6*, **25**: 5; 12. *74*, **7**: 341; 10. *34*, **150**: 1754; 10. **152**: 85; 11. **156**: 1983; 13. (19) Broniewski and Hackspill, *34*, **153**: 814; 11. *6*, **29**: 455; 14.

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(30) des Coudres, *8*, **43**: 673; 91. (31) Dewar and Fleming, *3*, **40**: 95; 95. *cf.* Dickson, *174*, **47**: 737; 11. (32) Dupuy and Portevin, *34*, **155**: 1082; 12. *74*, **12**: 657; 15. (33) Englisch, *8*, **50**: 88; 93. (33.1) Erhard, *8*, **14**: 504; 81. (34) Feussner and St. Lindeck, *89*, **2**: 501; 95. (35) Fischer and Pfleiderer, *95*, **13**: 237; 21. (35.1) Fischer and Pfleiderer, *523*, **4**: 440; 19. (36) Forsythe, W. E., Nela Park Laboratory, Cleveland, Ohio, *0*. (37) Fuller, *78*, **27**: 241; 15. (38) Gehlhoff and Neumeier, *88*, **15**: 876; 13. (39) Geibel, *93*, **69**: 38; 11. **70**: 240; 11.

(40) Gottstein, *8*, **43**: 1079; 14. (41) Haken, *8*, **32**: 291; 10. (42) Haga, *8*, **28**: 179; 86. (43) Hall, Campbell, Serviss and Churchill, *65*, **42**: 597; 07. (44) Hirsch, *78*, **20**: 57; 11. (45) Holborn and Day, *8*, **2**: 505; 00. *12*, **10**: 171; 00. *76*, **1899**: 691. (46) Holborn and Wien, *8*, **47**: 107; 92. (46.1) Holmes, R. M., Cornell Univ., *0*. (47) Hunter and Bacon, *78*, **36**: 323; 19. (48) Hutchins, *12*, **48**: 226; 94. (49) Ingersoll, *2*, **16**: 126; 20.

(50) Jahn, *8*, **34**: 755; 88. (51) Jordan, *3*, **21**: 454; 11. (52) Koenigsberger and Weiss, *8*, **35**: 1; 11. (53) La Rosa, *59*, **12**: 284; 16. (54) Laws, *3*, **7**: 560; 04. (55) Lecher, *8*, **19**: 853; 06. **20**: 480; 06. (56) Ledoux, *34*, **155**: 35; 12. (57) LeRoux, *6*, **10**: 201; 67. (57.1) Morugina, *97*, **7**: 486; 26. (58) Nettleton, *5*, **29**: 59; 16. (59) Noll, *8*, **53**: 874; 94.

(60) Norsa, *34*, **155**: 348; 12. (61) Northrup, *33*, **9**: 45; 13. **15**: 193; 16. (62) Onnes and Holst, *64P*, **17**: 760; 17. (63) Oosterhuis, *18*, **2**: 7; 12. (64) Pécheux, *34*, **139**: 1202; 04. **147**: 532; 08. **148**: 1041; 09. **149**: 1062; 09. **167**: 487; 18. (65) Pelabon, *16*, **13**: 169; 20. *34*, **176**: 1305; 23. (66) Reichardt, *8*, **6**: 832; 01. (67) Riecke, *Lehrbuch der experimental Physik*, **II**: 345; 96. (68) Rohn, *95*, **16**: 297; 24. (69) Rudolfi, *93*, **67**: 65; 10.

(70) Schoute, *18*, **12**: 175; 07. (71) Sedström, *8*, **59**: 134; 19. *95*, **13**: 155; 21. (72) Shearer, *2*, **34**: 238; 12. (73) Siebel, *8*, **60**: 260; 19. (74) Siegel, *8*, **38**: 588; 12. (75) Smith, *2*, **32**: 178; 11. **19**: 285; 22. **22**: 58; 23. (75.1) Sosman, *12*, **30**: 1; 10. (76) Steele, *3*, **37**: 218; 94. (77) Swisher, *2*, **10**: 601; 17. (78) Wagner, *8*, **27**: 955; 08. (79) Wick, *2*, **25**: 382; 07.

(80) Wietzel, *8*, **43**: 605; 14. (81) Worthing, *2*, **7**: 497; 16.

ELECTRICAL CONDUCTIVITY OF AQUEOUS SOLUTIONS

INTRODUCTION

ABBREVIATIONS, SYMBOLS AND UNITS

κ Specific conductance in ohm^{-1} cm^{-1}.

C Concentration in milliformula-weights per l of solution at the temperature t, unless otherwise indicated.

$\Lambda = 10^6\kappa/C$.

The unit of specific conductance is the reciprocal ohm and it is assumed that the standardizing solutions shown in the tables below have the specific conductances there given. To bring the older data into harmony with these values, the authors' conductance values have been increased by the appropiate amount as indicated in column 5 of Table 1.

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L'unité de conductibilité spécifique est l'ohm réciproque et il a été admis que les solutions étalons données dans les tables ci-dessous ont les conductibilités spécifiques mentionnées à cette place. Pour mettre en harmonie avec ces valeurs les données plus anciennes, les valeurs de conductibilité données par les auteurs ont été augmentées d'une quantité appropriée, comme cela est indiqué dans la colonne 5 de la Table 1.

ABKÜRZUNGEN, SYMBOLE UND EINHEITEN

κ Spezifische Leitfähigkeit in Ohm^{-1} cm^{-1}.

C Konzentration in Milligrammformel-Gewicht für ein l der Lösung bei der Temperatur t, wenn nichts anderes angegeben.

$\Lambda = 10^6\kappa/C$.

Die Einheit der spezifischen Leitfähigkeit ist das reziproke Ohm. Es wird angenommen, dass die Lösungen, welche zur Bestimmung der Widerstands-Kapazität den Gefässen dienten, den spezifischen Leitfähigkeit haben, welcher in den unteren Tabellen angegeben ist. Um ältere Daten mit diesen in Übereinstimmung zu bringen, werden die Leitfähigkeitswerte der Autoren um einen entsprechenden Anteil erhöht, wie es in der Kolonne 5 der Tafel 1 angegeben ist.

ABBREVIAZIONI, SIMBOLI, E UNITÀ

κ Conduttura specifica in ohm^{-1} cm^{-1}.

C Concentrazione in milliformula-grammo per l di soluzione a temperatura t, a meno che non venga altrimenti indicato.

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L'unità della conducibilità specifica è il reciproco dell' ohm; si suppone inoltre che le soluzioni titolate di confronto che figurano nelle tabelle più sotto hanno la conducibilità specifica ivi indicata. Per poter mettere d'accordo con questi i valori più vecchi, i valori datdagli autori sono stati accrei sciuti nel rapporto dovuto, come è indicato nella colonna 5 della Tabella 1.

(30) des Coudres, *8*, **43**: 673; 91. (31) Dewar and Fleming, *3*, **40**: 95; 95. *cf.* Dickson, *174*, **47**: 737; 11. (32) Dupuy and Portevin, *34*, **155**: 1082; 12. *74*, **12**: 657; 15. (33) Englisch, *8*, **50**: 88; 93. (33.1) Erhard, *8*, **14**: 504; 81. (34) Feussner and St. Lindeck, *89*, **2**: 501; 95. (35) Fischer and Pfleiderer, *95*, **13**: 237; 21. (35.1) Fischer and Pfleiderer, *523*, **4**: 440; 19. (36) Forsythe, W. E., Nela Park Laboratory, Cleveland, Ohio, *0*. (37) Fuller, *78*, **27**: 241; 15. (38) Gehlhoff and Neumeier, *88*, **15**: 876; 13. (39) Geibel, *93*, **69**: 38; 11. **70**: 240; 11.

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SOLUTIONS FOR DETERMINING CELL CONSTANTS (199)

TABLE 1.—KOHLRAUSCH SOLUTIONS

The values given below have the following significance: Col. 2, grams of KCl per 1000 g H_2O, weights in air ($d = 0.0012$). Col. 3, temperature of measurement. Col. 4, specific conductance $\text{ohm}^{-1}\ \text{cm}^{-1}$. Col. 5, % difference, Col. 4 value minus the older Kohlrausch value.

1	2	3	4	5
Solution number	$\frac{\text{g KCl*}}{\text{kg } H_2O}$	t, °C	κ (I. C. T. value)	Corr., %
1	76.9153	0	0.6531	0.150
		18	.098116	.108
		25	.111687	.101
2	7.49313	0	.0071416	.118
		18	.0111846	.048
		25	.0128765	.027
3	0.74756	0	.0077422	.229
		18	.00122238	.214
		25	.00141037	.186
4	76.925	18	.098128	.145
5	7.4945	18	.0111871	.145
6	0.74766	18	.00122252	.145
7	Max., H_2SO_4	25	0.8242	0.18

TABLE 2.—PARKER SOLUTIONS

$$\kappa = A + 10^{-3}Bt + 10^{-6}Ct^2$$

g KCl/kg H_2O*	76.6276	7.47896	0.746253
d, g/cm³, 0°C	1.04804	1.004887	1.000372
t, °C	Values of κ, $\text{ohm}^{-1}\ \text{cm}^{-1}$		
0	0.065098	0.0071295	0.00077284
5	.073876	.0082055	.00089203
10	.082886	.0093158	.00101513
15	.092132	.0104603	.00114215
18	.097790	.0111636	.00122023
20	0.101607	0.0116393	0.00127307
25	.111322	.0128524	.00140789
30	.121267	.0140996	.00154661
A =	0.065098	0.0071295	0.00077284
B =	1.7319	2.1178	2.3448
C =	4.681	6.850	7.816

* In air (d = 0.0012), brass weights.

IONIC CONDUCTIVITY

TABLE 3.—ION CONDUCTANCES AT 18°C

Based upon I. C. T. atomic weights (*v.* Vol. I, p. 43) and upon the I. C. T. cell-constant values (Table 1 *supra*). Ion conductances not given here may be obtained by subtracting Λ_H (resp. Λ_{OH}) from the Λ_0 values given in the tables beginning on p. 259.

Ion	Λ	$\frac{1}{\Lambda}\left(\frac{d\Lambda}{dt}\right)_{18}$	Ion	Λ	$\frac{1}{\Lambda}\left(\frac{d\Lambda}{dt}\right)_{18}$
H	315.2	0.01573	OH	173.8	0.018
Cs	67.46	.0212	Cl	65.24	.0216
K	64.20	.0217	Br	67.31	.0215
NH_4	64.3	.0222	I	66.25	.0213
Na	43.16	.0244	NO_3	61.62	.0205
Li	33.02	.0265	ClO_3	54.87	.0215
Tl	65.3	.0215	BrO_3	47.6	
Ag	53.8	.0229	IO_3	33.78	.0214
½Ca	51	.0247	$C_2H_3O_2$	35	.0238
½Mg	45	.0256	½C_2O_4	61	.0231
½Ba	55	.0239	½SO_4	68	.0227
½Pb	61	.0240	½CrO_4	72	

SOLUTIONS OF SALTS AND OF ALL INORGANIC STRONG ELECTROLYTES

PART I. CONDUCTIVITY OF NEUTRAL HALIDES, NITRATES AND SULFATES

EDWARD W. WASHBURN AND ALFONS KLEMENC

CONTENTS	MATIÈRES	INHALTSVERZEICHNIS	INDICE
Table 1.—Values of C up to 0.5.	Table 1.—Valeurs de C jusqu'à 0,5.	Tabelle 1.—Werte von C bis 0,5.	Tabella 1.—Valori di C fino a 0,5.
Table 2.—Values of C from 0.5 to 1000.	Table 2.—Valeurs de C de 0,5 à 1000.	Tabelle 2.—Werte von C von 0,5 bis zu 1000.	Tabella 2.—Valori di C da 0,5 a 1000.
Table 3.—Values of C above 1000.	Table 3.—Valeurs de C au dessus de 1000.	Tabelle 3.—Werte von C über 1000.	Tabella 3.—Valori di C sopra 1000.
In each table the salts are grouped according to the anion in the order F, Cl, Br, I, SO_4, NO_3 and under a given anion the cations follow the standard arrangement (*v.* Vol. III, p. viii).	Dans chaque table les sels sont groupés en accord avec l'anion dans l'ordre F, Cl, Br, I, SO_4, NO_3 et sous un anion donné, les cations suivent l'arrangement type (*v.* Vol. III, p. viii).	In jeder Tabelle sind die Salze in der Reihenfolge ihrer Anionen angeordnet; F, Cl, Br, I, SO_4, NO_3. Unter den gegebenen Anionen folgen die Kationen in der Standardanordnung (*v.* Bd. III, S. viii).	In ciascuna tabella i sali sono raggruppati secondo l'anione nell'ordine F, Cl, Br, I, SO_4, NO_3 e per un dato anione i cationi seguono l'ordinamento tipo (*v.* Vol. III, p. viii).

TABLE 1.—VALUES OF *C* UP TO 0.5

For literature references, *v*. Table 2

C	$10^6\kappa/C$
F	
TlF, 18°	
0.1	114.40
0.2	114.66
NaF, 18°	
0.1	89.10
0.2	88.81
KF, 18°	
0.1	110.02
0.2	109.79
Cl	
NH_4Cl, 18°	
0.1	129.3
0.2	128.9
$(C_2H_5)_4NCl$, 25°	
0.01	109.139
0.05	108.933
0.07	108.837
0.1	108.692
0.2	108.281
⅓$InCl_3$, 25°	
0.3	225
TlCl, 18°	
0.1	130.15
0.2	129.82
½$CaCl_2$, 18°	
0.1	115.01
0.2	114.39
½$SrCl_2$, 18°	
0.1	(118.5)
0.2	(117.4)
LiCl, 18°	
0.1	97.82
0.2	97.53
NaCl, 18°	
0.1	107.88
0.2	107.60
KCl, 18°	
0.01	129.379
0.02	129.317
0.05	129.126
0.07	129.003
0.10	128.836
0.20	128.483
100°	
0.2	402.6
RbCl, 18°	
0.1	132.1
CsCl, 18°	
0.1	132.0
0.2	131.7
Br	
$(CH_3)_4NBr$, 25°	
0.01	124.263
0.05	123.958
0.07	123.807
0.1	123.586
0.2	123.010
½$RaBr_2$, 18°	
0.1	123.9
0.2	122.9
KBr, 18°	
0.1	130.86
0.2	130.57
I	
$(C_3H_7)_4NI$, 25°	
C	$10^6\kappa/C$
0.01	99.649
0.05	99.492
0.07	99.378
0.1	99.307
0.2	98.990
KI, 18°	
0.1	129.50
0.2	129.24
SO_4	
½$(NH_4)_2SO_4$, 18°	
0.1	130
0.2	128
½$ZnSO_4$, 18°	
0.1	109.6
0.2	107.6
½$CdSO_4$, 18°	
0.1	109.69
0.2	107.45
½$CuSO_4$, 18°	
0.1	109.80
0.2	107.80
½$MgSO_4$, 18°	
0.1	109.6
0.2	107.8
½$CaSO_4$	
C	$10^6\kappa/C$
18°	
0.1	115.5
0.2	114.0
25°	
0.1	136.5
0.2	133.1
½Na_2SO_4, 18°	
0.1	109.7
0.2	108.8
½K_2SO_4, 18°	
0.1	130.5
0.2	129.8
NO_3	
NH_4NO_3, 18°	
0.1	(125.9)
0.2	(125.8)
½$Pb(NO_3)_2$, 18°	
0.1	120.59
0.2	119.80
$TlNO_3$, 18°	
0.1	126.59
0.2	126.26
$AgNO_3$, 18°	
0.1	114.85
0.2	114.40
½$Ca(NO_3)_2$, 18°	
0.1	111.75
0.2	111.03
½$Sr(NO_3)_2$, 18°	
0.1	111.58
0.2	110.91
½$Ba(NO_3)_2$, 18°	
0.1	115.16
0.2	114.49
$LiNO_3$, 18°	
0.1	94.17
0.2	93.86
$NaNO_3$, 18°	
0.1	104.30
0.2	103.94
KNO_3	
18°	
0.1	125.2
0.2	124.90
100°	
0.2	380.2

TABLE 2; *see* p. 232 to 238

TABLE 3.—VALUES OF *C* ABOVE 1000

For literature references, *v*. Table 2

C	$10^6\kappa/C$
F	
NH_4F, 18°	
2 000	55.3
3 000	48.1
4 000	42.2
TlF, 18°	
2 000	62.8
AgF, 18°	
2 000	45.8
3 000	38.7
KF, 18°	
2 000	66.2
3 000	58.9
4 000	52.7
5 000	46.9
6 000	(42.0)
RbF, 18°	
2 000	71.3
3 000	64.2
4 000	57.5
Cl	
NH_4Cl	
0°	
2 000	63.0
3 000	62.0
4 000	(60.0)
18°	
2 000	92.2
3 000	88.3
4 000	85.1
5 000	80.7
$C_6H_5NH_2HCl$, 25°	
2 000	44.8
3 000	33.0
4 000	23.0
¼$SnCl_4$, 18°	
2 000	66.9
3 000	47.9
4 000	32.7
¼$ThCl_4$, 18°	
2 000	44.33
3 000	36.3
4 000	29.81
⅓$InCl_3$, 25°	
3 000	10.2
½$ZnCl_2$	
18°	
2 000	39.5
3 000	29.6
4 000	22.9
5 000	18.4
6 000	15.2
7 000	12.9
8 000	10.60
11 520	5.36
15 370	2.36
½$ZnCl_2$.—(*Cont'd*)	
C	$10^6\kappa/C$
25°	
2 000	44.0
3 000	32.7
4 000	25.6
5 000	20.7
6 000	17.1
7 000	14.5
8 000	12.2
9 000	10.16
10 000	8.40
12 000	5.72
14 000	3.85
16 000	2.48
18 000	1.45
20 000	0.750
22 000	0.452
½$CdCl_2$	
18°	
2 000	14.17
3 000	10.02
4 000	7.06
5 000	4.85
6 500	3.33
7 760	2.27
9 180	1.45
25°	
2 000	16.06
3 000	11.42
4 000	8.26
5 000	5.74
6 492	4.10
7 745	2.85
9 160	1.86
100°	
2 220	31.3
3 420	21.1
½$CuCl_2$	
0°	
2 000	28.9
3 000	22.4
4 000	16.8
18°	
2 000	43.4
3 000	33.6
4 000	26.0
½$MnCl_2$	
18°	
2 000	45.3
3 000	35.7
4 000	28.17
5 000	21.8
6 000	16.30
½$MnCl_2$.—(*Cont'd*)	
C	$10^6\kappa/C$
25°	
2 000	51.7
3 000	41.3
4 000	32.4
5 000	24.9
6 000	20.0
½$FeCl_2$, 18°	
2 000	48.11
3 000	38.81
4 000	30.84
5 000	24.05
6 000	18.13
⅓$FeCl_3$	
0°	
2 000	24.2
3 000	17.8
4 000	13.0
18°	
2 000	37.5
3 000	27.8
4 000	20.9
5 000	15.90
6 000	12.40
8 000	6.20
½$CoCl_2$, 18°	
2 000	49.2
3 000	39.7
4 000	32.1
7 630	11.7
½$NiCl_2$, 18°	
2 000	50.6
3 000	41.0
4 000	33.33
⅓$CrCl_3$, Violet, 18°	
2 000	44.8
3 000	35.2
⅓$AlCl_3$	
0°	
2 000	27.3
3 000	21.5
4 000	16.4
5 000	12.5
6 000	8.57
18°	
2 000	44.5
3 000	34.2
4 000	27.16
½$BeCl_2$, 18°	
2 000	41.4
3 000	34.4
4 000	29.0
½$MgCl_2$	
0°	
2 000	33.0
3 000	27.7
8 034	7.49

Continued on p. 239

TABLE 2.—VALUES OF C FROM 0.5 TO 1000*

	°C	C = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
[F]; NH_4F	18									89.9	83.8	74.3	70.3	65.6	(95)
TlF	18	114.47	113.27	111.30	108.20	105.45	102.24	97.37	95.2_0	92.62	87.0_2	78.79	75.4_5	71.55	(99, 138)
	25		131.0	129.4	126.4	123.5	119.9								(72)
AgF	18									80.6	74.4	65.2	61.2	56.5	(95)
NaF	18	88.25	87.65	86.74	85.04	83.33	80.8_7	76.99	75.0_9	72.9_4	67.8_0	59.8_1	56.2_0	51.8	(138, 185)
KF	18	109.03	108.45	107.48	105.74	103.85	101.46	97.33	95.6_4	93.63	89.1_4	82.1_1	79.2_1	75.7_1	(95, 129, 185)
RbF	18										92.8	86.1	83.4	$80._0$	(99)
[Cl]; NH_4Cl	0		78.1	77.7	76.9	76.0	74.5	71.7	70.6	69.6	67.8	65.5	64.8	64.1	(109, 110, 131, 132)
	18	128.2	127.5	126.2	124.3	122.3	118.2	115.3		$110._8$		101.5		97.1	(133, 248)
	25		147.6	146.3	144.1	141.4	138.3	132.8	130.5	127.8	122	115	136.1†	107	(28, 34, 110, 248)
	50		227	$225._7$	222.5	218.6	(212.7)	202.3	198.6	194.5	185.1	171.9			(109)
	100			398.2		382.1	(378.8 at C = 12.5)								(180)
	156			600.1		571.9									(180)
	218			800		757									(180)
	306			1029		923	(826 at C = 30)								(180)
$C_7H_8O_2.HCl.2H_2O$	18					$356._9$	$352._8$	339.8	331.8	319.7	288.0	(*Also* at t = 19.8°C)			(224)
$(CH_3)_3NHCl$	18	104.5	103.8	(103.6 at C = 1.33)								(*Also* at t = 32, 35°C)			(172)
	25		121.4	120.2	117.9	115.8	113.1	108.6	106.7						(34, 172)
$C_3H_7NH_2HCl$	18	98.5	97.8	96.8	(95.9 at C = 3)										(172)
	25		114.7	113.6	112.1							(*Also* at t = 32, 35°C)			(172)
$C_6H_5NH_2HCl$	25									89.7	83.8	72.5	67.2	60.8	(244)
$(C_2H_5)_2NH_2Cl$	18	94.9	93.8	(93.0 at C = 3)											(172)
	25			110.0	(108.7 at C = 3)										(172)
$(C_3H_7)_2NH_2Cl$	18	90.1	89.2	(88.4)											(172)
	25	(105.9)	104.9	103.6								(*Also* at t = 32, 35°C)			(172)
$(C_2H_5)_3NHCl$	18	92.4	91.8	90.6											(172)
	25		107.3	106.2	(105.3 at C = 3)							(*Also* at t = 32, 35°C)			(172)
$(C_2H_5)_4NCl$	25	107.42_7	106.53_2												(11); *cf.* (28)
$(C_3H_7)_3NHCl$	18		86.5	85.3											(172)
	25		100.4	99.1	(98.1 at C = 3)							(*Also* at t = 32, 35°C)			(172)
$(C_2H_5)_2C_{16}H_{33}NHCl$	56	229	198	133	$91._6$	74.3	64.0								(220)
$C_{20}H_2\ N_3Cl$	0	49.4	49.7	50.6	Rosaniline hydrochloride										(56)
	25			92.6	91.7	88.3									(56)
$(C_6H_5CH_2)_3CH_3NCl$	18				79.5	77.5	74.4	(68.8)	(72.2 at C = 30)						(64)
$C_9H_{12}ClNO$	25	Hydroxyhydrindamine hydrochloride													(206)
$TiCl_3$															(98)
$ZrOCl_2$															(233, 256)
$\frac{1}{4}SnCl_4$	18											(217)		(122)	(99)
$\frac{1}{2}PbCl_2$	0		73.0	72.2	69.0	64.7	59.2								(109)
	18		118.98	115.7	109.1	102.0	93.1	79.1							(105, 185)
	25		138.5	134.4	126.7	118.1	107.5	91.2							(105, 185)
	50		219	205	193	179	160								(109)
$\frac{1}{4}ThCl_4$	18											61.0	57.7	54.0	(99)
$\frac{1}{3}InCl_3$	25	(101 at C = 3)					(50.6 at C = 30) (30.5 at C = 300)								(251)
$TlCl$	0	(81.9)	81.13	80.16	78.21		(77.41$_1$ at C = 6.779$_8$ or satd. soln.)								(212)
	18	129.00	128.05	126.63	123.56	120.04	(118.30 at C = 12.78 or satd. soln.)								(138)
	25			(146)	142.9	138.8	(135.3 at C = 16.07 or satd. soln.)								(26)
$\frac{1}{2}ZnCl_2$	18									86.5	79.3	68.7	63.2	56.2	(95, 154)
	25											79.4	73.0	64.3	(154, 207)
$\frac{1}{2}CdCl_2$	0		$64._1$	$60._4$	$54._9$	$50._8$	$45._1$	37.5	34.8	31.8	25.9	17.9			(109)
	18		$104._8$	$99._5$	$90._7$	82.9	74.1	60.1	55.2	50.0	41.0	29.6	25.7	21.6_4	(84, 85, 273)
	25		$120._5$	$116._2$	$105._5$	95.7	84.2	68.5	63.1	57.4	47.0	34.2	29.7	24.9	(84, 85, 109, 273)
	50				159	142	125	101	92	$83._5$	$67._4$	47.8			(109)
	100	($95._2$ at C = 192) ($55._1$ at C = 959)													(92)
$\frac{1}{2}HgCl_2$	18	(2.59 at C = 17.0) (1.51 at C = 75.4) (1.07 at C = 392)													(85)
	25	(3.38 at C = 16.9) (1.30 at C = 75.3) (1.25 at C = 391)													(85)
$\frac{1}{2}CuCl_2$	0			65.3	63.0	60.9	58.7	55.1	53.6	51.9	48.5	42.9	40.3	37.0	(109, 110)
	18									83.2	77.1	67.0	62.3	56.9	(48, 95)
	25			$123._4$	$118._7$	114.9	110.2	102.5	99.2	95.4	87.2	74.7	69.6	64.1	(109)
Ir and Pt	H_2IrCl_6, H_2PtCl_6, $(NH_4)_2PtCl_6$, K_2PtCl_6 (177.5), $PtCl_4$ (258)														
$\frac{1}{2}MnCl_2$	0		(61)	$60._4$	59.1	57.3	55.2	51.9	50.5	48.9	45.4	39.7	37.5	35.2	(109)
	18											66.4	61.8	57.4	(99)
	25			(118)	$112._8$	$108._7$	$104._8$	97.2	94.2	90.7	84.0	73.5	69.3	64.4	(109, 154)

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* When the literature cited contains data at other temperatures, this is indicated thus: (*Also* at t = 32, 35°C). † At C = 30.

TABLE 2.—(*Continued*)

	°C	C = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$\frac{1}{2}$MnCl$_2$.—(*Continued*)	50		198	194	186	179	170	158	152	146	131	107	96	94	(109)
$\frac{1}{2}$FeCl$_2$	18											69.4	65.5	60.6	(99)
$\frac{1}{3}$FeCl$_3$	0				136	100	75	59	57	55.2	50.5	41.8	38.0	33.6	(109)
	18											66.5	60.4	53.1	(99)
$\frac{1}{2}$CoCl$_2$	18												65.6	60.8	(99, 165); *cf.* (103.5)
$\frac{1}{2}$NiCl$_2$	18											70.8	66.8	62.1	(99)
$\frac{1}{3}$CrCl$_3$, violet	18										75.4	68.6	(64.5)	58.9	(99)
CrCl$_3$.6H$_2$O, green															(15, 16, 98)
$\frac{1}{3}$CrCl$_3$, blue	25			(159.9)	143.1	131.1	120.0	106.9	102.6	98.6					(15)
UO$_2$Cl$_2$	0	(*Also* at t = 12.5, 25, 35, 50, 65° C)													(109)
	25														(62, 109)
VOCl$_3$															(2)
$\frac{1}{3}$AlCl$_3$	0			65.8	62.0	59.0	56.1	51.8	50.3	48.7	45.0	39.6	37.3	34.4	(109, 110)
	18											65.0	61.0	56.2	(99)
	25		144	136	125	117.9	110.0	99.7	96.2	92.2	84.4	73.7	69.6		(15, 109)
	50				204	191	178	161	154	147	134	115	107		(109)
$\frac{1}{3}$ScCl$_3$	25		141.5	133.5	123.1	115.8	108.4	98.4							(19)
$\frac{1}{3}$YCl$_3$	25	131.5	129.4	126.2	120.4	115.2	108.9	100.3	96.9						(19, 146)
$\frac{1}{3}$LaCl$_3$	25		131.7	127.6	121.6	115.9	109.7	101.3	98.1	94.6					(8, 19, 146, 177)
$\frac{1}{3}$CeCl$_2$	25		134.4	130.7	124.1	118.4	111.9	102.9	(99.2)						(8, 19)
$\frac{1}{3}$PrCl$_3$	25		139.6	135.8	129.3	124.2	118.4	107.7							(8, 19)
$\frac{1}{3}$NdCl$_3$	25		138.1	134.2	128.4	115.8	108.5								(19)
	25		133.6	129.4	123.0	117.3	109.6								(8)
$\frac{1}{3}$SaCl$_3$	25		134.0	129.8	122.8	115.9	107.5								(8, 224)
$\frac{1}{3}$YbCl$_3$	25		140.3	136.0	128.4	121.4	113.3								(221)
$\frac{1}{2}$BeCl$_2$	18											58.4	54.2	51.6	(99)
$\frac{1}{2}$MgCl$_2$	0				67.7	65.7	63.4	59.4	57.6	55.2	51.8	46.0	43.6	40.6	(109, 110, 130, 131, 132)
	25		127.2	124.4	120.3	116.6	112.2	(106)	(103)	(101)	(94)	(84)	(79.2)	73.5	(130, 131, 132, 260)
$\frac{1}{2}$CaCl$_2$	0		70.7	68.9	66.4	64.1	61.6	57.9	56.4	54.9	51.8	47.4	45.7	43.4	(109, 110, 135)
	18	113.18	111.80	109.92	106.55	103.23	99.24	93.16	90.75	88.07	82.68	74.82	71.42	67.45	(133)
	25													77.54	(135)
	50				191	185	178.6	166.4	161.0	154.8	142.6	126.8			(82, 109)
	100													201	(82, 92); *cf.* p. 240
$\frac{1}{2}$SrCl$_2$	0		73	71.5	68.9	66.6	64.0	59.9	58.3	56.6	53.2	48.4	46.5	44.3	(109, 110, 130, 131, 132)
	18	115.8	114.3	112.3	108.8	105.3	101.2	95.2	92.9	90.4	85.1	76.1	72.3	67.9	(130, 131, 132, 133)
	25		132	129	123.8	119.5	114.8	108.5	106.0	103.2	97.2	87.7	83.6	78.4	(109; 130, 131, 132)
	40						(110.0 at C = 654)								(130, 131, 132)
	100										270	(234)	(219)	202	(92)
$\frac{1}{2}$BaCl$_2$	0	72.3	71.6	70.4	68.2	66.3	63.9	60.1	58.5	56.8	53.7	49.6	48.1	46.2	(60, 109, 116, 130, 131, 132, 185, 274)
	18	116.85	115.44	113.6	110.0	106.52	102.39	95.91	93.6	90.65	85.23	77.18	74.40	70.04	(48, 133)
	25		134.5	131.7	127.7	123.7	119.2	111.7	108.6	105.3	98.6	88.8	85.1	80.5	(109, 128, 130, 131, 132, 146)
	50		212	205	196	188.3	179.8	167.3	162.6	157.4	147.1	130.3	124.4	117.6	(109, 110, 140)
	100						(235 at C = 400)				261			197.8	(92)
LiCl	0		59.03	58.91	57.89	56.68	55.30	53.14		50.86	48.31	43.99	42.10	39.85	(103, 131, 132, 265)
	18	96.87	96.20	95.30	93.62	91.84	89.62	85.85		82.76	77.69	70.50		63.18	(137)
	25		114.0	112.7	109.1	107.0	104.3	99.7	97.8	95.5	89.9	81.0	77.8	73.1	(81, 109, 195, 235)
	50		178.3	175.9	172.1	168.0	163.0	155.1		143.2	139.9	125.5	119.0	112.3	(103, 109)
	100									288.0	265.5	237.2	216.8	199.3	(92, 103)
NaCl	0		65.8	65.2	64.2	63.2	61.7	59.5	58.7	57.7	55.6	51.8	49.9	47.5	(130, 131, 132, 185)
	18	106.95	106.27	105.31	103.54	101.72	99.40	95.51		91.82	87.53	80.76		74.19	(137)
	25	125.0	124.12	123.08	120.88	118.68	115.85	111.08	109.01	106.66	101.55	93.31			(135, 156, 185)
	50		195.8	193.6	190.1	185.6	179.9	170.8	167.1	163.4	155.6	141.9			(109)
	100	354.9	352.5	348.5	341.9	335.0	325.4	309.7	303.2	295.6	287.9	274.4	263.6	247.5	(92, 182, 263)
	140	491		481		461	(411 at C = 80)			403.5					(180)
	156	545		534		511	(540.5 at C = 80)			441.5					(180)
	218	741		723		686	(501 at C = 80)								(180)
	281	922		895		820	(674 at C = 80)								(180)
	306	1003		955		860	(680 at C = 80)								(180)

TABLE 2.—(*Continued*)

	°C	*C* = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
KCl	0	80.0	79.7	79.2	78.4	77.284	75.6	73.2	72.2$_5$	71.295	69.4	66.9	66.0	65.098	(130, 131, 132, 199, 274)
	18	127.86	127.07	126.05	124.15	122.18	119.72	115.51	113.7	111.79	107.74	102.25	100.3	98.08	(137, 199, 269)
	25		147.4	146.3	143.8	141.180	138.0$_4$	133.1	131.0$_8$	128.62$_0$	123.9	117.2	114.6	111.86$_1$	(136, 156, 199)
	50		226.$_0$	224.$_0$	219.1	215.1	210.1	201.5		194.3	187.9	173.3			(109, 182)
	75					295.0				264.4					(180)
	100	399.6	396.6	392.5$_9$	385.1	376.6	366.1	350.2	343.8	335.6		(341.1 at *C* = 80)			(180, 263)
	128					465.5				414.6					(180)
	140			534		(455 at *C* = 80)				446					(180)
	156			588		560	(498 at *C* = 80)			489					(180)
	218			780		742	(639 at *C* = 80)								(180)
	281			930		874	(723 at *C* = 80)								(180)
	306			100$_8$		910	(720 at *C* = 80)								(180)
$\frac{1}{3}K_3W_2Cl_9$	1				77.1	73.4	68.9	62.6	60.1	57.4					(51)
RbCl	6											81.6		79.3	(49)
	18		130.1			125.2					114.8	111.1	106.2	102.0	(49, 94, 95, 125, 126, 127, 128, 129, 133)
	25		149.9	149.7	147.4	144.9	141	(139 at *C* = 30)							(22, 28)
CsCl	0										70.8	68.3	67.8	67.4	(207)
	18	131.05	130.35	129.20	127.15	124.89			115.5	113.28	108.6	102.7	100.8	98.8	(93, 138, 185)
	25		152.0	150.3	147.7	145.0	141.3	(138.7 at *C* = 30)							(22, 28)
	50											(167)	162.$_2$	156.$_4$	(207)
[Br]; NH_4Br	0*			1.153	1.140	1.127	1.107	1.073	1.059	1.043	1.016	**1.000**			(109)
	18							117.8	116.2	114.3	110.0	104.8	103.3	101.7	(82, 93)
$(CH_3)_4NBr$	25	121.88	120.00												(11)
$(C_6H_5CH_2)_3NHBr$	18				81.5	79.1	75.2								(64, 66)
	25					(90.3 at *C* = 14.4)									(66)
$\frac{1}{3}InBr_3$	18									53.9	46.8	37.0	33.1	28.74	(93, 95, 96, 97, 99)
$\frac{1}{2}ZnBr_2$	25						(100.$_1$ at *C* = 90)					83.$_9$	79.$_7$	74.$_3$	(207)
$\frac{1}{2}CdBr_2$	0		64.$_0$	59.$_3$	52.$_2$	46.$_5$	40.3	32.4	29.8	27.1	21.8	15.2			(109)
	18		103.$_7$	97.$_0$	85.$_9$	75.8	65.7	52.4	47.9	43.2	35.1	25.2	22.0	18.8	(84, 85, 273)
	25		120	110.$_9$	98.$_3$	87.9	76.9	61.4	56.0	50.3	40.2	29.0$_0$	25.4	21.7	(84, 85, 109, 273)
	50		187	173	153	135	117	94.$_5$	86.$_3$	77.$_6$	62.$_0$	43.$_6$	37.$_6$	31.7	(207)
$\frac{1}{2}HgBr_2$	18			(1.29 at *C* = 12.4)				(1.10 at *C* = 23.6)							(85)
	25			(1.63 at *C* = 12.4)				(1.34 at *C* = 23.6)							(85)
$\frac{1}{2}CuBr_2$	0		68	66.$_8$	64.$_2$	62.$_3$	60.$_2$	56.$_7$	55.$_4$	53.$_9$	50.$_2$	44.$_6$	42.$_5$	40.$_0$	(109)
	25		128	125	122	119	114	107	104	100	92	81	77	72	(109)
$PtBr_4$															(171)
$\frac{1}{2}MnBr_2$	18											72.3	68.8	64.7	(99)
	25		124.$_5$	122.$_2$	117.$_7$	112.$_8$	107.$_5$								(3)
$\frac{1}{2}FeBr_2$	18											72.2	68.8	64.3	(99)
$\frac{1}{2}CoBr_2$	0			64.3	63.9	62.7	60.6	57.0	55.7	54.2	51.5	46.7			(109)
	18											73.2	69.7	65.5	(99)
	25			123.$_1$	119.$_7$	116.$_3$	112.$_3$	105.$_3$	102.$_5$	99.$_3$	92.8	82.7			(109)
	50				186	180	173	162	157	152	142	127			(109)
$\frac{1}{2}NiBr_2$	18									86.$_2$	81.0	73.3	69.9	65.8	(99)
$\frac{1}{3}CrBr_3$; violet	18									87.6	81.6	72.7	68.6	63.8	(99)
$\frac{1}{3}AlBr_3$	0		67.4	65.6	63.0	60.8	58.7	55.4	54.1	52.6	49.5	44.5			(115)
	25		138.1	132.2	124.1	118.1	112.1	103.9	100.8	97.3	90.6	80.9	76.2	70.6	(115)
$\frac{1}{2}MgBr_2$	0		68.$_9$	67.$_6$	65.$_6$	63.$_8$	61.$_6$	58.$_6$	57.$_4$	55.$_9$	52.$_9$	47.$_4$	45.$_1$	42.$_6$	(109)
	18							94.4	91.8	89.0	83.0	73.4	69.6	65.2	(93)
	25		128.$_3$	125.$_0$	120.5	117.2	113.7	107.8	105.1	102.0	95.4	83.6	78.6	72.9	(109)
	50				188	182	174	162	156	151	142	134			(109)
$\frac{1}{2}CaBr_2$	18							97.9	96.0	92.9	87.0	78.9	75.6	71.7	(93)
$\frac{1}{2}SrBr_2$	18							100.3	97.1	93.7	87.3	78.4	74.9	71.0	(93)
$\frac{1}{2}BaBr_2$	0		70.$_9$	69.8	67.9	66.1	64.0	60.8	59.6	58.2	55.0	50.9	49.4	47.8	(109)
	18							98.1	95.9	93.5	88.4	80.4	77.3	73.8	(93)
	25		133.$_2$	131.5	127.9	123.8	118.9	111.9	109.3	106.4	100.4	91.2	87.3	83.1	(109)
	50			205	200	195	187	174	169	164	153				(109)
$\frac{1}{2}RaBr_2$	18	121.1	119.6	117.2	113.5†	110.1	105.8	99.5†							(134)

* Relative to $\Lambda_{500} = 1$. † For temp. coeff., *see* (134).

TABLE 2.—(*Continued*)

	°C	C = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$LiBr$	0		61.2	61.0	60.5	59.3	57.4	55.1	54.3	53.4	51.4	47.5	45.6	43.4	(109, 110)
	18							87.8	86.1	84.3	80.8	74.1	71.0	67.2	(93)
$NaBr$	18							99.0	97.6	95.9	91.7	84.5	81.7	78.0	(93)
	25	126.9	126.2	125.0	122.8	120.5	117.8	113.2	111.3	109.1	104.4	97			(109, 156, 195)
	50	1.0500	1.0452	1.0395	1.022	**1.000**	0.9697	0.9265	0.8880	0.8410	0.7570	(Relative to Λ_{10} = 1)			(109)
KBr	0								(74.7)	73.6	71.1	69.1	68.8	68.5	(245)
	18	129.86	129.10	128.04	126.13	124.13	121.61	117.53		113.98	110.17	105.06	103.22	101.2	(48, 82, 93, 94, 138)
	25	150.8	149.9	148.5	146.1	143.5	140.5	135.7	133.6	131.4	127	123			(109, 156, 205)
	50	(234)	233.8	231.5	227.7	223.1	217.4	208.8		201.1	192.5	180.4	175.8	170.6	(82, 109)
$RbBr$	6											82.7	82.1	81.2	(49)
	18	(Relative to Λ_{500} = 1)								1.0860	1.0465	**1.000**		0.9674	(95)
	25	(Relative to Λ_{500} = 1)				1.476	1.424	1.345	1.309	1.265	1.161	**1**			(57)
$CsBr$	18											106.3	104.2	101.7	(99)
[I]; NH_4I	18							117.9	116.6	114.9	110.9	105.9	104.6	103.4	(93)
$(C_3H_7)_4NI$	25	98.36	97.65												(11)
$(C_2H_5)_4NI$	0		56.7	56.2		53.6				40.2					(109)
	25	106.7	105.4	104.1	101.8	99.2	95.4	88.8	86.1	83.0					(109, 203)
	35		127	126	124	121	116	107	102	98					(109)
$(CH_3)_4NI$	25		123.5	121.2	116.8	112.4	107.1	98.7	95.2	91.2					(100)
$\frac{1}{2}ZnI_2$	25			(105 at C = 60)								87.5	83.6	78.6	(207)
$\frac{1}{2}CdI_2$	0		57.7	51.7	43.9	37.5	30.9	22.7	20.2	17.7	13.8	10.8			(109)
CdI_2															(35)
$\frac{1}{2}CdI_2$	18		98	91.2	76.6	64.7	53.3	39.3	34.5	29.7	23.5	18.3	16.8	15.32	(84, 85, 273)
	25		111	100.2	89.5	77.2	63.9	47.3	41.5	35.9	27.9	21.4	19.7	17.9	(84, 85, 109, 273)
	50		176	161	139	121	102	76	66.5	58.0	44.5	32.8			(109)
	100		(79 at C = 192) (42.2 at C = 959)												(92)
$\frac{1}{2}MgI_2$	18							94.5		89.7	84.1	75.6	72.4	68.6	(93)
$\frac{1}{2}CaI_2$	18							99.4	97.3	94.7	89.5	82.1	79.0	75.4	(93)
$\frac{1}{2}SrI_2$	18							98.9	96.5	93.8	88.6	81.5	78.6	75.1	(93)
$\frac{1}{2}BaI_2$	18							102.3	99.6	96.7	91.2	83.7	80.8	77.3	(93)
LiI	18							89.3	88.3	84.9	81.4	75.4	72.7	69.2	(93)
NaI	0		66.0	65.8	65.3	64.5	63.1	61.2	60.4	59.5	57.6	55.2			(109)
	18							97.6	96.0	94.2	90.1	84.0	81.6	78.5	(93)
	25		124.8	123.7	122.2	119.8	117.0	112.8	111.0	108.9	104.9	99.5	96.5	92.9	(109, 207)
	50			1.052	1.024	**1**	0.972	0.931	0.916	0.899	0.865	(Relative to Λ_{10} = 1)			(109)
KI	0		81.7	81.1	79.9	78.7	77.4	75.1	74.2	73.4	71.8	70.2	70.0	70.1	(109, 112, 245)
	18	128.71	127.99	126.96	125.07	123.19	120.83	117.01	115.42	113.78	110.43	106.07	104.72	103.39	(48, 93, 135, 138, 185)
	25		147.3	146.3	144.2	141.9	139.1	134.4	132.5	130.5	126.3	120.5			(25, 109, 110, 203)
	50		230	226	217.7	213.0	209.1	202.0	198.6	194.8					(109)
KI (satd. with I)	25		131	130	128	125.8	123.1	118.8	116.5	114.7					(25)
KI_3	25	113.0	112.0	110.9	108.6	106.4	103.7	99.7	(Corrected for solubility of I_2)						(25); *cf.* (35)
RbI	6				(83.8 at C = 400)								82.7	82.2	(49)
	18								(119.2)	117.1	113.0	108.3	106.9	105.4	(49, 95)
	30											133.7	131.5	128.9	(49)
[SO_4]; $\frac{1}{2}(NH_4)_2SO_4$	18	127	124.5	122.0	117.9	113.5	(107.4)	(98.9)	(95.7)	92.0	(84.9)	75.5	71.9	68.2	(94, 124, 202)
	25		143.4	141.5	137.7	133.1	126.8	115.9	111.8	107.8	99.1	87.1	82.7	77.9	(109, 124)
$ZrOSO_4$															(256)
$Zr(SO_4)_2$															(234, 256)
$\frac{1}{2}Tl_2SO_4$	18		127.35	124.2	118.4	112.3	104.55	92.7	88.0	83.1	73.8				(105, 185)
	25		147.8	144.2	137.3	130.0	120.9	107.1	102.0	96.0	85.0				(105, 185)
$\frac{1}{2}ZnSO_4$	0	63.6	60.3	56.4	50.4	45.4	39.7	33.4	31.4	29.4	25.5	20.9	18.9	16.3	(109, 116, 185)
	18	103.4	98.5	92.1	81.8	72.8	63.8	52.8	49.1	45.4	39.1	31.4	28.7	26.0	(133, 135)
	25		112	106	95	84.3	73.4	60.6	56.5	52.4	44.8	36.3	33.3	30.08	(109, 135)
	50		183	168	145	127	110	89	82	76	65.5	55.6			(109)
$\frac{1}{2}CdSO_4$	0	61.6	58.7	55.1	49.0	43.7	38.1	31.1	28.7	26.2	22.4	18.3	16.7	15.0	(116, 185)
	18	102.79	97.58	90.79	79.59	70.23	60.87	49.53	45.91	42.15	35.84	28.70	26.75	23.56	(85, 133)
	25		113.2	105.5	93.0	81.7	70.4	57.0	52.9	49.0	(41.8)	33.3	30.5	27.3	(85, 273)
$CuSO_4$	0	62.7	59.6	55.9	47.9	44.2	38.8	32.1	30.2	27.7	23.7	18.9	17.5	15.9	(109, 116, 274)
	18	103.42	98.42	91.81	80.87	71.64	62.32	51.09	47.38	43.79	37.61	30.72	28.25	25.74	(133, 135)

TABLE 2.—(*Continued*)

	°C	C = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$\frac{1}{2}CuSO_4$.—(*Continued*)	25		115.2	110.3	97.5	83.3	72.2	58.8	54.6	50.48	43.5	35.1	32.3	29.3	(89, 109, 135)
	50		182	166	142	123.0	106.0	85.6	79.0	72.4	61.0	49.9			(109)
$\frac{1}{2}Ag_2SO_4$	18		116.8	114.2	108.9	103.3	95.5								(65, 105)
	25		135.2	132.4	126.1	119.7	111.5								(105)
$AgC_2H_5SO_4$	25		101.1	100.2	97.8										(153)
$\frac{1}{2}MnSO_4$	0			56.9	50.4	45.4	40.8	33.6	31.5	29.2	24.9	19.8			(109)
	18											(30.0)	27.5	24.73	(124)
	25			107	93.9	84.0	74.0	60.8	56.4	52.1	44.5	35.5	32.4	29.00	(109, 124)
	50						104	87.2	81.1	74.7	63.1	47.9			(109)
$\frac{1}{2}FeSO_4$	18											30.8	28.5	25.8	(124)
	25				85.9	76.8	68.5					35.5	32.9	29.7	(124, 259)
$\frac{1}{2}CoSO_4$	0		58.8	54.4	48.4	43.6	38.7	32.1	29.8	27.5	23.6	18.9	17.3	15.7	(109)
	25		113.4	104.6	92.3	82.5	72.7	60.1	55.7	51.4	43.9	35.3	32.5	29.3	(109)
	50		181	(160)	(135)	(118)	104	88.6	83.1	77.4	66.2	50.8			(109)
$\frac{1}{2}NiSO_4$	18	102	94.4	88.4	78.3	69.8	61.1	50.3	47.1	43.8	37.9	30.6	28.1	25.40	(124, 135, 202); *cf.* (176.5)
	25			106.3	94.2	83.9	73.2	59.7	55.6	51.6	44.5	35.8	32.8	29.6	(109, 124); *cf.* (176.5)
	50			147	126	110	(97)	(82)	(77)	(72)	63.1	52.2			(109)
$\frac{1}{6}Cr_2(SO_4)_3$, violet	0		(59)	53.0	45.3	39.7	34.6	28.7	26.8	24.7	20.9	15.8	14.1	12.3	(109, 272)
	25		128	116.9	99.8	85.9	74.5								(260, 261, 262)
UO_2SO_4	0	(*Also* at *t* = 12.5, 25, 35, 50, 65°C)													(62, 109)
$VOSO_4$															(139)
$\frac{1}{6}Al_2(SO_4)_3$	25		107.0	95.0	78.9	67.3	57.2								(261)
$\frac{1}{6}Sc_2(SO_4)_3$	25		(65.7)	54.4	42.7	35.8	29.9	24.1	22.2	(Original values are lowered 5 %)					(19)
$\frac{1}{6}Y_2(SO_4)_3$	25		86.0	73.1	57.6	48.2	40.4	32.1	(29.4)						(19)
$\frac{1}{6}La_2(SO_4)_3$	0			39.8	(31.2)	26.3	(22.0)	17.2	15.8	14.4	12.1				(186)
	18			60.1	(48.0)	39.7	(33.1)	25.7	23.5	21.4	17.8				(186)
	25			67.9	(53.5)	44.6	(37.0)	28.7	26.3	23.9	19.8				(186)
$\frac{1}{6}Ce_2(SO_4)_3$	25		87.6	72.3	56.2	46.8	39.4	31.1	(28.4)						(19, 170)
$\frac{1}{6}Pr_2(SO_4)_3$	25		85.6	71.6	55.9	(46.9)	39.5	30.9	28.2	25.7	21.3	16.3			(19)
$\frac{1}{6}Nd_2(SO_4)_3$	25		83.1	71.3	57.2	47.7	39.6	31.2	28.7	26.1	21.7				(19, 113)
$\frac{1}{6}Sa_2(SO_4)_3$	25		88.7	74.7	58.8	48.8	40.8								(8, 19)
$\frac{1}{6}Gd_2(SO_4)_3$	25		87.6	74.1	59.0	49.2	41.7								(19)
$\frac{1}{6}Er_2(SO_4)_3$	25		96.1	82.7	66.5	56.3	47.5								(19)
$\frac{1}{6}Yb_2(SO_4)_3$	18			68.6	54			31.7		27.2	23.0				(50)
$\frac{1}{2}MgSO_4$	0	63.3	60.4	56.9	51.4	46.7	41.7	35.2	32.9	30.6	26.5	21.4	19.7	17.9	(60, 116, 185, 274)
	18	104.2	99.9	94.21	84.31	76.07	67.56	56.78	53.29	49.57	43.05	34.89	31.99	28.99	(70, 89, 133, 191)
	25	123.2	117.6	110.9	98.8	88.92	79.02	66.50	62.20	57.84	49.81	40.75	37.38	33.60	(89, 124, 135)
	50			168	147	132	116	97	91	84	73	58	53	48	(109)
	100*			302		223.2	189.8	151.3		129.4	110.4	(100.5 at C = 320)			(191)
	156†			377		240.7	194.8	148.8		125.9	109.0	(98.6 at C = 320)			(180)
	217.8			260		143	110.4	(88.4 at C = 40) (75.1 at C = 80) (62.4 at C = 160)							(180)
$\frac{1}{2}CaSO_4$	18	109.25	103.94	97.16	86.42	77.42	68.30	(62.94 at C = 29.5 or satd. soln.)							(89, 104, 133, 166)
	25	127.22	121.40	113.04	100.01	90.02	79.21	(72.3 at C = 30.5 or satd. soln.) (69.1 at C = 36.4)							(89)
	50	(159.8 at C = 4)		175.8		136.4	117.9	(107.5 at C = 30.0 or satd. soln.) (142.2 at C = 8)							(166)
	100	(257.7 at C = 4)		294.6		208.8	173.8	(166.6 at C = 23.3 or satd. soln.) (220.2 at C = 8)							(166)
	156			341	(280 at C = 4) (243 at C = 6.4 or satd. soln.—soluble anhydrite)										(166)
$\frac{1}{2}Li_2SO_4$	0			57.0	55.1	53.0	50.1	45.2	43.6	41.3	37.1	30.7	28.1	25.0	(109)
	18	97.57	96.14	94.31	90.70	86.75	81.94	74.48	71.36	67.97	60.86	50.38	46.22	41.22	(94, 99, 125, 126, 127, 128, 129, 133, 185)
Na_2SO_4	0‡		127.08	123.49	117.39	111.5	104.51	93.99	85.24	75.62					(211)
$\frac{1}{2}Na_2SO_4$	0		64.2			58.5		51.2							(60, 185)
	18	107.3	105.8	104.1	100.2	96.1	91.0	83.68	80.9	77.6	70.4	59.4	55.2	50.3	(4, 94, 99, 124, 125, 126, 127, 128, 129, 133, 185, 241)
	25			122.1	117.28	112.39	106.80	97.8	94.2	90.0	81.54				(185)
	50				187	178	169	152.9	147.0	140.5	122.3	107.4	99.6	91.1	(140)

* 212.2 at C = 12.5, 178.8 at C = 25, 159.8 at C = 40, 135.9 at C = 80, 116.4 at C = 160.

† 224.7 at C = 12.5, 179.8 at C = 25, 157.8 at C = 40, 132.9 at C = 80, 114.7 at C = 160.

‡ Concentrations are *m*(= millimole/kg H_2O) and conductance data are $10^6\kappa/m$.

Table 2.—(*Continued*)

	°C	C = 0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$\frac{1}{2}$K$_2$SO$_4$	0	79.$_4$	78.8	77.$_4$	74.$_6$	72.1	68.$_9$	63.7	61.$_6$	59.$_4$	55.$_1$	49.$_2$			(60, 109, 116, 185)
	18	128.3	126.7	124.4	120.1	115.6	110.1	101.8$_4$	98.4	94.8$_2$	87.8$_0$	78.3$_0$	75.0	71.5$_0$	(124, 133, 185, 191, 241)
	25			144.6	139.6	134.2	127.9	117.98	114.1$_0$	109.7$_1$	101.2$_6$	90.3	(96.0$_2$ at C = 300)		(26, 87, 185)
	100	(357.5 at C = 12.5)		40.09		364.7		311.6		285.6	(319.6 at C = 40)				(191)
	156			605		537	(454.4 at C = 40) (414.4 at C = 80)								(191)
	217.8			805		672	(545 at C = 40) (482 at C = 80)								(191)
	280.9			892		687	(519 at C = 40) (448 at C = 80)								(191)
	305.7			866		637	(466 at C = 40) (395 at C = 80)								(191)
$\frac{1}{2}$Rb$_2$SO$_4$	6											64.9	62.6	60.1	(49)
	18									103.5	95.9	85.8	82.1	78.2	(95)
	30											106.7	102.1	96.9	(49)
[NO$_3$]; NH$_4$NO$_3$	0		78.4	77.2	76.0	74.9	73.5	70.8	69.7	68.4	65.7	62.1	60.6	59.0	(109, 245)
	18		124.3	122.8	120.3	118.2	115.0	110.4	108.5	106.3	101.5	94.4	91.7	88.6	(70, 126)
	25		142	141.$_4$	138.7	136.2	133.3	128.0	125.5	122.8	116.9	108.0			(109)
	50		218.$_7$	215.3	211.2	207.1	201.8	192.8	188.4	184.9	174.7	159.2			(109)
	100									(324)	304	273	260	244	(207)
C$_9$H$_{12}$N$_2$O$_4$	25		Hydroxyhydrindamine nitrate												(217)
$\frac{1}{2}$Pb(NO$_3$)$_2$	0		(73.3)	71.34	67.93	64.71	60.42	53.27	50.28	47.04	40.55	31.8	28.0	24.3	(109, 212)
	18	117.94	116.00	113.41	108.56	103.44	96.89	86.28	82.05	77.18	67.29	53.15	47.80	41.97	(133, 154, 185)
	25		135.4	134.0	128.1	121.1	112.9	101.0	96.3	90.9	79.1	62.9	56.9	50.3	(72, 87, 154)
	50		211	204	193	184	173	155	148	139	122	96.$_8$	86.$_5$	76.$_0$	(109)
TlNO$_3$	0		80.6$_5$	79.8$_0$	78.2$_0$	76.3$_6$	73.8$_7$	69.3$_3$	66.9	64.7$_8$					(114)
	18	125.57	124.67	123.44	121.07	118.34	114.60	107.90	104.8$_0$	101.14					(138, 185)
	25		144.2$_4$	142.5$_6$	139.5$_0$	136.3$_7$	132.0$_4$	124.2$_5$	120.7	116.6$_0$					(114)
	100									312	290	252	234	212	(208)
$\frac{1}{2}$Zn(NO$_3$)$_2$	0			61.$_8$	60.$_6$	59.$_8$	57.$_9$	54.$_5$	52.$_8$	51.2	47.9	42.9			(109)
	18									80.5	75.2	67.2	63.6	59.2	(95)
	25		117	115.$_1$	112.$_7$	110.$_8$	115.$_9$	98.$_9$	95.$_7$	92.1	85.4	77.9			(109)
	50		191	185	177	171	163	152	148	143	131	112			(109)
$\frac{1}{2}$Cd(NO$_3$)$_2$	18		108.2	105.0	100.2	96.2	91.9	85.$_5$	82.7	79.7	73.5	63.4	59.1	53.9	(85, 273)
	25				114.$_8$	110.$_8$	106.$_5$	99.$_3$	96.$_3$	92.9	85.1	72.3	67.0	60.9	(85, 273)
$\frac{1}{2}$Hg$_2$(NO$_3$)$_2$															(193, 243, 262)
$\frac{1}{2}$Cu(NO$_3$)$_2$	0			64.9	63.1	61.0	58.5	54.8	53.4	51.7	48.2	42.9	40.6	37.6	(109, 245)
	18									81.9	76.0	67.2	63.0	57.8	(95)
	25		121.$_8$	120.$_3$	117.$_4$	113.$_5$	108.$_2$	100.$_5$	97.5	94.0	86.9	76.3	71.9	66.8	(72, 109)
AgNO$_3$	0	72.4	71.9	71.2	70.0	68.8	66.9	63.3	61.5	59.7	55.8	50.3	47.6	44.4	(60, 116, 185, 245)
	18	113.72	113.00	111.92	109.88	107.62	104.9$_0$	99.6$_3$	97.17	94.20	87.8$_8$	77.3$_9$	72.9	67.5$_1$	(99, 133, 191)
	25		130.1	128.7	126.6	124.1	120.9	115.0	112.1	108.7	101.8				(87, 153, 235)
	50			187	183	178	173	163	158.$_9$	154.$_0$	143.$_0$	124.$_9$			(109)
	100			353	334.0*	334.0	325.0	307.1	293.6†	288.6	260	228	212	194	(191, 208)
	156			539		507	486.8	(461.3 at C = 40) (431.4 at C = 80)							(191)
	217.8			727		673	639	(599 at C = 40) (552 at C = 80)							(191)
	280.9			877		790	(680 at C = 40)			(614 at C = 80)					(191)
	305.7			935		818	(680 at C = 40)			(604 at C = 80)					(191)
$\frac{1}{2}$Mn(NO$_3$)$_2$	18											66.8	63.2	58.9	(99)
$\frac{1}{3}$Fe(NO$_3$)$_3$	18											75.9	70.2	63.8	(99)
$\frac{1}{2}$Co(NO$_3$)$_2$	0			(62)	59.$_2$	56.$_9$	54.3	50.9	49.6	48.0	44.8	40.0	38.1	35.7	(109, 110)
	18											66.2	62.3	58.0	(99)
	25		116.$_5$	113.$_9$	109.$_9$	106.$_8$	101.$_6$	94.9	92.1	89.2	83.0	73.6	69.9	65.5	(72, 109)
	50				176	169	162	150.$_5$	146	141	131	115			(109)
$\frac{1}{2}$Ni(NO$_3$)$_2$	0			(60.0)	57.4	55.5	53.5	50.3	49.2	47.9	45.1	40.3	38.2	35.7	(109, 110)
	18											66.9	62.6	57.6	(99)
	50			183	177	171	163	151	147	141.$_5$	130	113	106	97	(109)
$\frac{1}{3}$Cr(NO$_3$)$_3$	0			73.7	68.6	64.5	(60.4)	(54.5)	52.3	50.1	45.6	39.4	37.0	34.3	(109)
	18			130.7	117.6	108.6	99.4	88.6	(85.0)	80.2	74.0	64.8	61.0	55.9	(15, 99)
	19.8			134.5	120.7	110.9	101.7	90.6	(86.8)						(15)
	25			149.8	134.$_3$	(123)	(112)	98.$_9$	94.$_9$	91.1	84.4	75.2	70.4	63.8	(109)
	50			258	229	(209)	(189)	164	156	148	133	112.$_6$	104.$_1$	94.$_5$	(109)

* At C = 12.5.

† At C = 80.

TABLE 2.—(*Continued*)

	°C	C = **0.5**	**1**	**2**	**5**	**10**	**20**	**50**	**70**	**100**	**200**	**500**	**700**	**1000**	Lit.
$UO_2(NO_3)_2$	0	(*Also* at t = 12.5, 25, 35, 50, 65°C)													(109)
	25														(62, 164)
$\frac{1}{3}Al(NO_3)_3$	0		64	62.6	60.3	58.2	55.7	51.5	49.9	48.2	44.6	39.2	37.0		(109)
	25		125	120.4	114.0	108.5	102.9	94.8	91.5	87.9	80.5	69.6	65.0		(109)
	50		224	211	194	181	168	151	145	138	126	107	100		(109)
$\frac{1}{3}La(NO_3)_3$	0			68.9	(65.3)	62.4	(59.0)	54.0	52.0	49.9	46.0				(186)
	18			110.7	(104.8)	100.0	(94.5)	86.6	83.6	80.2	(73.6)	64.0	59.7	54.0	(99, 186)
	25		133.5	128.8	(122.2)	116.4	(109.6)	99.6	95.8	91.7	83.4				(177, 186)
$\frac{1}{2}Be(NO_3)_2$	18											63.8	60.2	56.2	(99)
$\frac{1}{2}Mg(NO_3)_2$	0		(64)	63.1	61.1	59.5	57.6	54.2	52.9	51.4	48.1	42.7	40.5	37.9	(109, 110)
	18		102.5	100.7	97.6	94.52	90.8	85.2	82.9	80.4	75.2	67.2	63.9	59.5	(48, 105, 185)
	25		119.4	117.3	113.6	109.90	105.6	98.9	97.3	94.0	87.1	70.7	72.3	67.2	(105, 135, 185)
	50				179	173	165	154	149	144	134	117	110	103	(109)
$\frac{1}{2}Ca(NO_3)_2$	0			66.4	64.1	62.2	59.8	55.5	53.1	51.8	47.8	41.6	39.4	36.2	(109, 110, 186)
	18	109.78	108.34	106.39	103.93	99.39	95.05	88.29	85.38	82.37	75.84	65.61	61.22	55.79	(133, 135)
	25			123.6	119.5	115.8	110.9	102.5	99.3	95.7	88.4	77.0	72.5	66.7	(135, 186)
	50				183	177	168	155	150	143	130	113			(109)
$\frac{1}{2}Sr(NO_3)_2$	0	66.9	66.0	64.7	62.4	60.2	57.4	53.8	51.1	49.1	44.8	37.9	35.2	32.2	(109, 116)
	18	109.61	108.16	106.20	102.60	98.90	94.39	87.18	84.17	80.82	73.70	62.64	58.00	52.00	(133, 185)
	25			124	119.5	115.3	109.8	101.0	97.7	93.8	85.4	72.2	66.5	59.8	(109, 135)
	50				184	177	168	155	149	143	129	110			(109)
$\frac{1}{2}Ba(NO_3)_2$	0	71.2	70.0	68.4	66.2	63.6	59.8	54.1	51.5	48.7	42.6				(109, 116, 135, 185)
$Ba(NO_3)_2$	0*		137.60	133.57	126.34	119.29	110.67	97.18		85.47	72.08				(211)
$\frac{1}{2}Ba(NO_3)_2$	18	113.14	111.56	109.35	105.14	100.82	95.53	86.69	81.5	78.83	70.08	56.52			(133, 185, 191)
	25			124.4	120.2	115.8	110.3	100.6	96.3	91.6	81.7	65.8	59.5		(87, 109, 135)
	50				188.8	179.5	169.4	153.9	147.9	140.9	125.5				(109, 140)
	100	(315.5 at C = 12.5)		351.5		321.5		273.1		248.6	(279.6 at C = 40) (257.1 at C = 60)				(191)
	156			536		481	(412 at C = 40) (372 at C = 80)								(191)
	217.8			714		618	(507 at C = 40) (449 at C = 80)								(191)
	280.9			827		657	(503 at C = 40) (430 at C = 80)								(191)
	305.7			823		615	(448 at C = 40)								(191)
$LiNO_3$	0		54.9	54.8	54.6	53.6	51.5	49.4	48.6	47.4	44.7	41.0			(109)
	18	93.23	92.58	91.68	90.05	88.33	86.15	82.46	80.85	78.95	74.79	67.80		60.61	(137, 185)
	25		103	102.7	100.6	98.5	95.7	91.0	89.0	86.5	81.7	75.2			(109)
	50				162	157.4	150.8	143.6	141.5	138.8	130.7				(109)
$NaNO_3$	0		(64.7)		63.4	62.6	60.8	57.7	55.8	54.5	51.4	46.3	43.8	41.9	(109, 185, 245)
	18	103.38	102.60	101.65	99.83	97.93	95.43	91.22	89.42	87.04	82.09	73.88	70.07	65.72	(48, 137, 185)
	25		120.4	119.1	116.3	113.7	110.7	105.3	102.5	98.7	92.0	83.0			(109, 195)
	50		185.0	182.3	178.2	174.1	169.3	161.6	157.9	153.4	143.3	128.0			(109, 238)
	100		331.5	326.5	320.5	312.5	302.6								(263)
KNO_3	0	79.29	78.89	78.25	77.09	75.60	73.70	70.29	68.8	66.80	63.4	57.4			(109, 186, 263)
	18	124.16	123.37	122.32	120.21	117.93	114.96	109.62		104.56	98.53	89.12	85.08	80.33	(137, 185, 263)
	25			140.5	138.3	135.7	132.3	126.10	123.3	120.16	113.26	101.4			(26, 87, 109, 186)
	50			212.4	208.9	204.6	199.0	189.4	185.2	180.1	169.0	151.0			(109, 186)
	100	377.7	374.7	370.6	363.3	354.8	344.1	326.7	318.7	309.3					(186, 263)
	128			461.8	(436.7 at C = 12.5)			404.8		381.9					(186)
	156			551.9	(522.4 at C = 12.5)			479.4		451.3					(186)
$RbNO_3$	6											72.7	69.3	65.6	(49)
	18									112.6	105.7	95.3	90.8	85.6	(95)
	30											118.7	112.7	106.0	(49)
$CsNO_3$	0	83.0	82.4	81.7	80.2	78.5	76.4	72.7	71.0	69.3	65.3	59.0			(263, 265)
	18	128.4	127.4	126.2	123.6	121.1	117.9	(112.0)	(109.4)	106.4	100.1	90.7	86.7	82	(99, 263)
	100	382.5	379.0	375.0	367.0	358.6	347.0								(263)

* Concentrations are m(= millimole/kg H_2O) and the conductance data $10^6\kappa/m$.

TABLE 3.—(*Continued from p. 231*)

Cl.—(*Cont'd*)

½$\mathrm{MgCl_2}$.—(*Cont'd*)

25°

C	$10^6\kappa/C$
2 000	60.4
3 000	49.2
4 000	39.6
5 000	31.1
7 984	15.79
9 363	9.95

½$\mathrm{CaCl_2}$

See also p. 240

0°

C	$10^6\kappa/C$
2 000	37.89
3 000	32.94
4 000	28.21
5 000	23.48
6 000	19.14
7 000	15.36
8 500	(9.94)

18°

C	$10^6\kappa/C$
2 000	58.02
3 000	49.7
4 000	42.4
5 000	35.6
7 000	23.5
8 468	16.13

25°

C	$10^6\kappa/C$
2 000	66.65
3 000	56.6
4 000	48.35
5 000	40.7
6 000	33.40
6 915	27.60
8 418	18.89

50°

C	$10^6\kappa/C$
4 910	61.1
6 879	42.0

100°

C	$10^6\kappa/C$
2 000	167
3 000	140
4 000	119
5 000	101
6 000	85.5
7 000	71.6
7 911	56.9
9 070	46.8

½$\mathrm{SrCl_2}$

0°

C	$10^6\kappa/C$
2 000	(41.0)

18°

C	$10^6\kappa/C$
2 000	57.5
3 000	49.7

40°

C	$10^6\kappa/C$
1 369	94.9

100°

C	$10^6\kappa/C$
2 000	164
3 000	138
4 000	118
5 000	99

½$\mathrm{BaCl_2}$

0°

C	$10^6\kappa/C$
2 000	40.6
3 000	35.3

18°

C	$10^6\kappa/C$
2 000	60.50
3 000	51.5

25°

C	$10^6\kappa/C$
2 000	68.5
3 000	58.2

100°

C	$10^6\kappa/C$
1 400	182.6
2 000	164.4
3 000	141.6

LiCl

0°

C	$10^6\kappa/C$
2 000	33.67
3 000	28.81
4 000	24.74
5 000	21.11
6 000	17.77
7 000	14.55
8 000	12.04
9 000	9.65
10 000	7.42
11 000	5.42
12 000	3.03

18°

C	$10^6\kappa/C$
2 000	53.0
3 000	45.2
5 000	33.3
10 000	11.3

25°

C	$10^6\kappa/C$
2 000	61.7
3 000	52.9
4 000	44.7
5 000	37.8
6 000	31.7
7 000	26.0
8 000	20.9
9 000	16.4
10 000	13.2
11 000	10.4
12 000	8.14
14 040	5.11

50°

C	$10^6\kappa/C$
2 000	95.6
5 000	57.5
7 000	39.3
10 000	21.6

100°

C	$10^6\kappa/C$
2 000	164
3 000	137.1
4 000	116.4
5 000	98.8
6 000	83.7
7 000	71.7
8 000	60.8
9 000	50.8
10 000	41.1

NaCl

0°

C	$10^6\kappa/C$
2 000	41.4
3 000	36.5
4 000	31.5
5 000	26.6
5 500	24.6

18°

C	$10^6\kappa/C$
2 000	64.66
3 000	56.4
4 000	42.6

25°

C	$10^6\kappa/C$
5 000	44.7

100°

C	$10^6\kappa/C$
2 000	209.7
3 000	184.1
4 000	164.6

KCl

0°

C	$10^6\kappa/C$
2 000	63.5
3 000	62.2

18°

C	$10^6\kappa/C$
2 000	92.3
3 000	88.1

RbCl

6°

C	$10^6\kappa/C$
2 000	77.1
3 000	75.4
4 000	73.9

18°

C	$10^6\kappa/C$
2 000	97
3 000	93
4 000	88

CsCl

0°

C	$10^6\kappa/C$
2 000	67.0
3 000	65.9
4 000	63.5
5 000	59.2
6 000	53.7
7 000	(47.2)

18°

C	$10^6\kappa/C$
2 000	94.2
3 000	88.7
4 000	(85.7)

50°

C	$10^6\kappa/C$
2 000	144.6
3 000	135.1
4 000	125.8
5 000	103.2
6 000	99.9
7 000	86.5
8 000	(72)

100°

C	$10^6\kappa/C$
5 000	(164)
6 000	141.0
7 000	121
8 000	102
8 500	93.1
9 000	(84)

Br

$\mathrm{NH_4Br}$, 18°

C	$10^6\kappa/C$
2 000	97.6
3 000	93.7
4 000	90.0

⅓$\mathrm{InBr_3}$, 18°

C	$10^6\kappa/C$
2 000	19.83
3 000	14.42
4 000	10.10

½$\mathrm{ZnBr_2}$, 25°

C	$10^6\kappa/C$
2 000	54.9
3 000	40.0
4 000	29.9
5 000	22.7
6 000	17.7
7 000	14.5
8 000	10.75
10 300	6.71
13 700	2.95
16 400	1.36
19 700	0.487

½$\mathrm{CdBr_2}$

18°

C	$10^6\kappa/C$
2 000	12.8
3 000	9.35
4 000	6.00
5 000	(5.1)

25°

C	$10^6\kappa/C$
2 000	15.01
3 000	10.64
4 000	8.40
5 000	(6.16)

50°

C	$10^6\kappa/C$
2 000	21.7
3 000	16.6
4 000	12.8
5 000	10.18
6 000	7.90
7 000	6.18
8 000	4.38
9 000	2.90

½$\mathrm{MnBr_2}$, 18°

C	$10^6\kappa/C$
2 000	53.54
3 000	43.6
4 000	35.64

½$\mathrm{FeBr_2}$, 18°

C	$10^6\kappa/C$
2 000	51.9
3 000	41.94
4 000	33.65
5 000	26.25

½$\mathrm{CoBr_2}$, 18°

C	$10^6\kappa/C$
2 000	54.7
3 000	45.5
4 000	37.56

½$\mathrm{NiBr_2}$, 18°

C	$10^6\kappa/C$
2 000	54.5
3 000	45.1
4 000	37.40

⅓$\mathrm{CrBr_3}$, Violet, 18°

C	$10^6\kappa/C$
2 000	51.3
3 000	41.3
4 000	33.22

½$\mathrm{MgBr_2}$, 18°

C	$10^6\kappa/C$
2 000	54.1
3 000	45.2
4 000	38.1

½$\mathrm{CaBr_2}$, 18°

C	$10^6\kappa/C$
2 000	62.0
3 000	53.0
4 000	45.7

½$\mathrm{SrBr_2}$, 18°

C	$10^6\kappa/C$
2 000	62.0
3 000	53.5
4 000	45.6

½$\mathrm{BaBr_2}$, 18°

C	$10^6\kappa/C$
2 000	64.7
3 000	56.0
4 000	48.3

LiBr, 18°

C	$10^6\kappa/C$
2 000	57.7
3 000	50.5
4 000	44.2

NaBr, 18°

C	$10^6\kappa/C$
2 000	69.1
3 000	60.5
4 000	53.0

KBr

0°

C	$10^6\kappa/C$
2 000	67.7
3 000	66.3

18°

C	$10^6\kappa/C$
2 000	96.5
3 000	91.9
4 000	86.9

50°

C	$10^6\kappa/C$
2 000	157.1
3 000	145.6
4 000	132.2

RbBr

6°

C	$10^6\kappa/C$
2 000	(78.3)
3 000	(76.0)
4 000	74.0

18°

C	$10^6\kappa/C$
2 000	0.92644*
4 000	0.82277*

* Λ_C/Λ_{500}.

CsBr, 18°

C	$10^6\kappa/C$
2 000	(95.5)
3 000	89.8
4 000	84.1

I

$\mathrm{NH_4I}$, 18°

C	$10^6\kappa/C$
2 000	99.9
3 000	95.5
4 000	91.3

½$\mathrm{ZnI_2}$, 25°

C	$10^6\kappa/C$
2 000	62.4
3 000	44.8
4 000	30.4
5 000	20.7
6 000	14.8
7 000	10.6
9 250	4.90
10 800	2.90
13 900	0.916

½$\mathrm{CdI_2}$

18°

C	$10^6\kappa/C$
2 000	12.13
3 000	9.83
4 000	7.95

25°

C	$10^6\kappa/C$
2 000	14.03
3 000	11.38
4 000	9.18

100°

C	$10^6\kappa/C$
1 914	33.3

½$\mathrm{MgI_2}$, 18°

C	$10^6\kappa/C$
2 000	58.6
3 000	49.4
4 000	41.0

½$\mathrm{CaI_2}$, 18°

C	$10^6\kappa/C$
2 000	66.1
3 000	57.3
4 000	49.1

½$\mathrm{SrI_2}$, 18°

C	$10^6\kappa/C$
2 000	66.0
3 000	56.8
4 000	47.8

½$\mathrm{BaI_2}$, 18°

C	$10^6\kappa/C$
2 000	68.4

LiI, 18°

C	$10^6\kappa/C$
2 000	60.6
3 000	52.7
4 000	46.2

NaI

18°

C	$10^6\kappa/C$
2 000	70.1
3 000	61.8
4 000	53.9

25°

C	$10^6\kappa/C$
2 000	82.9
3 000	73.4
4 000	63.8
5 000	53.8
6 000	44.8
7 000	36.0

KI

0°

C	$10^6\kappa/C$
2 000	70.1
3 000	68.8
4 000	66.4
5 000	62.9

18°

C	$10^6\kappa/C$
2 000	99.6
3 000	92.8
4 000	89.4
5 000	80.6

I.—(*Cont'd*)

RbI

C	$10^6\kappa/C$
6°	
2 000	81.9
3 000	79.2
4 000	74.6
18°	
2 000	101.6
3 000	96.8
4 000	89.9
30°	
2 000	121.9
3 000	114.2
4 000	105.2

SO_4

½$(NH_4)_2SO_4$

C	$10^6\kappa/C$
18°	
2 000	60.3
3 000	54.6
4 000	49.5
5 000	44.6
6 000	(39.5)
25°	
2 000	67.8
3 000	61.7

½$ZnSO_4$

C	$10^6\kappa/C$
18°	
2 000	20.0
3 000	15.6_0
4 000	11.9_5
5 000	8.9_0
25°	
2 000	23.2_0
3 000	18.2_0
4 000	14.1_8
5 000	10.6_8

½$CdSO_4$

C	$10^6\kappa/C$
18°	
2 000	17.9_2
3 000	13.9_8
4 000	10.8_2
5 000	8.2_8
25°	
2 000	20.5
3 000	16.1
4 000	12.8
5 000	10.0

½$CuSO_4$

C	$10^6\kappa/C$
18°	
2 000	19.9_9
2 500	17.9_0
3 000	(16.2)
25°	
2 000	23.2
2 500	20.9

½$MnSO_4$

C	$10^6\kappa/C$
18°	
2 000	18.53
3 000	14.17
4 000	10.76
5 000	8.05
6 000	5.80
7 000	(3.80)

½$MnSO_4$.—(*Cont'd*)

C	$10^6\kappa/C$
25°	
2 000	21.7_5
3 000	16.8_0
4 000	12.8_0
5 000	9.5_5
6 000	7.0_0
7 000	(4.85)

½$FeSO_4$

C	$10^6\kappa/C$
18°	
2 000	19.5
3 000	15.3_0
4 000	11.9_3
25°	
2 000	22.6
3 000	17.9
4 000	(13.9)

½$NiSO_4$

C	$10^6\kappa/C$
18°	
2 000	19.25
3 000	15.07
25°	
2 000	22.7_2
3 000	17.8_3

½$MgSO_4$

C	$10^6\kappa/C$
18°	
2 000	21.4
3 000	16.1
4 000	12.0
5 000	8.8
25°	
2 000	25.2_5
3 000	18.9_5
4 000	14.2_0
5 000	10.4_0

½Li_2SO_4, 18°

C	$10^6\kappa/C$
2 000	30.3_9
3 000	23.1_6
4 000	17.9_7
5 000	13.7_9

½Na_2SO_4, 18°

C	$10^6\kappa/C$
2 000	39.6

½Rb_2SO_4

C	$10^6\kappa/C$
6°	
2 000	54.3
3 000	49.4
18°	
2 000	69.9
3 000	63.2
30°	
2 000	85.8
3 000	77.0

NO_3

NH_4NO_3

C	$10^6\kappa/C$
0°	
2 000	55.3
3 000	52.0
4 000	48.3
5 000	44.7
6 000	(41.6)
7 000	(39.2)
8 000	(35.6)
8 418	31.0

NH_4NO_3.—(*Cont'd*)

C	$10^6\kappa/C$
18°	
2 000	80.5
3 000	74.2
4 000	68.4
5 000	62.3
6 000	56.5
7 000	50.7
7 500	48.3
100°	
2 000	210
3 000	183
4 000	162
5 000	142
6 000	124
7 000	112
8 000	$99._1$
9 000	$86._3$
9 500	$79._9$
11 600	$58._0$
13 800	$38._8$
15 000	$29._0$

½$Pb(NO_3)_2$

C	$10^6\kappa/C$
18°	
2 000	30.6_8
2 500	27.0_5
25°	
2 000	36.5
2 500	31.6

$TlNO_3$, 100°

C	$10^6\kappa/C$
2 000	164
3 000	135
4 000	115
5 000	99
6 000	$86._0$

½$Zn(NO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	47.9
3 000	38.8_5
4 000	31.0_8

½$Cd(NO_3)_2$

C	$10^6\kappa/C$
18°	
2 000	40.8
3 000	31.4
4 000	24.2
5 000	18.4
6 000	13.7
6 500	11.5
25°	
2 000	46.0
3 000	35.4
4 000	27.2_1
5 000	20.5_0
6 000	14.0_8
6 490	13.3_3

½$Cu(NO_3)_2$

C	$10^6\kappa/C$
0°	
2 000	29.7
3 000	23.4
4 000	18.3
5 000	13.9_8
6 000	10.4_9
7 000	7.7_0
8 000	(4.8)

½$Cu(NO_3)_2$.—(*Cont'd*)

C	$10^6\kappa/C$
18°	
2 000	45.5
3 000	36.3
4 000	28.4
9 872	4.69

$AgNO_3$

C	$10^6\kappa/C$
0°	
2 000	36.5
3 000	31.4
4 000	27.7
5 000	(24.6)
18°	
2 000	55.9
3 000	48.4
4 000	42.3
25°	
1 500	69.9
2 000	64.0
3 000	55.2
4 000	48.5
5 000	43.0
8 460	29.5
100°	
2 000	156
3 000	132
4 000	115
5 000	102
6 000	92
7 300	$80._7$
9 580	$64._2$
12 100	$51._0$
15 100	$36._1$

½$Mn(NO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	47.5
3 000	37.9
4 000	30.3_0
5 000	23.5_4
6 000	17.6_6
10 000	4.66

⅓$Fe(NO_3)_3$, 18°

C	$10^6\kappa/C$
2 000	48.5_3
3 000	37.5_0
4 000	28.5_0

½$Co(NO_3)_2$

C	$10^6\kappa/C$
0°	
2 000	28.8
3 000	22.7
4 000	17.8

½$Co(NO_3)_2$.—(*Cont'd*)

C	$10^6\kappa/C$
18°	
2 000	46.8
3 000	37.6
4 000	29.9
5 000	23.3_0

½$Ni(NO_3)_2$

C	$10^6\kappa/C$
0°	
2 000	28.8
3 000	22.8
4 000	17.3
18°	
2 000	46.0
3 000	37.2
4 000	29.3
5 000	22.7
6 000	16.0

⅓$Cr(NO_3)_3$, 18°

C	$10^6\kappa/C$
2 000	43.2_5
3 000	33.3_4
4 000	25.5_4
5 000	18.9_7

⅓$La(NO_3)_3$, 18°

C	$10^6\kappa/C$
2 000	39.1
3 000	28.4_5
4 000	19.92

½$Be(NO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	45.8_0
3 000	37.8
4 000	31.0_0
5 000	24.8_5

½$Mg(NO_3)_2$

C	$10^6\kappa/C$
0°	
2 000	$31._5$
3 000	$26._8$
18°	
2 000	47.9
3 000	39.2
4 000	32.1
25°	
2 000	54.7
2 500	49.7

½$Ca(NO_3)_2$

C	$10^6\kappa/C$
0°	
2 000	$27._8$
3 000	$21._3$

½$Ca(NO_3)_2$.—(*Cont'd*)

C	$10^6\kappa/C$
18°	
2 000	42.7
3 000	33.5
4 000	26.5
6 190	14.1_5
9 202	5.10
25°	
2 000	50.5
3 000	38.8
4 000	30.0
6 130	16.3_1
9 110	6.29

½$Sr(NO_3)_2$

C	$10^6\kappa/C$
18°	
2 000	38.4
3 000	$28._9$
4 000	21.1
5 000	16.4
25°	
2 000	44.5
3 000	33.7_0
4 000	25.6_0
4 470	22.5_6

$NaNO_3$

C	$10^6\kappa/C$
0°	
2 000	(35.1)
18°	
2 000	54.6_0
3 000	46.1_0
4 000	39.2_3

KNO_3, 18°

C	$10^6\kappa/C$
2 000	69.0_0
2 500	65.0_0
3 000	(61.3)

$RbNO_3$

C	$10^6\kappa/C$
6°	
2 000	57.1
18°	
2 000	73.7
2 500	68.9
3 000	(64.4)
30°	
2 000	90.5
2 500	84.5
3 000	(79.2)

Specific conductance of $CaCl_2$ solutions (⁵⁴)

Wt. %, $CaCl_2$	10°C	15°C	17.9°C	20°C	25°C	30°C
29.60	0.1377	0.1554	0.1656	0.1730	0.1910	0.2095
37.30	0.0975	0.1114	0.1197	0.1260	0.1412	0.1575
38.36	0.0906	0.1039	0.1120	0.1180	0.1324	0.1474
40.73	0.0742	0.0858	0.0930	0.0985	0.1120	0.1259
41.98	0.0678	0.0797	0.0865	0.0918	0.1043	0.1177
45.95	0.0426	0.0520	0.0573	0.0612	0.0711	0.0817

PART II. CONDUCTIVITY OF STRONG ELECTROLYTES*

HENRY C. PARKER AND ALFONS KLEMENC†

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TABLE 1.—VALUES OF C UP TO 0.5

For Literature References, *v.* Table 2

𝔅-Table.—Standard arrangement; *v.* Vol. III, p. viii

HCl, 25°

C	Λ
0.05	424.84
0.1	424.64
0.2	424.24
0.3	423.84

HIO_3, 25°

C	Λ
0.01	388.96
0.02	388.90
0.03	388.85
0.05	388.74
0.1	388.47
0.2	387.93
0.3	387.40

½H_2SO_4

t, °C	Λ
C = 0.2	
18	374.4
25	417.9
50	566.1
75	692.6
100	779
128	806
156	758

HNO_3

C = 0.3	
18	373.7

H_3PO_4

C = 0.2	
18	330.4
25	366.8
50	492.4
75	599.6
100	687.7
128	761.2
156	803.7

$TlH(C_4H_4O_6)$

C = 0.2	
18	373

½MgC_2O_4, 18°

C	Λ
0.1	94.4
0.2	86.9

½$Ca(HCO_3)_2$, 25°

C	Λ
0.1	(109.5)
0.2	(106.0)
0.3	104.2

½$Ca(C_2H_3O_2)_2$, 18°

C	Λ
0.1	82.2

¼$Ca_2Fe(CN)_6$, 0°

C	Λ
0.2	67.5
0.3	64.4

½$Sr(C_2H_3O_2)_2$, 18°

C	Λ
0.1	82.4
0.2	82.0

¼$Sr_2Fe(CN)_6$, 0°

C	Λ
0.2	66.8

$LiIO_3$, 18°

C	Λ
0.1	66.57
0.2	66.34

$LiClO_4$

C	Λ
0°	
0.2	54.3
18°	
0.2	87.9
100°	
0.2	293.1

$NaClO_3$, 18°

C	Λ
0.1	97.4
0.2	97.0

$NaBrO_3$, 18°

C	Λ
0.1	90.8
0.2	90.5

$NaIO_3$, 18°

C	Λ
0.1	76.58
0.2	76.33

$NaHCO_3$, 25°

C	Λ
0.1	(97.4)
0.2	(96.0)
0.3	95.2

$NaC_2H_3O_2$, 18°

C	Λ
0.1	77
0.2	76.5

$Na_4C_{11}H_2O_{10}$, Benzenepentacarboxylate

C	Λ
0°	
0.2	245
25°	
0.2	483
50°	
0.2	774

$Na_5C_{11}HO_{10}$, Benzenepentacarboxylate

C	Λ
0°	
0.2	325
25°	
0.2	640
50°	
0.2	1019

$NaC_4H_6BrO_2$, α-Bromobutyrate

C	Λ
0°	
0.24	46.1
15°	
0.24	70.6
25°	
0.24	89.7
35°	
0.24	110.1

$KClO_3$, 18°

C	Λ
0.1	118.45
0.2	118.17

$KClO_4$, 100°

C	Λ
0.2	371.5

KIO_3

C	Λ
18°	
0.1	97.50
0.2	97.20
25°	
0.2	112.84

½$K_2C_2O_4$, 18°

C	Λ
0.1	124.90
0.2	124.64

½KHC_2O_4, 18°

C	Λ
0.2	274.0
0.3	247.3

$KC_2H_3O_2$, 18°

C	Λ
0.1	100
0.2	99

½$K_2C_8H_4O_4$, Phthalate, 25°

C	Λ
0.4	(123.3)

$KHC_8H_4O_4$, Biphthalate, 25°

C	Λ
0.1	152.7
0.2	141.8

$KC_6H_2N_3O_7$, Picrate, 0°

C	Λ
0.2	54.9
18°	
0.2	88.7

$KCNS$, 18°

C	Λ
0.1	119.94
0.2	119.74

TABLE 2; *see* p. 242 to 253

TABLE 3.—VALUES OF C ABOVE 1000

For Literature References, *v.* Table 2

𝔅-Table.—Standard arrangement; *v.* Vol. III, p. viii

HCl

C	$10^6\kappa/C$
18°	
2 000	253.8
3 000	214.7
4 000	(182)
5 000	152.0
10 000	64.3
25°	
2 000	282.4
35°	
2 000	316.6

$HClO_3$, 18°

C	$10^6\kappa/C$
2 000	246.7
3 000	205.0

$HClO_4$

C	$10^6\kappa/C$
25°	
2 000	291.5
3 000	226.0
4 000	185.7
5 000	150.0
6 000	118.4
7 000	91.0
8 000	68.4
9 000	52.0
10 000	41.4
11 000	31.7
12 000	23.1
13 000	16.4
50°	
4 250	232
13 300	22.8

HBr, 18°

C	$10^6\kappa/C$
2 000	253.3
3 000	213.1
4 000	176.4
5 000	145.9

HI, 18°

C	$10^6\kappa/C$
2 000	254.4
3 000	(212.8)
4 000	178.4
5 000	146.7

HIO_3, 18°

C	$10^6\kappa/C$
2 000	106.0
3 000	(85.0)
4 000	70.4

½H_2SO_3

C	$10^6\kappa/C$
0°	
1 012	27.9
1 936	20.4
20°	
1 012	33.4
1 936	24.5
25°	
1 012	34.1
1 936	24.9

½H_2SO_4, 18°

C	$10^6\kappa/C$
2 000	182.7
3 000	166.5
4 000	150.5
5 000	134.6
6 000	119.1
7 000	105.0
8 000	92.3
9 000	80.8
10 000	70.3
11 000	(60.6)
16 248	28.12
23 047	9.35
27 180	4.54
29 840	3.32
30 900	3.17
31 410	3.145
31 900	3.165

½H_2SO_4.—*(Cont'd)*

C	$10^6\kappa/C$
32 390	3.188
33 340	3.219
33 800	3.232
34 260	3.215
34 710	3.155
35 580	2.876

HNO_3

C	$10^6\kappa/C$
18°	
2 000	259.1
3 000	220.0
4 000	184.4
5 000	154.6
6 000	129.1
7 000	108.6
8 000	91.9
9 000	77.6
10 000	64.9
16 500	20.43
17 000	17.65
18 000	12.55
19 000	8.50
20 000	5.50
21 000	2.90
22 385	1.009
22 870	0.6690
23 660	0.8538
23 800	1.667
24 060	1.720
25°	
2 000	289.8
3 000	242.2

⅓H_3PO_4, 0°

C	$10^6\kappa/C$
2 000	24
6 000	14.3
7 000	13
8 000	11.7
11 000	11.3
12 000	11

Continued on p. 254

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* Except halides, nitrates and sulfates, for which *see* p. 230, and soap solutions, for which *see* Vol. V, p. 458.

† Critical compilation by Henry C. Parker. Graphical interpolation to round values of C by Alfons Klemenc.

TABLE 2.—VALUES OF Λ BETWEEN C = 0.5 AND 1000,* STANDARD ARRANGEMENT; *v.* Vol. III, p. viii

Solute	C °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
HCl	0		261.4	260.6	259.1_5	257.2	254.4_3	249.8_7	247.8_0	245.3_0					(212); *cf.* (14, 109)
	12.5														(109)
	18		377	375.5	372.4	369.3	364.9	357.6	354.1	350.1	341.5	326.6	316.6	300.5	(79, 128, 135, 157, 183); *cf.* (31)
	19.8														(224)
	20														(103.5, 145)
	25				415.6	412.0	407.3	399.0		$391._8$	$381._8$	360.6		331.9	(163.5)
	25	423.04	421.38	419.17	415.11	411.08	406.07	397.8_0	393.9	389.8	379.6	359.2	348.5	332.8	(24, 145, 198); *cf.* (25, 71)
		(417.91 at C = 31)													
	35	(For 45°C, *v.* (140); for 51 and 81°C, *v.* (31))				476	470	460	455	450	436	408.6	$392._2$	374.8	(109, 135)
$HClO_3$	18								(347.6)	343.6	334.6	316.6	306.2	291.4	(93, 95); *cf.* (48)
	25	(For 50°, *v.* (150))			400	396	391	382	379	375	366	352			(195)
$HClO_4$	25				405	405	402	$393._0$	$389._0$	$384._4$	$373._8$	$359._0$	$352._5$	$342._5$	(150, 195, 246)
HBr	18									355.2	347.7	328.4	316.5	301.1	(95)
	25					418	$410._7$	$400._2$	$396._0$	$391._2$	$380._7$	$362._2$	$351._0$	334	(58, 196)
$HBrO_3$	25		400	395	386	377	366								(196)
HI	18									346.4	339.2	323.0	311.6	296.8	(93, 155)
	25		420.0	418.2	415.2	412.0	407.8	400.8	397.4	393.2	$383._4$	367			(195, 249, 266)
HIO_3	18		344.59							252.3	219.7	174.5	158.4	141.2	(95, 141)
	25	386.34	383.95	379.93	370.85	359.69	343.04	310.66	295.6_0	278.34	242.18	219.5	191.6		(83, 141, 195)
HIO_4	25		386	372	335	297	253	192	172	150	110				(195)
$\frac{1}{2}H_2SO_3$	0	(93.6 at C* = 16.3)				(63.0 at C† = 107.3)									(151)
	20	(127.6 at C* = 16.3)				(80.1 at C† = 107.3)									(151)
	25	(133.7 at C* = 16.3)				(82.7 at C† = 107.3)									(151)
$\frac{1}{2}H_2SO_4$	0					226.1	211.1	191.2	183.9	176.9	165.2	155.3			(105, 109)
H_2SO_4	0‡		471.7	456.3	426.4	399.0	369.3	333.3		310.9					(211)
$\frac{1}{2}H_2SO_4$	18	371.3		353.4		308.6		253.1	243.5	232.9	(For 14, 26, 38°C, *v.* (173, 174))			198.6	(75, 105, 125, 127, 184)
	25	413.1	(399.5)	390.3	(364.9)	336.4	308.0	272.6	261.5	250.8	234.3	222.5	(For 35°C, *v.* (109))		(105, 109, 184)
	50	552.6	(528)	500.6	(448)	405.4	$367._3$	322.9	309.8	299.9					(184)
	75	656.1	(608)	560.0	(481)	434.4	$395._7$	355.5	345.0	335.9					(184)
	100	705		570	(488)	445	414	384	375	368					(184)
	128	695		550	(485)	(458)	438	416	410	403					(184)
	156	643		535	(498)	480	(463)	447	442	434					(184)
	218	585		562	(545)	532	521	501	492	482					(184)
	306			636					(473 at C = 80)						(184)
$\frac{1}{2}H_2S_2O_4$	18					258.4	$237._6$	$199._6$	184.6	168.0		(*Also* at 25°C)			(107)
$\frac{1}{2}H_2S_2O_6$	25			414	410	405	399	389	385	379	367				(195)
$\frac{1}{2}H_2S_4O_6$	25			421	414	408	400	388	383	378	367				(195)
$\frac{1}{2}H_2SeO_4$	25			384	366	349	328	295	283	272	253	233	226	219	(195)
$\frac{1}{6}H_6TeO_6$	25		17.9	6.3	2.9	1.8_5	1.30	0.73							(231)
HNO_3	0					$253._4$	$251._7$	$248._6$	$247._1$	$245._3$	$241._3$				(109)
	18	373.3	372.6	370.6	$366._8$	364.0	$360._4$	353.0	349.6	345.7	336	$321._5$	$315._5$	305.5	(79, 132, 135, 184, 255)
	25				411.2	407.3	402.4	394.0		386.0	376.1	356.5		329.8	(163.5)
	25	416.2	414.6	412.9	409.0	405.2	400.8	392.5	388.7	384.2	374.4	356.6	347.0	333.2	(109, 184, 246)
	35					$455._8$	$450._4$	$441._4$	$437._4$	$432._6$	$419._0$				(109)
	50	562.8	(560.7)	557.7	(552)	546.9	(540)	527.4	(521.9)	514.7					(184)
	75	695.7	(692.3)	688.3	(681.6)	674.7	665.2	647.6	639.6	630.6					(184)
	100	813.2	(809)	804.6	(795)	784.5	(772)	748.6	737.7	727.0					(184)
	128	928		917	(904)	891	(872)	843	(830)	815					(184)
	156	1026	(1018)	1010	(993)	976	(954)	915	(898)	878					(184)
	218			1164			(924 at C = 80)								(184)
	306			1154					482			(453 at C = 80)			(184)
NH_4NO_2	20			110	109	106	103	96							(215.5)
NH_4ClO_4	18										96.0	90.2		83.8	(99)
NH_4IO_3	0		$60._6$	$60._2$	$58._7$	$57._0$	$55._0$	$52._1$							(267)
	25		114	113	110	107	103	97		(*Also* at 35°C)					(267)

* When the literature cited contains data at other temperatures this is indicated thus: (*Also* at 25°C). † Values of C are for t = 0°C. (For 10, 30, 40, 50, 60, 70°C, *v.* (151).) ‡ Concentrations are m (= millimole/kg H_2O) and Λ values are $10^6\kappa/m$.

TABLE 2.—(*Continued*)

Solute	C °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
NH_4HSO_4	0		316	308	292	275	253	223	213	202.2		165.3			(109)
	25		514	492	454	416	372	(275 at $C = 125$)				226			(109)
$\frac{1}{3}H_3PO_4$	0		(For 17°C, *v.* (13))									31.7	30	28.3	(204); *cf.* (41)
H_3PO_4	18			282.8	(273.0)	202.7	(166.7)	122.5	(108.7)	96.4					(184)
	25			311.5		221.7	(180.3)	132.4	(117.7)	103.9					(184)
	50			400.2		272.7	(216)	157.6	(139.2)	122.5					(184)
	75			463.0		299.6	(236)	168.4	(148.4)	129.7					(184)
	100			463.0		307.6	(236)	167.6	(148.2)	128.2					(184)
	128			507.0		297.6	(226)	157.8	(138.0)	120.0					(184)
	156			488.4		273.6	(206)	141.8	(123)	107.6					(184)
$\frac{1}{4}H_4P_2O_6$	25				151.6	136.4	122.5	107.6	103.1	98.6					(254)
$H_4P_2O_6$	20		627	565	489	443.7	405.8								(254)
NH_4PO_3	18														(250)
$\frac{1}{3}NH_4H_2PO_4$	0				19.5	18.9	18.2	17.2	16.8	16.4	15.6	14.1			(267)
	25				35.7	34.5	33.7	32.4	31.7	30.9	29.1	26.1			(267)
	35				43	42	41.0	39.4	38.6	37.6	35.2	31.6			(267)
$(NH_4)_2HPO_4$	17														(13)
$(NH_4)_3PO_4$	17														(13)
H_3AsO_4	25		308.2	279.8	230.0	187.0	150.8	103.4	91.4	80.0					(261)
H_3SbO_4															(160.5)
$NH_4C_2H_3O_2$	18				92.9	91.4	89.0	84.9	82.7	(79.5)	(73.2)	(63.8)	(59.6)	54.7	(95, 187, 189)
	100					299.2		(286.0 at $C = 25$)							(189)
	156					455		(525 at $C = 25$)							(189)
	218		(217.4 at $C = 5.97$)				319.1								(189)
	306					81.4		(81.8 at $C = 29.35$)							(189)
$C_aH_bN_2O_2$	Various substituted ammonium nitrites														(215.5, 217)
$C_3H_5N_3O_4$	27.5			115.3	111.2	108.3	105.3	$CH(CN)NO_2COONH_4$							(253)
$C_3H_7N_3O_5$	27.5		115.2	113.3	109.7	105.9	101.4	$CONH_2.CHNO_2.COONH_4$							(253)
$C_3H_9N_3O_6$	27.5			109.2	104.7	101.1	97.4	$(NH_4O_2C)_2CHNO_2$							(253)
$C_8H_{14}N_2O_2$	25		77.2	76.3	74.2	(72.2)	Piperidine cyanoacetate								(175)
$C_{14}H_{22}N_4O_7$	0	30.4	30.0	29.6	28.9	28.1	26.9	Tetraethylammonium picrate							(263)
	18	51.9	51.3	50.6	49.3	47.8	45.8								(263)
	100		189.2	185.7	179.7	173.2	164.3								(263)
$C_{17}H_{19}N_3O_6$	25		56.6	55.2	52.9	50.6	(47.1)	Diethylphenylammonium 3-5-dinitrobenzoate							(149)
CH_6ClN	18	(114.8)	114.1	112.9	110.8			CH_3NH_2HCl				(*Also* at 32.35°C)			(172)
	25		133.1	131.8	129.4	126.8	123.2	117.1	114.2	110.8					(34, 172)
C_2H_8ClN	18		108.1	107.1	(106.4 at $C = 3$)			$(CH_3)_2NHHCl$							(172)
	25	(126.6)	125.7	124.4	122.0	119.6	116.4	110.6	107.9						(34, 172)
C_2H_8ClN	18	102.5	101.8	100.6								$C_2H_5NH_2HCl$			(172)
	25	120.9	120.1	119.0	(117.9 at $C = 3$)										(172)
$C_{17}H_{20}BrNO$	25				92.8	91.9	89.7	82.9	79.6	Allylbenzylmethylphenylammonium bromide					(268)
$C_{17}H_{22}BrNO$	25				92.8	91.9	89.7	82.9	79.6	Propylbenzylmethylphenylammonium bromide					(268)
$C_{22}H_{48}NI$	56	Triethylcetylammonium iodide													(220)
NH_4CNS	0		76.5	75.4	74.1	72.9	71.5	69.1	68.2	67.1	64.5				(267)
	18									104.1	99.5	93.8	91.7	89.7	(93, 95)
	25			137	134.8	132.7	128.8	123.9	121.6	119.0	114.0				(48, 267)
	35			164	161	158	154	148	145	142	136				(48, 267)
$C_6H_{13}N_2SI$	$[NH_2.CS.NHC_3H_5]C_2H_5I$														(77)
$\frac{1}{2}H_2SiF_6$	25		322	245	198	183	175	165	161	155	146	129	119	108	(195)
$\frac{1}{2}Pb(C_2H_3O_2)_2$	0		44.8	39.6	32.9	27.8	23.1	16.9	14.7	12.7	9.50	5.95			(109)
	18									21.4	15.95	10.15	8.37	6.67	(95)
	25		84	74.2	61.3	52.1	43.5	32.1	28.0	24.3	18.3	11.8	(*Also* at 50 and 65°C)		(109)
	35		101	89	74	62	52	38	34	29	22	14			(109)
$\frac{1}{2}Pb(C_6H_5CO_2)_2$	30														(61)
$Tl(OH)$	25			248	247	242	236	222	214	206	188				(195)
$TlClO_3$	20		123.9	(100.8 at $C = 134.0$)											(181)
	25		135.1	133.8	131.4	129.0	125.8								(72)
$TlClO_4$	25		143.4	141.6	138.8	136.2	132.5								(72)
$TlBrO_3$	25		127.8	126.6	124.3	(121.8)									(72)
$TlIO_3$	25		112	111.4											(72)
$\frac{1}{2}Tl_2S_2O_6$	25		170.3	166.3	157.2	148.2	138.2								(72)

TABLE 2.—(*Continued*)

Solute	C °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$TlHSO_4$	18	493.0	477.5	(454.4)	413.0	376.0	337.4	289.6	275.5	262.0	(248.2 at C = 150)				(65)
$\frac{1}{2}Tl_2SeO_3$	25		130.4	123.2	111.9	102.2	90.9								(72)
$\frac{1}{2}Tl_2SeO_4$	25		141.9	138.4	132.7	126.2	117.4								(72)
$\frac{1}{3}Tl_3PO_4$	25		122.7	122	114.$_5$										(72)
$\frac{1}{3}TlH_2PO_4$	25				35.7	34.9	33.8	32.1							(72)
$\frac{1}{3}TlH_2AsO_4$	25			(36.5)	35.6	34.9	33.9	32.1							(72)
$\frac{1}{3}Tl_2HAsO_4$	25			56.4	55.7	54.6	52.8	49.2							(72)
$\frac{1}{2}Tl_2CO_3$	25		143.$_0$	136.9	126.2	115.0	102.4								(72)
$TlH(C_4H_4O_6)$	18	282	250.$_6$		104.$_2$	93.$_9$	85.$_2$								(65)
$\frac{1}{2}Zn(ClO_3)_2$	18									73.9	69.0	61.7	58.4	54.3	(93, 95); *cf.* (47)
$\frac{1}{2}Zn(BrO_3)_2$	18											51.3	47.6	43.2	(99)
$\frac{1}{2}Zn(NO_2)_2$	20														(215.5)
$\frac{1}{2}Zn(C_2H_3O_2)_2$	0		44.$_6$	43.$_2$	40.$_8$	38.$_8$	36.$_3$	31.$_4$	29.$_1$	26.$_6$	22.$_0$	14.$_8$			(109)
	25		90.$_7$	86.$_1$	79.$_2$	73.$_7$	67.6	57.4	53.0	48.5	39.2	25.3	19.1	11.8	(109, 236)
	35		106	103	97	91	83	70		59	46	19	(*Also* at 50 and 65°C)		(109)
$\frac{1}{2}Cd(ClO_3)_2$	18									75.0	69.9	62.1	58.6	54.3	(93, 95)
$\frac{1}{2}Hg(NO_2)_2$	20														(214)
$Hg_2NNO_2.\frac{1}{2}H_2O$															(216)
$\frac{1}{2}HgNCl_2H_2$	$\frac{1}{2}NH_2HgCl_2$														(215)
$HgCH_3OH$	25														(164)
$HgC_3H_6O_2$	25									4.9					(164)
$\frac{1}{4}Hg_2C_6Cl_4H_{12}$	$\frac{1}{4}(CH_2)_6.2HgCl_2$														(215)
$Hg_2C_8H_{16}S_2O_4$	18			67.7	57.0	48.7	40.6	30.2	(26.7)	$[Hg(SC_2H_5)_2.Hg](C_2H_3O_2)_2$					(247)
$HgC_aH_bN_c$, etc.	(For various complex salts of Hg with substituted NH_4 bases, *v.* (164, 214, 215, 216))														
$\frac{1}{2}Cu(ClO_3)_2$	18									75.7	70.6	62.7	59.2	54.7	(93, 95); *cf.* (47)
$\frac{1}{2}Cu(NO_2)_2$ and $Cu(NH_4)_2(SO_4)_2$															(123, 215.5)
$\frac{1}{2}Cu(C_2H_3O_2)_2$	18									22.9	17.3	10.9	8.7$_0$		(95, 99)
$AgClO_2$	25		111.0	109.1	105.4	102.0	(98.1)								(33)
$AgClO_3$	25		124.1	123.5	121.8	119.$_7$	113.$_2$								(153)
$AgClO_4$	25		128.0	127.1	124.7	122.6	119.8								(153)
$\frac{1}{2}Ag_2S_2O_6$	25		159.6	156.0	151.$_2$	146.$_0$	137.$_3$								(153)
$AgHSO_4$	18	481	463	439.$_2$	402.$_0$	365.$_5$	327.$_0$	(290.$_0$ at C = 42)							(65)
$AgNO_2$	25			128.3	115.6	112.3	85.4								(53); *cf.* (179)
$AgPO_3$	18														(250)
$AgC_2H_3O_2$	25		101.2	100.1	97.1	(99.0 at C = 3)									(153, 225); *cf.* (106)
$AgC_3H_7CO_2$	CH_3CH_2COOAg														(225)
$AgSO_3C_6H_5$	25		96.$_6$	96.$_2$	94.$_5$	92.$_0$									(153)
$AgSO_3C_9H_{11}$	25		89.0	87.6	85.6	83.0	79.6				Silver pseudocumenesulfonate				(153)
$AgSO_3C_{10}H_7$	25		101.3	99.8	97.6	95.5	(93.2)				Naphthalenesulfonate				(153)
$\frac{1}{2}Ag_2SiF_6$	25		117.5	116.4	113.8	110.8	107.4								(153)
$[Ir(NH_3)_5Br]Br_2$	95	753	727	695	641	596									(143)
$[PtNH_3(NH_2OH)_3]Cl_2$	18														(43)
$Pt_aN_bH_cX_dO_e$, etc.	(For various complex salts of Pt with NH_3 and $NH_aC_bH_c$, *v.* (43, 44, 45, 46, 61, 158))														
$\frac{1}{2}H_2Pt(CN)_4$	25			406	405	402	395	381							(261)
$HMnO_4$	25			402	400	395	389	378	374	369	358	336			(161)
$MnCl_2.Hg(CN)_2.2H_2O$	23		245	237		212	204		$MnHgC_2N_2Cl_2.2H_2O$						(86)
$AgMnO_4$	25		119.9	119.2	117.5	115.4	(111.9)								(72)
$FeNH_4O_8S_2$									$NH_4Fe(SO_4)_2.12H_2O$						(271)
$H_4Fe(CN)_6$	25	1360	129$_0$	121$_0$	111$_0$	104$_0$	97$_0$	89$_0$	85$_0$	79$_0$					(196)
$FeC_5N_8H_8O$	25		261	(253)	242.0	233.6	224.$_2$	210.$_4$	205.0	$(NH_4)_2Fe(CN)_5NO$					(40)
$FeC_6N_3H_{12}O_{12}$										$(NH_4)_3Fe(C_2O_4)_3$					(123)
$FeC_7N_8H_{12}O$	25		232.$_9$	226.$_0$	214.$_9$	204.$_5$	192.$_7$			$(CH_3NH_3)_2Fe(CN)_5NO$					(40)
$FeC_8N_7H_{10}O$	25		207	201	189	178	164	142		$(CH_3)_3NHFe(CN)_5NO$					(40)
$FeC_9N_7H_{12}O$	25		219.$_7$	213.$_0$	202.1	192.$_2$	180.$_5$	161.$_5$		$(C_2H_5)_2NH_2Fe(CN)_5NO$					(40)
$FeC_{13}N_8H_{12}O$	25		204.$_9$	197.$_5$	185.$_3$	172.$_2$	157.$_3$	143.$_7$	$[(CH_3)_4N]_2Fe(CN)_5NO$						(40)
$FeC_5NS_2H_6O_8$		Pyridine disulfatoferrate								$Fe(SO_4)_2HC_5H_5N.2H_2O$					(270.5)
$\frac{1}{2}Co(ClO_3)_2$	18											61.7	58.2	54.2	(99)
$CoN_5H_{20}O_4$	0		265.$_0$	257.$_0$	247.$_8$	240.$_1$	230.$_7$			$Co(NH_3)_5H_2O(OH)_3$					(144)
$\frac{1}{3}Co(NH_3)_6(OH)_3$	0		154.2		142.0		132.1		(119.3)	115.5					(144)
	25		275		242		224			197					(144)
	(For other complex Co salts, *v.* (42, 61, 67, 88, 144, 158, 169, 242))														

TABLE 2.—(*Continued*)

Solute	C °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$CoN_6Br_3H_{18}$	0	90.6	(88.4)	85.7	(80.2)	(75.0)	69.9	63.9	60.0	56.7	$Co(NH_3)_6Br_3$				(88)
	25	171.0	(166)	160.1	(149)	(140)	130.2	118.1	111.3	103.5					(88)
$\frac{1}{3}CoN_6Br_3H_{18}$	0		90.1		83.0		71.7		(61.0)	58.0	$\frac{1}{3}Co(NH_3)_6Br_3$				(144)
	25		166.1		151.3		132.2		(112.2)	106.3					(144)
$\frac{1}{2}Co(C_2H_3O_2)_2$	0		44	42.9	41.1	39.8	37.1	32.5	30.5	28.1	23.5	16.9	14.4	11.8	(109)
	25		87 .1	84.5	79.9	75.8	70.0	61.1	57.4	53.4	45.1	32.8	(28.0)	22.6	(109, 236)
	35	(*Also* at 50 and 65°C)		102	98	93	86	74	69	64	54	39	33	27	(109)
$\frac{1}{2}Ni(ClO_3)_2$	18											61.9	58.4	54.2	(99)
$\frac{1}{2}Ni(NO_2)_2$	20														(215.5)
$Ni(C_2H_3O_2)_2$	0	87.6	84.8	81.7	76.7	71.6	64.6	53.6	49.2	44.5	35.0	21.4			(109)
	25	171.0	165.8	159.6	149.4	139.2	124.6	102.0	93.6	84.6	66.6	41.8			(109)
	35	209	203	196	183	168	151	124	114	102	80	51	(*Also* at 50 and 65°C)		(109)
$\frac{1}{2}NiH_2(COS)_4$	25		(3.83 at C = 1.38)		(3.67 at C = 2.76)										(223)
$Ni(NH_4)_2(COS)_4$															(223)
$\frac{1}{2}H_2CrO_4$	25					193	193	190	188	186					(261)
$CrCl_3H_{12}O_{18}$											$[Cr(H_2O)_6](ClO_4)_3$				(271)
$\frac{1}{2}Cr(NH_4)_2O_4$	0			76	76.0	73.8	70.6	65.0	62.7	60.8	55.9	49.8	(*Also* at 15°C)		(267)
	25			139	138.9	135.8	129.0	117.9	113.5	108.9	99.7				(267)
	35			166	163	160	153	141	136	130	118				(267)
Cr	(For complex chromium salts, *v.* (61, 123, 262, 270))														
$UO_2(C_2H_3O_2)_2.2H_2O$	0	81.7	74.4	67.5	58.8	52.5	46.0	38.5	36.2	34.0					(109)
	25	140	127.7	117.8	103.6	93.6	83.4	70.9	66.8	62.7					(109)
	35	164	150	137	122	111	100	87	82	78					(109)
$(VO)_2H_2(SO_4)_3$															(139)
$[Al(H_2O)_6](ClO_4)_3$															(271)
$\frac{1}{3}AlMo_6N_3H_{18}O_{24}$										$\frac{1}{3}(NH_4)_3H_6[Al(MoO_4)_6].7H_2O$					(229)
$\frac{1}{3}Y(C_7H_5O_3)_3.3.5H_2O$	20	79.8	74.8	(69.6 at C = 1.67)						Salicylate					(36)
$\frac{1}{3}Y(C_7H_5O_3)_3.6H_2O$	20	77.5	71.8	63.4	51.5	41.6				*m*-Hydroxybenzoate					(36)
$\frac{1}{3}Y(C_7H_5O_3)_3$	20	70.1	63.6	55.2	43.1	33.6				*p*-Hydroxybenzoate					(36)
$\frac{1}{3}La(IO_3)_3$	25	(99.0 at C = 3.09)													(90)
$\frac{1}{3}La(C_7H_5O_3)_3$	20	90.2	81.6	(75.1 at C = 1.67)						Salicylate					(36)
$\frac{1}{3}La(C_7H_5O_3)_3.6H_2O$	20	82	73.9	65.2	53.0	43.5				*m*-Hydroxybenzoate					(36)
$\frac{1}{3}La(C_7H_5O_3)_3.2H_2O$	20	70.0	62.6	54.7	44.1	36.0				*p*-Hydroxybenzoate					(36)
$\frac{1}{3}Nd(C_7H_5O_3)_3.H_2O$	20	83.2	75.7	(69.7 at C = 1.66)						Salicylate					(36)
$\frac{1}{3}Nd(C_7H_5O_3)_3.6H_2O$	20	74.7	65.8	56.2	44.6	36.1				*m*-Hydroxybenzoate					(36)
$\frac{1}{3}Nd(C_7H_5O_3)_3.4H_2O$	20	77.0	58.6	49.7	38.2	30.6				*p*-Hydroxybenzoate					(36)
$\frac{1}{3}Gd(C_7H_5O_3)_3.H_2O$	20	84.7	79.1	(71.0 at C = 1.6)						Salicylate					(36)
$\frac{1}{3}Gd(C_7H_5O_3)_3.6H_2O$	20	74.8	66.9	57.9	45.1	36.1				*m*-Hydroxybenzoate					(36)
$\frac{1}{2}Mg(ClO_3)_2$	18									76.1	70.6	62.7	59.2	54.8	(93, 95); *cf.* (47)
$\frac{1}{2}Mg(BrO_3)_2$	18											52.7	49.0	44.7	(99)
$\frac{1}{2}Mg(IO_3)_2$	25		92.3	89.2	84.4	80.1	75.2								(261)
$\frac{1}{2}MgS_2O_3$	25		134.8	128.6	119.3	111.0	101.3								(260)
$\frac{1}{2}MgSeO_4$	25		112.4	105.8	96.0	87.8	78.9								(260)
$\frac{1}{2}Mg(NO_2)_2$	20														(215.5)
$\frac{1}{2}MgC_2O_4$	18	74.4	63.3	51.3	38.1	29.6	23.0	16.4	14.5	12.7	10.0				(133)
$Mg(HCO_2)_2$	0		100	97	93.8	89.7	84.4	74.0	(69.8)	65.1	(54.4)	39.7			(109)
	18									110.4		66.14	(87.3 at C = 250)		(99)
	25				179	172	160	142		127	(*Also* at 35, 50, 65°C)				(109)
$\frac{1}{2}Mg(C_2H_3O_2)_2$	0		44.6	42.9	40.6	38.9	37.1	33.6	31.9	30.1	26.0	20.0			(109)
	18									51.3	44.6	34.2	29.8	24.9	(95, 222)
	25		87.2	84.4	80.4	76.9	72.7	65.4	62.1	58.8	50.4	38.6		29.0	(109, 222)
	35		108	106	101	96	90	80	76	72	62	(*Also* at 50 and 65°C)			(109)
$\frac{1}{2}MgPt(CN)_4$	25		158.1	152.1	142.9	135.2	126.2								(206)
$\frac{1}{4}Mg_2Fe(CN)_6$	25		153.5	139.8	123.0	112.4	102.7								(206)
$\frac{1}{2}MgCrO_4$	18									(56.5)	50.7	42.9	39.8	36.34	(95); *cf.* (47)
	25		118.7	113.6	104.2	95.9	86.8								(206)
$\frac{1}{2}Ca(OH)_2$	25				226	220	210								(195)
$\frac{1}{2}Ca(ClO_3)_2$	6											49.0	45.7	41.8	(48)
	18									79.9	75.0	68.0	64.8	60.6	(93, 95)
	18			(*Also* at 30°C)								65.5	61.0	55.8	(48)

TABLE 2.—(*Continued*)

Solute	C °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$\frac{1}{2}\mathrm{Ca(NO)_2}$	0														(213)
$\frac{1}{2}\mathrm{Ca(NO_2)_2}$	20														(215.5)
$\mathrm{Ca(HCO_2)_2}$	0	108	106	104	101	96.$_6$	91.$_2$	82.$_0$	78.$_0$	73.$_5$	64.$_9$				(109)
	18	(89.7 at C = 250)										(73.7)	63.6	50.4	(99)
	25	203	199	195	189	183	172.$_5$	153.$_5$	146.$_0$	137.$_2$	119.$_6$	(*Also* at 35, 50, and 65°C)			(109)
$\frac{1}{2}\mathrm{Ca(HCO_3)_2}$	25	102.0	99.3	96.6	91.7	87.0	80.9								(120, 122)
$\mathrm{Ca(C_4H_4O_6).3H_2O}$	30														(61)
$\frac{1}{2}\mathrm{Ca(C_2H_3O_2)_2}$	18	80.6	79.5	77.7	75.0	71.8	67.6	60.2	57.2	54.0	47.0	36.0	31.4	26.4	(18, 95, 163); *cf.* (236)
$\frac{1}{2}\mathrm{Ca(C_2H_5CO_2)_2}$	18										43.8	32.9	28.4	23.4	(99)
$\frac{1}{2}\mathrm{Ca(HCN_2)_2}$	25					(114.7)	105.3	92.4	87.8	83.2	$\mathrm{Ca(CNNH_2)}$				(117)
$\frac{1}{2}\mathrm{Ca(MnO_4)_2}$	25		118.8	115.7	110.7	106.3	(101.5)								(72)
$\frac{1}{4}\mathrm{Ca_2Fe(CN)_6}$	0	59.7	53.6	45.4	(37.3)	(31.9)	(27.6)	23.2	22.2	21.3	20.1	19.1	18.7	18.1	(12); *cf.* (186)
	18			75.4		49.8	(43.5)	38.4	36.7	35.0	32.8				(186)
	25	67.6	57.4	49.3	41.8	39.6	37.6	35.6	34.7	34.2	33.8				(239); *cf.* (186)
$\frac{1}{6}\mathrm{Ca_3(Fe(CN)_6)_2}$	25	138.7	126.5	114.9	100.6	(90.8)	81.8	72.4	70.0	67.8	64.6	1.0	59.7	58.4	(239)
$\frac{1}{2}\mathrm{CaCrO_4}$	0		60.9	59.3	55.6	(51.7)	46.7	39.9	37.7	35.6	31.9	6			(109)
	18		106.7	(101.4)	93.0	85.0	(76.2)	65.8	(62.3)	58.6	(52.0)	4.6	(42.0)	39.2	(133)
	25		113.$_8$	110.$_8$	103.$_0$		85.$_6$	73.5	69.3	65.3	58.5	4			(109)
	35		140	134	124	(114)	112	87.$_5$	82.$_5$	77.$_8$	69.$_3$	(*Also* at 50 and 65°C)			(109)
$\frac{1}{2}\mathrm{Sr(OH)_2}$	25			225	224	220	214	204							(195)
$\frac{1}{2}\mathrm{Sr(ClO_3)_2}$	18									79.2	73.8	65.4	61.9	57.8	(93, 95); *cf.* (47)
$\frac{1}{2}\mathrm{Sr(BrO_3)_2}$	18										63.8	55.0	51.1	46.4	(99)
$\frac{1}{2}\mathrm{Sr(NO_2)_2}$	20														(215.5)
$\frac{1}{2}\mathrm{Sr(HCO_2)_2}$	18										60.6	49.8	45.7	41.0	(99)
$\frac{1}{2}\mathrm{Sr(C_2H_3O_2)_2}$	0		51.$_8$	49.$_6$	46.$_6$	44.$_6$	42.$_5$	38.$_8$	37.$_1$	35.$_3$	31.$_5$	24.$_6$		18.$_6$	(109)
												(*Also* at 35, 50, 60°C)			
	18	81.0	80.0	78.4	76.0	73.2	69.$_5$	62.$_9$	60.0	56.7	50.3	40.1	35.7	30.6$_2$	(95, 135, 163)
	25		96	94	90	86	82	75		68	61	52	48	44	(95, 109)
$\frac{1}{2}\mathrm{Sr(MnO_4)_2}$	25		117.4	116.5	113.4	110.1									(72)
$\frac{1}{4}\mathrm{Sr_2Fe(CN)_6}$	0	59.7	52.5	45.4								19.7	18.5	17.4	(12)
$\frac{1}{2}\mathrm{Ba(OH)_2}$	18	219	(217)	(215)	(211)	(207)	200.8	190.6	(185.7)	179.7					(126, 184)
	25	250	(247)	(245)	(240.$_8$)	235.0	226.6	214.6	(209.6)	203.6	191.4				(184, 196)
	50			358	349	341	328	307	(298)	290					(184)
	75					448	427	398	(386)	372					(184)
	100			590	568	547	519	477	(460)	442					(184)
	128					(663)	(614)	548	(523)	502					(184)
	156	(705 at C = 12.5)				(720)	669	592	(562)	530					(184)
$\frac{1}{2}\mathrm{Ba(ClO_2)_2}$	25		110.$_7$	108.1	103.9	100.1	95.1	(86.7)							(33)
$\frac{1}{2}\mathrm{Ba(ClO_3)_2}$	6										55.3	48.9	46.1	42.5	(47)
	18									79.5	73.8	64.7	61.0	56.4	(47, 95)
	30										93.8	82.0	77.0	70.9	(47)
$\frac{1}{2}\mathrm{Ba(BrO_3)_2}$	18		97.4	95.4	91.8	88.1	83.5	(78.2 at C = 40)							(105)
	25		113.4	111.0	106.8	102.6	97.2		(91.0 at C = 40.2)						(105)
$\frac{1}{2}\mathrm{BaS_2O_6}$	25		139.$_1$	132.0	120.6	110.5	99.1								(260)
$\frac{1}{2}\mathrm{Ba(NO_2)_2}$	20			124	121.$_4$	116.$_9$	110.$_0$	98.$_2$	93.$_1$	87.$_1$					(215.5)
$\frac{1}{2}\mathrm{Ba(H_2PO_2)_2}$	25		104.$_0$	101.1	96.8	92.9	88.0	(79.7)							(260)
$\mathrm{Ba(CHO_2)_2}$	0		109	108	105	101	95	87	83	79		55			(109)
	18			(For 25, 35°C, *v.* (109))						127.0	111.8	86.7$_6$	75.6	62.2$_8$	(99)
$\frac{1}{2}\mathrm{Ba(C_2H_3O_2)_2}$	0		51	49.$_7$	47.$_3$	45.$_0$	42.$_6$	39.$_1$	37.$_7$	36.$_1$	32.$_4$	(26.$_5$)	24.$_1$	21.$_4$	(109)
	18	86.$_0$	84.9	83.3	80.0	77.0	72.8	65.7	62.7	59.7	53.4	43.6$_0$	39.4	34.2$_8$	(18, 95, 163)
	25		99	97	92.$_8$	(88.$_8$)	(83.$_9$)	76.$_0$	72.$_7$	69.$_1$	61.$_8$	(50.$_3$)	(45.$_8$)	40.$_5$	(109)
$\frac{1}{2}\mathrm{Ba(C_2H_5CO_2)_2}$	18										51.6	41.2	36.9	32.0	(99)
$\frac{1}{2}\mathrm{Ba(MnO_4)_2}$	25		114.1	112.0	107.7	103.4	97.6								(72)
$\mathrm{Ba[FeCN)_5NO]}$	25		236	225	210	198	186	163							(40)
$\mathrm{Ba(COS)_4Ni}$															(223)
$\mathrm{Ba_3Cr_2C_{12}O_{24}}$											$\mathrm{3BaC_2O_4.Cr_2(C_2O_4)_3}$				(61)
LiOH	18	(For 30, 50, 60°C, *v.* (29); for 25°C, *v.* (206.5))								(180.5)	172.2	156.9	(149.1)	139.0	(29, 97, 126)
$\mathrm{LiClO_3}$	18									~~(74.5)~~	70.0	62.7	59.5	55.7	(93, 95); *cf.* (48)
	25		101 3	100.4	98.4	96.0	93.3		(For 20°C, *v.* (235))						(195)

TABLE 2.—(*Continued*)

Solute	C °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$LiClO_4$	0	54.1	53.7	53.3	52.5	51.5	50.3								(263)
	18	87.4	86.9	86.2	84.6	83.0	81.0								(263)
	25		112.8	111.4	108.9	106.5	103.9								(195)
	100	290.6	287.6	284.6	278.6	272.6	264.1								(263)
$LiIO_2$	18	65.78	65.18	64.34	62.80	61.15	58.97	55.18	53.45	51.43	46.81	38.93	35.35	31.17	(93, 129); *cf.* (47, 99)
$LiNO_2$	20														(215.5)
$\frac{1}{2}Li_2CO_3$	18	(63.4 at C = 54) (51.8 at C = 170)													(126); *cf.* (257)
$LiHCO_2$	18											48.0	43.6	38.8	(99)
$LiC_2H_3O_2$	18									51.2	46.2	37.4	33.5	28.7	(95)
$LiC_6H_2N_3O_7$	0	33.6	33.4	33.1	32.4	31.7	30.8				Picrate				(263)
	18	56.9	56.5	56.0	54.8	53.8	52.1								(263)
	100		209.2	207.2	202.2	196.7	190.2								(263)
$LiCNS$	18											64.3	61.4	57.8	(93)
$LiMnO_4$	25		101.2	98.8	95.8	92.4	89.3								(72)
$\frac{1}{2}Li_2CrO_4$	0		59	57.6	56.2	55.1	53.3	49.0	47.2	45.2	41.0	(*Also* at 15°C)			(267)
	18									74.4	67.5	57.4	53.2	48.3	(93, 95)
	25		111	110.2	108.2	105.4	101.0	92.9	89.2	85.3	77.1				(267)
	35		134	134	132	129	124	113		103.0	93.2				(267); *cf.* (47, 49)
$\frac{1}{2}Li_2Cr_3O_7$	18										73.0	66.0	62.8	58.6	(99)
$NaOH$	0									(For 10°C, *v.* (209))				104.7	(23)
	18			213.5	210.8	208.4	205.5	200.3	198.0	195.3	189.0	175.5	168.0	158.4	(23, 97, 126, 128, 187, 209)
	25	(*See further* (206.5))				(234.0)	230.0	224.0	221.4	218.2	210.0	(202.5 at C = 300)			(77, 117)
	50													260.6	(23)
	100			581.1			558.5	539.4	(575.7 at C = 4)					406.8	(23, 187)
	156			812.3			769.4	737.1	(803.6 at C = 4) (744.9 at C = 40)						(187)
	218						929	872	(1001 at C = 4) (888 at C = 40)						(187)
$NaClO_3$	0		59.8	59.6	58.9	57.6	56.1	(53.7)	52.6	51.8	(48.3)	(43.6)			(109)
	18	96.3	95.56	94.68	92.8	91.08	88.71	84.65	82.85	80.8	76.43	69.12	65.80	61.8	(48, 69, 95)
	25		(113.0)	111.4	108.8	106.4	103.4	(98.5)		(94.0)	(88.3)	79.5			(69, 109, 195)
	35			134	132	129	125	119		113	106	96			(109
$NaClO_4$	18											71.6	68.6	65	(93)
	25		123.4	121.7	119.1	116.6	113.5	(For 0, 12.5, 35°C, *v.* (109))							(195); *cf.* (109, 261)
$NaBrO_3$	0		56.5	56.0	54.4	53.0	51.2	48.6	47.4	46.1					(267)
	18	89.72	89.09	88.04	86.22	84.4	82.1	78.0	76.1	73.9	69.1	61.7	58.4	54.4	(69, 99)
	25		105	103	100.5	98.3	95.5	90.5	88.2	85.6					(267)
$NaIO_3$	18	75 72	75.08	74.20	72.52	70.76	68.48	64.34	62.50	60.37	55.37				(129)
$\frac{1}{5}Na_5IO_6$	25				171.1	168.3	159.4								(261)
$\frac{1}{5}NaH_4IO_6$	25				20.8	20.5	20.3	19.7	19.4	19.0					(261)
$\frac{1}{5}Na_2H_3IO_6$	25			44.6	43.7	41.7	38.7	33.8	31.8						(261)
$\frac{1}{5}Na_3H_2IO_6$	25				82	81.8	78.8	69.2							(261)
$\frac{1}{2}Na_2S$	0							76.8	76.7	76.4	75.2	(72.2)	(70.7)	68.7	(108)
	18							152	151	149	145	(129)	(120)	110.2	(108); *cf.* (18)
	25							177	174	171	162	143	135	125.8	(108)
	35									155	(153 at C = 150) (146 at C = 300)				(77)
$\frac{1}{2}Na_2S_2$	25		(128 at C = 150) (120 at C = 300) (103 at C =600)												(77)
$Na_2S_2O_3$	0		133	129	123	119	113	103		93					(267)
	25		254	248	236	226	214	195	187	177	159	(*Also* at 15 and 35°C)			(267)
$Na_2S_2O_4$	0		(102.5 at C = 7.8) (90.6 at C = 31.25) (75.5 at C = 125.0)												(107)
	18		186.1	181.8	(174.0)	166.3	157.7	144.2	138.3	131.5					(107)
	25		(198.3 at C = 7.8) (180.9 at C = 31.25)												(107)
$\frac{1}{2}Na_2S_2O_5$	25				80.9	79.4	75.6								(260)
$Na_2S_2O_6$	25		271	258	245	236	223	201		183	(*Also* at 0, 15, 35°C)				(267)
$\frac{1}{2}NaHS$	0					61.6	60.1	57.9	56.8	55.6	52.7	47.4	45.1	42.5	(108)
	18					92.4	90.7	87.6	86.0	84.1	79.9	72.9	69.6	65.5	(108)
	25					106.7	104.6	100.9	99.1	97.1	92.4	84.2	80.4	76.0	(108); *cf.* (77)
$\frac{1}{2}NaHSO_3$	0		(25.3 at C = 8.7) (23.3 at C = 75.2)												(151)
	25			52.6	50.4	48.2	46.5	44.6	43.9	(*Also* at 50 and 70°C)					(10, 151)
$\frac{1}{2}NaHSO_4$	25		262.8	254.5	236.8	218.5	197.35	168.62	158.5	148.27	130.64				(192); *cf* (10)
$\frac{1}{2}Na_2SeO_4$	25		119.9	117.3	113.3	109.4	104.1								(261)
$\frac{1}{2}NaHSe$	25			58.8			55.9	(57.4 at C = 4)							(32)

TABLE 2.—(*Continued*)

Solute	C / °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$NaNO$	0			65	57	53	49.9	46.2		44.2					(213)
$NaNO_2$	25			121.6	117.8	114.9	111.9	(For 20°C, *v.* (215.5))							(179)
$NaPO_3$	18														(250)
$\frac{1}{3}Na_3PO_4$	0				67.0		59.7			41.6		(*Also* at 15 and 35°C)			(267)
	25				122.2	118.6	111.0					(For 17°C, *v.* (13))			(260)
$\frac{1}{4}Na_4P_2O_7$	0		58.5	57.5	55.1	50.7	(45.8)	(38.7)		33.3	28.2	(*Also* at 35°C)			(267)
	18			99.8	90.2	81.5	72.5	61.4	57.5	53.5	46.2	(41.9 at C = 300)			(1)
	25		114.0	112.3	107.2	99.1	(88.4)	(73.5)		63.5	54.8				(260, 267)
NaH_2PO_2	18		78.1			73.3				64.3		52.0			(5)
	25		(92.9)	92.2	90.2	88.2	85.7	81.4	79.3	76.8	71.3	61.5			(210)
$\frac{1}{3}NaH_2PO_4$	18				22.06	21.95	21.60	20.80	20.40	19.85	18.75	16.88	16.0		(1); *cf.* (13)
$\frac{1}{3}Na_2HPO_4$	0			32.6	32.6	32.2	31.5	29.2	28.0	26.6	23.6	(For 17°C, *v.* (13))			(109)
	18				59.5	57.6	54.8	50.1	48.1	46.0	41.4	(34.5)			(1, 70)
	25			66.7	65.8	64.1	61.3	56.2							(260); *cf.* (109)
	35			85	82.7	79.9	76.3	69.6	66.8	63.8	(*Also* at 50 and 65°C)				(109)
$\frac{1}{4}Na_2H_2P_2O_7$	18		41.1	40.5	39.4	38.2	36.9	34.6	33.6	32.5	29.8	(25.4)			(1)
$\frac{1}{4}Na_3HP_2O_7$	18		72.4	70.1	66.8	63.4	(59.5)	53.3	50.8	48.0	43.0	(35.0)			(1)
$\frac{1}{3}Na(NH_4)HPO_4$	0			37.5	36.6	35.7	34.4	32.2	31.2	29.9	26.5				(109)
	18			62.1	(60.0)	58.3	(55.4)	51.3	(49.4)	47.4	(43.0)	36.2	(33.4)	30.3	(70)
	25				67	66	64	61		59	(*Also* at 35°C)				(109)
$NaAsO_2$	25		96.3	93.2	88.8	85.2	81.0								(261)
$\frac{1}{3}Na_3AsO_3$	25														(261)
$\frac{1}{3}Na_3AsO_4$	25		(128.3)	(127.5)	124.8	118.7	108.7								(261)
$\frac{1}{3}NaH_2AsO_4$	25			(28.3)	27.6	27.1	26.3	25.1	24.6	24.0					(261)
$\frac{1}{3}Na_2HAsO_4$	25			68.0	66.2	63.8	60.7	55.9							(261)
NaH_2SbO_4	25														(252)
$\frac{1}{2}Na_2CO_3$	0			59	56.4	54.4	52.0	47.6	45.8	43.7	39.2	(32.5)	(30.0)	27.0	(109)
	18		112	108.5	102.4	96.1	89.6	80.2	76.7	72.8	(65.0)	54.4	50.2	45.4	(126, 128)
	25				110.7	108.0	103.8	93.6	89.6	85.3	76.3	(63.4)	(58.6)	53.4	(109)
	35			143	137	132	125	115	110	105	93	78			(109)
$\frac{1}{2}Na_2C_2O_4$	25			117.2	113.1	108.7	103.4	95.0	91.7	88.1					(159)
$\frac{1}{6}C_6(CO_2Na)_6$	25				(104.7)	90.8	81.0	70.1	66.2	62.1	Mellitate				(159)
$NaHCO_2$	0		80	79.8	77.6	75.8	73.6	70.8	69.0	67.1	62.2				(267)
	18	89.7	88.6	87.3	85.4	83.6	81.2	76.9	75.0	72.9	68.7	61.3	57.7	53.4	(7, 99)
	25		(150)	149	147.9	145.7	142.0	133.2	129.1	124.4	114.2	(*Also* at 35°C)			(267)
$NaHCO_3$	0			47.7	46.8	45.7	44.2	(41.8)							(124.5)
	12.5			70.1	67.9	66.1	63.7	(59.7)		(For 18°C, *v.* (263.5))					(122)
	25	94.4	93.5	92.5	90.3	88.1	85.5	80.6	78.5	76.1		(95.2 at C = 0.3)			(121, 122)
$NaC_2H_3O_2$	0			44.4	43.9	43.2	41.9	39.9	39.0	38.0	35.4	30.5	(For 10°C, *v.* (157))		(109)
	18	75.87	75.1	74.45	72.60	71.12	69.10	65.58	64.0	62.1	57.57	49.66	45.9	41.16	(95, 126, 128, 148, 178, 183, 188)
	25	(For 50, 65°C, *v.* (109))		87.3	85.5	83.7	81.3	76.9	75.0	72.8	67.7	58.6	54.3	49.1	(109, 157, 225)
	100		274.0	267.0	259.0	252.8	(244.5)	(229.6)	(223.2)	(220.6 at C = 80)					(183)
	156		438.6	423.6	(408)	396.2	(For 89.75°C, *v.* (162))			(339.3 at C = 80)					(183)
	218		627	597		545				(452 at C = 80)					(183)
	306			799		701				(612 at C = 80)					(248)
$NaC_2H_5CO_2$	0	44.7	43.9												(276)
	18		72.4	(71.3)	(69.4)	67.8	(65.8)	(62.2)	60.5	58.4	53.5	45.4	41.6	36.8	(5, 99)
	25		87	85.3	82.7	80.2	77.4	(For 15, 35, 50, 65°C, *v.* (276, 277))							(196, 276)
$NaC_4H_5O_2$	0	(42.1 at C = 0.49)						Crotonate							(276)
	25	(84.1 at C = 0.49)													(276)
	35	(103.3 at C = 0.49)													(276)
$\frac{1}{2}NaC_4H_5O_4$	25		77.8	76.4	73.9	71.6	69.0		Bisuccinate						(196); *cf.* (5)
$NaC_4H_5O_6$	18		119.8	98.8	81.6	74.6	70.0	64.2	62.3	60.3	Bitartrate				(201)
$NaC_3H_7CO_2$	0	43.0	41.8	Butyrate											(276)
	25		82.5	80.5	78.0	76.0	73.4	(75.5 at C = 15.6)							(5, 225, 276)
	35	106	102												(276)
$NaC_4H_7O_3$	0	43.0		Hydroxyisobutyrate											(278)
	15	66.4													(278)
	25	84.5													(278)
	35	100.4	100.7	(*Also* at 50 and 65°C)											(278)

TABLE 2.—(*Continued*)

Solute	C °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$NaC_5H_3O_3$						Furancarboxylate									(276)
$NaC_5H_7O_3$	0	34.4			Levulate										(278)
	15	53.4													(278)
	25	68.0													(278)
	35	84.4	101.6						(*Also* at 50 and 65°C)						(278)
$NaC_5H_9O_2$	0	34.4						Isovalerate							(278)
	15	53.4													(278)
	25	68.0													(278)
	35	84.4	101.5					(*Also* at 50 and 65°C)							(278)
$NaC_7H_5O_2$	0	41.4						Benzoate							(276)
	14.5	64.1													(276)
	25	82.7	81.9	80.8	78.8	76.9	74.5								(145, 276)
	35	102.$_2$													(276)
$NaC_7H_5O_3$	0	43.$_2$	42.$_6$					*o*-Hydroxybenzoate							(276)
	25	85.0	83.7	82.0	79.6	77.7									(148, 276)
	35	105	102												(276)
$NaC_7H_5O_3$	35	105.3						*m*-Hydroxybenzoate							(278)
	50	136													(278)
	65	170													(278)
$NaC_7H_5O_3$	20		69.6	68.7	67.3	65.2	62.7	*p*-Hydroxybenzoate							(36)
	25		(79.3)	77.$_5$	74.$_6$	72.$_5$									(148)
	35		105					(*Also* at 50 and 65°C)							(278)
$NaC_7H_5O_4$	35		101.$_3$					2, 4-Dihydroxybenzoate							(278)
	50		130.$_5$												(278)
	65		163												(278)
$NaC_7H_5O_5$	0	40.4						Gallate							(276)
	25	79.$_1$													(276)
	35	97.$_7$													(276)
$NaC_8H_7O_2$	25		81.4	79.9	77.3	74.9	72.4	*o*- *m*- *p*-Toluate and Phenylacetate							(195); *cf.* (225)
$NaC_8H_7O_3$	25		82.2	80.1	77.2	75.0	*o*- and *p*-Hydroxymethylbenzoate								(147)
$NaC_8H_7O_3$							Mandelate (At 0, 25, 35°C)								(276)
$NaC_8H_7O_3$	25			78.6	(76.2)	74.0	71.3	*o*- and *p*-Methoxybenzoate							(147)
$NaC_8H_{15}O_2$								Caprylate (At 0, 25, 35, 50, 65°C)							(277, 278)
$NaC_9H_7O_2$							Phenylacrylate (At 0, 25, 35°C)								(276)
$NaC_{14}H_{11}O_3$	0	38.7	37.4					Diphenylglycolate							(277, 278)
	25	76.0	69.9												(277, 278)
	35	94.$_5$	91.$_7$												(277, 278)
$NaC_{16}H_{31}O_2$	89.7	Palmitate (*see also* Vol. V, p. 458)				135		86		79	77	77		65	(162)
$\frac{1}{2}Na_2C_3H_2O_4$	25			107.4	103.9	100.0	95.3		Malonate						(159)
$\frac{1}{2}Na_2C_4H_4O_4$	25	Succinate		100.7	97.7	94.3	90.1	83.4	80.6	77.6	71.1	60.5	56.0	50.5	(159)
$\frac{1}{2}Na_2C_4H_2O_6$	25			105	103	99	95	Dihydroxymaleate							(152)
$\frac{1}{2}Na_2C_4H_4O_6$	25	Tartrate		*dl* (97.2$_3$ at C = 7.81)			*l* (97.6 at C = 7.81)			*d* (98.2$_5$ at C = 7.81)					(225)
$\frac{1}{2}Na_2C_8H_4O_4$	25			96.5	93.0	89.5	85.2	77.7	74.6	71.4		Phthalate			(159)
$\frac{1}{2}Na_2C_8H_4O_4$	25		97.8	95.9	92.6	89.5	85.6	79.4	(76.8)			Isophthalate			(159)
$\frac{1}{2}Na_2C_8H_4O_4$	25			95.2	92.0	89.0$_5$	85.2$_5$					Terephthalate			(159)
$\frac{1}{4}Na_4C_{10}H_2O_8$	25		120.0	116.1	108.3	101.1	93.2	82.4	78.5	Pyromellitate (1, 2, 4, 5)					(159)
$Na_4C_{11}H_2O_{10}$	0	232.$_4$	216.$_8$	200.$_5$	177.$_9$	160.$_5$	143.5	120.4		Benzenepentacarboxylate					(190)
	25	455	426.$_8$	395.$_4$	349.$_4$	314.$_0$	281.$_5$	240.$_0$							(190)
	50	729	679	628	553	497	445	379							(190)
$Na_5C_{11}HO_{10}$	0		278.$_0$	(253)	217.8	177.4	154.6	141.2	Benzenepentacarboxylate						(190)
	25		538.$_8$	488.$_0$	419.$_2$	371.$_0$	329.$_0$	278.$_2$	(577 at C = 0.6)						(190)
	50			764	634	562	505	434	(914 at C = 0.6)						(190)
$NaCH_2ClCO_2$	25			88.0$_5$	85.3$_7$	82.9$_0$	80.2$_0$	76.0$_5$	74.3$_5$	72.2$_4$	66.6$_0$				(59)
$NaCHCl_2CO_2$	18		73.3			68.8	(66.6)	(63.0)		59.4	(54.7)	48.0			(6)
$NaC_4H_4Cl_3O_2$	25		76.8	75.7	73.9	72.2	70.0			Trichlorobutyrate					(121); *cf.* (210)
$NaC_6H_4ClCO_2$	0		40.5							*o*-Chlorobenzoate					(276)
	15		62.8												(276)
	25	81.5	80.7	79.6	77.7	75.7	73.2								(121)
	35		99.3							(*Also* at 50 and 60°C)					(276)
$NaC_8H_6ClO_2$	25		79.6	78.0	75.5	73.3	(70.1)			Phenylchloroacetate					(240)

Table 2.—(*Continued*)

Solute	C °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$NaC_3H_4BrO_2$	0	47.7	44.7							α-Bromopropionate					(278)
	25	95.3	89.6												(278)
	35	115	112												(278)
$NaC_3H_6Br_2O_2$		(At 0, 15, 25, 35°C)								α, β-Dibromopropionate					(278)
$NaC_4H_4BrO_2$	0	45.1	44.1							α-Bromobutyrate					(278)
	15	69.2	68.3												(278)
	25	87.7	87.2												(278)
	35	109.2	107.5												(278)
$NaC_3H_4IO_2$		(At 0, 15, 25, 35°C)								β-Iodopropionate					(278)
$NaC_6H_5SO_4$	25			80.6	78.3	76.0				*o*-Phenolsulfonate					(147)
$NaC_6H_5SO_4$	25		80.9	79.4	76.9	74.5				*p*-Phenolsulfonate					(147)
$NaC_{10}H_7SO_3$	25				76.1	74.5	72.3	68.6	66.8	64.7	β-Naphthalenesulfonate				(210)
$NaC_{16}H_{33}SO_3$		(At 40, 50, 60. 65°C)(*see also* Vol. V, p. 458)									Cetylsulfonate				(220)
$NaC_{14}H_8BrSO_3$							10-Bromophenanthrene-3(6)-sulfonate								(237)
$NaCHN_2$	25					116	108.2	98.4	95.1	91.7	Bicyanamide				(117)
NaC_7H_8N	18		72.4	71.7	69.9	67.9	65.5				*o*-Toluidine				(160)
$NaC_3H_2NO_2$	25	87.7	86.9	85.6	83.8	81.9	79.3	74.7	72.9	$CH_2.CN.CO_2Na$ (At 0, 25, 35, 50, 65°C (278))					(119, 121); *cf.* (210, 225)
$NaC_3H_3N_4O_2$									*N*-Methyltetrazolecarboxylate						(194)
$NaC_5H_3N_4O_3$											Urate				(73)
$NaC_6H_2N_3O_7$	18					64.8		60.4	Picrate						(80, 118)
	25		82.4	81.1	79.1	77.3	74.8								(118, 196)
$NaC_7H_4NO_4$	25	82.9	81.2	79.5	77.1	75.1	72.5	68.0	(66.2)	*o*-Nitrobenzoate					(119, 121)
	35		101.3	*o* and *m*-Nitrobenzoate											(278)
$NaC_7H_4NO_4$	50		132.4		*m*-Nitrobenzoate										(278)
	65		166												(278)
$NaC_7H_4NO_4$	0	42.4	41.4		*p*-Nitrobenzoate										(277)
	25	81.4	80.6												(277)
	35	102.0	99.3					(For 50, 60°C, *v.* (277, 278))							(277)
$NaC_7H_6NO_2$	0	40.7						*o*-Aminobenzoate							(276)
	25	80.7													(276)
	35	98.5													(276)
$NaC_7H_3N_2O_6$	35		99.1								1, 2, 4-Dinitrobenzoate				(278)
	50		128.9												(278)
	65		161.5												(278)
$NaC_7H_3N_2O_6$	25	77.9	77.2	76.1	74.3	72.5	(70.4)				1, 3, 5-Dinitrobenzoate				(119, 121)
	35		99.3								(*Also* at 50 and 65°C)				(278)
$NaC_9H_8NO_3$	0	38.5	37.9								Hippurate				(276)
	25	76.2	75.3												(276)
	35	93.6	92.3												(276)
$NaC_{10}H_6NO_2$	25	α-Cyanocinnamate				78.8	78.2	77.3	77.1	76.6	75.4	72.7	71.0	68.9	(252)
NaCNS	0		61	61.4	59.8	58.8	57.4	55.2	54.3	53.3	50.7	(*Also* at 25 and 35°C)			(267)
	18											74.2	71.9	68.8	(93, 267)
$NaC_6H_4NSO_5$	25	*m*-Nitrobenzenesulfonate						72.3		67.9	62.1				(77)
$NaC_6H_6NSO_3$	0	42.0	40.9								*o*-Aminobenzenesulfonate				(276)
	25	82.7	81.1												(276)
	35	102	100		(*Also* at 11.9°C)										(276)
$NaC_6H_6NSO_3$											*p*-Aminobenzenesulfonate				(248.5)
$NaC_7H_6NSO_4$	35	99.6									*p*-Sulfaminobenzoate				(278)
	50	131.2													(278)
	65	164													(278)
$Na_2C_{32}H_{22}N_6S_2O_6$	18		73.3	68.7	59.6	53.3					Congo red				(21)
	25		171	159.6	137.8	123.8	112.5								(63)
$NaC_9H_{12}PO_2$											Mesitylenephosphinite				(52)
$\frac{1}{2}Na_2C_3H_7PO_6$	0	Glycerophosphate				47.6	46.4	43.5	41.4	38.1	29.7				(9)
$NaC_6H_4AsCl_2O_4$	18		84.2	79.0	74.7	71.5	68.1				Dichlorophenolarsenate				(160)
$NaC_6H_7As_2O_6$	18		300	234	163.5	127.0	101.0				*p*-Phenylenediarsenate				(160)
$Na_2C_6H_3AsCl_2O_4$	18		179.2	174.7	166.2	157.6					Dichlorophenolarsenate				(160)
$Na_2C_6H_6As_2O_6$	18		139.1	117.5	95.7	84.3	76.1				*p*-Phenylenediarsenate				(160)
$NaC_6H_4AsBr_2O_4$	18	93.0	85.4	79.8	75.1	70.2	66.9				Dibromophenolarsenate				(160)
$Na_2C_6H_3AsBr_2O_4$	18	176	170.0	166.1	160.5	152.0					Dibromophenolarsenate				(160)

TABLE 2.—(*Continued*)

Solute	C / °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$NaC_6H_5AsNO_6$	18	80.3	77.4	74.6	71.5	69.2	66.6				3-Nitro-4-hydroxyphenylarsenate				(160)
$NaC_6H_7AsNO_3$	18		71.7	71.2	69.9	68.6	66.5				$NaC_6H_4(NH_2).AsO(OH).O$				(160)
$NaC_6H_4AsN_2O_8$	18	259	217.7	183.2	146.2	124.4	116.2				Dinitrophenolarsenate				(160)
$NaC_6H_6AsN_2O_5$	18		73.7	73.0	71.8	70.6	68.0				3-Nitro-4-aminophenylarsenate				(160)
$NaC_6H_8AsN_2O_3$	18		71.2	70.8	69.8	68.3	66.1				*o*-Phenylenediaminearsenate				(160)
$NaC_8H_{11}AsNO_3$	18		72.7	71.8	70.6	69.1	66.7				Dimethylaminophenylarsenate				(160)
$Na_2C_6H_4AsNO_6$	18	169.2	168.4	167.5	163.0	155.4					3-Nitro-4-hydroxyphenylarsenate				(160)
$Na_2C_6H_5AsN_2O_5$	18		173.8	171.3	163.0	155.4					3-Nitro-4-aminophenylarsenate				(160)
$Na_3C_6H_3AsNO_6$	18		290.9	281.4	261.2	244.5					3-Nitro-4-hydroxyphenylarsenate				(160)
$Na_3C_6H_2AsN_2O_8$	18		289.6	279.7	261.8	243.4					Dinitrophenolarsenate				(160)
½Na_2SiO_2	18		144		139	136		124		116		87.5		71.4	(95, 128)
	25	(*Also* other compounds)			158.5	155.5		143.3		130.8	112.7	96.8		81.2	(91)
½$Na_2Hg(SO_3)_2$	25		112.7	109.3	104.2	100.0	95.1								(10)
Na_2HgNO_2															(215.5)
½$Na_2Pt(CN)_4.7H_2O$	25		130.1	127.4	123.2	119.2	114.2								(261)
$NaMnO_4$	25		112.5	111.2	108.6	105.7	(102.3)								(72)
$NaFe(ClO_4)_4.6H_2O$															(271)
¼$Na_4Fe(CN)_6$	0		73.8	70.8	66.4	62.2	57.5	51.1	48.7	46.2	41.6	35.4	(*Also* at 35, 50, 65°C)		(109)
	25	151	145.8	140.3	129.4	119.9	109.9	96.8	92.4	88.0	79.9				(185)
$Na_4Fe(CN)_6.10H_2O$															(39)
$Na_2[Fe(CN)_5NO]$	25		236	229	220	211	202	188	181	174					(40); *cf.* (61)
$Na_3Co(NO_2)_6$															(61, 242)
$Na_2NiC_{12}H_{12}O_6$											Dipyrocatechinodiaquonickelate				(219)
½Na_2CrO_4	0			62	61.6	60.1	57.7	53.3	51.6	49.6	45.8	39.8	(*Also* at 15°C)		(267)
	18									82.1	75.8	66.3	62.4	57.8	(95); *cf.* (47)
	25			118	115.5	112.4	108.4	100.9	97.5	93.7	85.9				(267)
	35					(138)	132	122	118	114	103				(267)
½$Na_2Cr_2O_7$	0				57.0	56.6	56.0	54.5	53.6	52.5	50.0	(*Also* at 15°C)			(267)
	25				103		102.0	98.3	96.6	94.9					(267)
	35				125		123	117	115	113.6					(267)
½Na_2MoO_4	25		120.5	117.5	113.3	109.4	104.0								(260)
⅕$Na_5Mo_6H_{17}O_{24}$		$Na_5H_5[H_2(MoO_4)_6].15\frac{1}{2}H_2O$													(226)
½$Na_2[P(Mo_2O_7)_3]$															(230)
½$Na_2WO_4.2H_2O$	0			57.9	56.4	54.5	51.9	47.8	46.0	44.0	39.0	31.7			(267)
	25		116.1	113.4	109.2	104.8	99.8	92.2	89.2	85.8					(260, 267)
	35			136	134	129	123	112		104	95	(*Also* at 15°C)			(267)
½$Na_2B_2O_4.8H_2O$	25		88.9	86.7	83.2	80.1	76.2			Metaborate					(260)
½$Na_2B_4O_7$	0		43.2	42.3	41.0	39.8	38.1	34.9	33.6	32.1	(*Also* at 35, 50, 65°C				(109)
	25		86.0	84.4	81.5	78.6	75.1	(69.3)							(260)
$Na_5BW_{12}H_4O_{42}$										⅕$Na_5H_4[B(W_2O_7)_6].27H_2O$					(229)
$Na[Al(ClO_4)_4].12H_2O$															(271)
KOH	18		234	233	230	228	224	218	216	213	207	197	192	184	(97, 126, 128)
	30	(For 25°, *v.* (206.5))		(*Also* at 20, 45, 60, 75°C)				270	269	267	262	248	241	233	(78)
	90							519		507	492	461	447	(431)	(78)
KHF_2	25		270	217	167	150	138								(261)
$KClO_2$	25		124.0	122.2	119.5	117.2	114.2								(33)
$KClO_3$	0	73.8	74.3	73.4	72.2	71.0	68.8	65.4	64.0	62.6					(109, 263); *cf.* (116, 140)
	18	117.50	116.74	115.67	113.67	111.47	108.65	103.58	101.45	99.04	93.59				(138, 263)
	25		135.7	134.4	132.0	129.6	125.7	119.2	116.4	113.3	(For 50, 65°C, *v.* (159))				(109)
	35		162	161	158	154	150	142		135					(109)
	100	360.0	359.0	356.0							(For 95°C, *v.* (116, 140))				(263)
$KClO_4$	0	76.3	75.9	75.3	74.0	72.6	70.5								(263); *cf.* (109)
	18	120.6	118.8	118.5	116.4	114.0	110.9	105.5							(263)
	25		139.1	137.3	134.4	131.7	127.5								(109); *cf.* (181, 195)
	35		166	164	161	158	153		(*Also* at 50 and 65°C)						(109)
	100	369.0	366.5	362.0	355.0	347.0	336.0								(263)
$KBrO_3$	0		69.7	69.1	67.8	64.9									(263)
	18		109.7	108.5	106.7	104.5	101.9	97.2	95.1	92.9	87.7				(105, 263)
	25		126.7	125.6	123.4	120.8	117.6	112.2	109.8	107.0	101.0				(105, 261)
	100		340.5	337.0	331.0										(263)

TABLE 2.—(*Continued*)

Solute	C °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
KIO_3	0	60.0	59.8	59.2	58.0	56.9									(263)
	18	96.58	95.90	94.91	93.07	91.11	88.51	83.94	81.87	79.56	74.23	(95.293 at C = 1.4934) (141)			(129, 263)
	25	112.21	111.41							(110.694 at C = 1.4910(141))					(90)
	100	315.0	312.5			293.1									(263)
$\frac{1}{2}K_2S$	18												138.6	135.4	(18)
$\frac{1}{2}K_2SO_3$	25		143.2	139.5	133.9	129.2	123.6	114.0	110.1	105.9	97.7	86.4	82.2	77.8	(10)
$\frac{1}{2}K_2S_2O_8$	25		153.2	150.2	145.1	139.9	132.2								(27)
$\frac{1}{2}KHS$	18		(46.4)	45.9	41.7	34.7	19.7								(18)
$\frac{1}{2}KHSO_3$	25			64.8	62.4	60.4	58.2	55.0	53.8						(10)
$KHSO_4$	0			(310)	291	273	252	222	211	200	183	164			(109)
	18			455.3	(414)	378.3	(341)	295.0	(278.8)	263.2	234.2	204.0	194.8	186.0	(126, 184)
	25			505.4	(456)	416.3	(374)	317.7	(300)	282.6					(184); *cf.* (109)
	50			659.8	(571)	507.1	(446)	373.7	(351)	328.5					(184); *cf.* (109)
	75			752.7		557.0	(476)	402.1	(377)	353.8					(184)
	100			782.6		579.0	(504)	421.4	(397)	373.9					(184)
	128			771.7		598.9	(526)	445.2	(423)	401.3					(184)
	156			752.6		609.9	(548)	476.1	(455)	434.2					(184)
KN_3	0													59	(30)
KNO_2	25		166	161.6	157.0	153.5	150.0		(For 20°C, *v.* (215.5))						(179)
KPO_3	20														(250)
$\frac{1}{3}K_3PO_4$	0				68.0	66.7	64.3	57.8	54.2	50.4		(*Also* at 35 and 65°C)			(109)
	25				129	128	125	113	106	98		(For 17°C, *v.* (13))			(109)
$\frac{1}{2}KH_2PO_4$	0			15	15.0	14.6	14.2	13.5	13.2	12.8	11.8	(*Also* at 35°C)			(267)
	18		31.7		30.1	29.5	(28.7)	27.7	27.1	26.5	(25.3)	23.2	22.4	21.4	(70, 126)
	25			29	28.4	27.8	27.0	25.6	25.1	24.4	22.7				(260, 267)
$\frac{1}{3}K_2HPO_4$	0	(*Also* at 25, 35°C; for 17°C, *v.* (13))		(39)	38.5	37.6	36.5	34.5	33.5	32.5	(30.4)	(26.9)	(25.6)	(24.1)	(109)
$\frac{1}{3}KH_2AsO_4$	25			(35.6)	35.0	34.4	33.6	32.3	31.7	31.2					(261)
KH_2SbO_4	25														(252)
$K_3Bi(S_2O_3)_2.1.5H_2O$															(61)
$\frac{1}{2}K_2CO_3$	0	(*Also* at 50 and 65°C)			69.0	66.9	64.4	60.5	58.9	57.1	53.6	(48.6)	(46.6)	44.9	(109)
	18		133	128	121.4	115.3	(109.2)	100.6	(97.5)	94.0	(87.3)	77.7	(74.2)	70.6	(126, 128)
	25				131.8	127.5	122.4	114.2	110.8	107.9	99.1	(88.2)	(84.2)	80.0	(109)
	35				150	144	138	127	122	117				84	(109)
$\frac{1}{2}K_2C_2O_4$	0			74.8	(72.3)	70.0	67.3	62.9	61.1	59.2	55.7				(186)
	18	123.63	122.25	120.28	116.55	112.66	107.91	100.62	97.80	94.65	88.55	80.25	77.00	73.52	(126, 133)
	25			139.0	(135.0)	130.7	125.0	116.3	112.9	109.3	102.1				(186)
$\frac{1}{2}KHCO_3$															(126)
$\frac{1}{2}KHC_2O_4$	18	216.9	183.2	160.8	134.5	121.6	109.8	96.4	92.5	88.9					(65)
$KC_2H_3O_2$	0	63.1	62.0	60.9	59.5	(58.4)	57.3	55.0	53.9	52.6	50.0	(*Also* at 50 and 65°C)			(109)
	18	98.8	98.2	97.3	95.6	93.8	91.5	87.8	86.2	84.4	79.6	70.7	66.8	62.4	(18, 93, 128)
	25	115.3	113.7	112.1	109.8	108.0	105.6	100.8	98.8	96.3	90.7	(For 90°C, *v.* (38))			(109)
	35	138	137	136	133	131	128	121	118	115	108				(109)
$KHC_4H_4O_6$	18		142	120	101	93	86.8								(201)
$KC_6H_{11}O_2$	90	Hexoate (*See* Vol. V, p. 458)													
$KC_8H_5O_4$	25	128.8	119.3	111.6	103.7	99.9	95.5	89.3		83.8	76.8	Biphthalate			(200)
$KC_7H_5O_3$	25		101.7	100.1	98.0	95.9						*p*-Hydroxybenzoate			(148)
K-Soaps	(*See* Vol. V, p. 458)														
$\frac{1}{2}K_2C_8H_4O_4$	25		121.8	120.3	116.2	112.1	107.1	99.1	95.8	92.2		Phthalate	(123.3 at C = 0.4)		(200)
$\frac{1}{3}K_3(C_6H_5O_7)$	0			70.9	67.5	63.8	(59.7)	54.3	52.4	50.1	43.4	Citrate			(186)
	18	119.9	(117.7)	115.2	109.7	101.6	(95.2)	87.7	84.3	80.7					(186)
	25	139.2	(137.0)	134.3	128.0	118.5	(111.0)	101.9	98.1	93.8					(186)
$KC_2Cl_3O_2$	25		106.6	104.7	101.7	99.2	96.3	91.6	90.0	87.5	82.5	74.6	Trichloroacetate		(121)
$KC_2HCl_2O_2$*	25		108.7	106.8	104.2	102.1	99.7	95.5	93.5	91.4	86.6	77.7	73.4	68.5	(121)
$K_2C_2H_6TeO_4$										$K_2[H_6TeO_6.C_2O_4]$					(231)
KCN	18	(104.0 at C = 506) (9.7 at C = 1029)													(126)
KCNO	18														(178)
$KC_6H_2N_3O_7$	0	54.6	54.3	53.8	52.8	51.0			Picrate						(263)

* Dichloroacetate.

TABLE 2.—(*Continued*)

Solute	C / °C	0.5	1	2	5	10	20	50	70	100	200	500	700	1000	Lit.
$KC_6H_2N_3O_7$.—(*Continued*)	18	88.1	87.4	86.6	85.0	83.3	81.0								(263)
	100		282.1	279.1	272.6	271	258.1								(263)
$KC_{10}H_6NO_2$	25	α-Cyanocinnamate				96.0	95.2	94.1	93.6	93.0	91.7	88.7	86.7	83.8	(252)
$KC_7H_6NSO_5$	25		102	100	98.0	(96.1)			Nitrotoluenesulfonate						(102)
$KCNS$	0		76.9	76.7	75.8	74.7	72.9	69.8	68.6	67.3	64.8	61.3	(*Also* at 50 and 65°C)		(109)
	18	119.10	118.36	117.39	115.55	113.69	111.33	107.50	106.10	104.5	101.9	95.48	93.7	91.41	(93, 138)
	25		139.9	138.8	136.9	134.4	130.8	124.9	122.5	119.8	(114)	(For 25.7°C, *v.* (17))			(109)
	35			163	160	157	154	149	147	144	138				(109)
$K_3Sb(C_2O_4)_3.H_2O$															(61)
$\frac{1}{2}K_2Hg(SO_3)_2$	25		134.0	130.8	125.7	121.0	115.1								(10)
$\frac{1}{2}K_2HgN_4O_8$									$\frac{1}{2}2KNO_2.Hg(NO_2)_2$						(214)
$K_2[Pt(NO_2)_4]$	25														(46)
$KMnO_4$	25	133.9	133.0	131.7	129.5	127.4	124.1	118.7	116.2	113.6	(For 0, 35, 50, 65°C, *v.* (109))				(27, 156); *cf.* (109)
$KFe(SO_4)_2.H_2O$															(271)
$K_3FeC_{18}H_{15}O_7$	18		320	295	264	(249 at C = 8)			Tripyrocatecholaquoferrate						(219)
$\frac{1}{3}K_3Fe(CN)_6$	0		89.1	86.2	82.0	78.6	74.6	68.6	66.4	63.9	59.6				(267); *cf.* (51)
	18											86.4		82.0	(99); *cf.* (39)
	25	167	162.1	158.5	150.8	143.9	135.8	123.8	119.5	115.1	106.9	97.3			(261, 267)
	35		197	191	181	172	162	148	143	138	127				(267); *cf.* (123)
$\frac{1}{4}K_4Fe(CN)_6$	0	91.5	(87.0)	84.7	(78.5)	72.8	(66.8)	58.1	55.4	52.9	48.7				(186); *cf.* (109)
	18			136.8	(122.9)	113.2	(103.9)	92.6	88.8	85.1	78.3	71.1	68.9	66.6	(99, 186); *cf.* (39, 140)
	25	172.8	166.8	160.0	146.8	135.2	123.2	108.2	103.1	98.1	89.7	80.9	78.9	77.14	(185, 239); *cf.* (109)
	35	(*Also* at 50, 65°C)	186.9	181.6	172.7	162.8	(148.9)	130.3	124.2	117.9	107.7	97.0	93.9	90.9	(109)
$K_2[Fe(CN)_5NO]$	25		256.3	250.0	240.8	232.4	222.2	208.4							(40)
$K_3Co(NO_2)_6$															(61)
$K_3CoC_{18}H_{15}O_7$	18		342	312	272	(252 at C = 8)			Tripyrocatecholaquocobaltate						(219)
$K_4CoC_{18}H_{14}O_7$	18		480	443	397	(378 at C = 8)			Tripyrocatecholhydroxycobaltate						(219)
$K_3(COS)_6Co$	25					348	319		Cobaltidithiooxalate						(223)
$K_3Co(CN)_6$															(39, 61)
$KCoC_9H_{14}N_5O_6$															(42)
$K_2Co(CNS)_4$															(61)
$K_2Ni(CN)_4$															(123)
$K_2Ni(COS)_4$															(223)
$\frac{1}{2}K_2CrO_4$	0		80.6	79.7	77.8	76.0	73.6	68.9	66.9	64.7	60.4	54.5	52.4	51.3	(109)
	18									100.4	94.3	86.4	83.1	79.4	(93)
	25		149.0	147.2	143.5	138.7	132.7	123.8	120.3	116.3	107.7	88.2			(109); *cf.* (260)
	35		178	176	173	166	159	147		139	129	105	(*Also* at 50 and 65°C)		(109)
$\frac{1}{2}K_2Cr_2O_7$	0		72.4	71.6	70.3	69.5	68.4	66.1	64.8	63.1	59.5	(*Also* at 50 and 65°C)			(109)
	18									98.1	93.0	85.3			(99)
	25		130.5	128.0	125.7	124.2	122.5	118.2	116.0	113.2	106.7				(109, 260)
	35		156	152.7	149.0	148.2	146.8	141.0	137.9	134.5	127.1				(109)
$K_3Cr(C_2O_4)_3$															(123)
$\frac{1}{3}K_3Cr(CN)_6$	25		171.6	166.9	159.9	153.4	145.5	(For 18°C, *v.* (39))							(261)
$\frac{1}{3}K_3W(CN)_8$	1		89.9	87.9	83.8	79.5	75.0	68.7	66.5						(51)
$K_3Cr(CNS)_6.4H_2O$															(61)
$\frac{1}{4}K_4Mo(CN)_8.2H_2O$															(227)
$K_3H_6[Fe(MoO_4)_6].7H_2O$															(229)
$K_3H_6[Cr(MoO_4)_6].7H_2O$															(229)
$\frac{1}{4}K_4W(CN)_8.2H_2O$															(227)
$\frac{1}{4}K_4H_5[Fe(WO_4)_6].9H_2O$															(229)
$\frac{1}{2}K_2B_2O_4$	0					53.0	50.6	49.3	47.8	44.4	Metaborate				(168)
$\frac{1}{2}K_2B_4O_7$	0					52.2	49.3	47.7	45.6	40.8					(228)
	25	123	114	105	101	98	91								(228)
$\frac{1}{2}K_2B_{10}O_{16}.8H_2O$	0	(59)	58	56	53.6	50.7	45.1								(228)
	25	(120)	116	110	105	100	89								(228)
$KAl(SO_4)_2$															(123)
$K_3H_6[Al(MoO_4)_6].7H_2O$															(229)
$K_2CaFe(CN)_6.3H_2O$															(61)
$K_2BaFe(CN)_6.3H_2O$															(61)
$\frac{1}{2}KNaSO_3$	25	125.3	123.9	119.3	114.4	108.9									(10)
$RbOH$	18	(For RbOH and CsOH at 25°C, *v.* (206,5))							220.2	213.3	202.8	197.1	189.4		(97)

TABLE 3.—(*Continued from p. 241*)

$\frac{1}{3}H_3PO_4$.—(*Cont'd*)

C	$10^6\kappa/C$
14 700	9.3
22 000	6.3
33 700	2.3
39 600	1.2
50 400	0.44
57 700	0.24

H_3PO_4, 18°

C	$10^6\kappa/C$
1 076	52.53
1 658	51.18
3 613	45.72
5 930	35.13
7 716	25.59
10 820	13.23
15 086	4.662

$NH_4C_2H_3O_2$, 18°

C	$10^6\kappa/C$
2 000	42.7
3 000	33.8
4 000	26.5

NH_4CNS, 18°

C	$10^6\kappa/C$
2 000	84.6
3 000	79.1
4 000	73.9

$\frac{1}{2}Pb(C_2H_3O_2)_2$, 18°

C	$10^6\kappa/C$
2 000	3.85
3 000	2.52

$\frac{1}{2}Zn(ClO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	44.0
3 000	35.4
4 000	28.7

$\frac{1}{2}Zn(BrO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	32.3
3 000	24.2

$\frac{1}{2}Cd(ClO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	43.6
3 000	34.6
4 000	27.3

$\frac{1}{2}Cu(ClO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	43.5
3 000	34.5

$\frac{1}{2}Co(ClO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	43.7
3 000	35.1
4 000	27.9
5 000	21.6

$\frac{1}{2}Ni(ClO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	43.6
3 000	34.6
4 000	27.5

$\frac{1}{3}H_3BO_3$, 18°

C	$10^6\kappa/C$
1 409	0.015
1 777	0.0175

$\frac{1}{2}Mg(ClO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	44.3
3 000	35.6
4 000	28.4

$\frac{1}{2}Mg(BrO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	34.0
3 000	25.6

$\frac{1}{2}Mg(C_2H_3O_2)_2$

C	$10^6\kappa/C$
18°	
2 000	14.8
3 000	8.8
4 000	4.85
5 000	2.61
6 000	1.30
6 550	0.770
7 744	0.218
25°	
2 000	17.4
3 000	10.4
5 000	3.41
6 550	1.08
7 744	0.333

$\frac{1}{2}MgCrO_4$,18°

C	$10^6\kappa/C$
2 000	28.00
3 000	21.55
4 000	16.20
5 000	11.90

$\frac{1}{2}Ca(ClO_3)_2$

C	$10^6\kappa/C$
6°	
2 000	32.1
3 000	24.9
4 000	19.3
18°	
2 000	49.9
3 000	41.0
4 000	(33.7)

$\frac{1}{2}Ca(C_2H_3O_2)_2$, 18°

C	$10^6\kappa/C$
2 000	15.6
3 000	9.40

$\frac{1}{2}Ca(C_2H_5CO_2)_2$

C	$10^6\kappa/C$
18°	
2 000	13.0
3 000	6.70

$\frac{1}{4}Ca_2Fe(CN)_6$, 0°

C	$10^6\kappa/C$
2 000	15.7

$\frac{1}{2}Sr(ClO_3)_2$, 18°

C	$10^6\kappa/C$
2 000	46.9
3 000	37.6

$\frac{1}{2}Sr(BrO_3)_2$, 18°

C	$10^6\kappa/C$
1 500	39.9

$\frac{1}{2}Sr(CHO_2)_2$, 18°

C	$10^6\kappa/C$
1 500	35.3

$\frac{1}{2}Sr(C_2H_3O_2)_2$, 18°

C	$10^6\kappa/C$
2 000	19.13
3 000	11.85

$\frac{1}{4}Sr_2Fe(CN)_6$, 0°

C	$10^6\kappa/C$
2 000	15.3

$\frac{1}{2}Ba(ClO_3)_2$

C	$10^6\kappa/C$
6°	
1 500	37.9
2 000	(34.4)
18°	
2 000	44.7
30°	
1 500	62.4
2 000	(55.7)

$\frac{1}{2}Ba(C_2H_3O_2)_2$, 18°

C	$10^6\kappa/C$
2 000	22.43
3 000	(14.8)
4 000	9.20

$\frac{1}{2}Ba(C_2H_5CO_2)_2$

C	$10^6\kappa/C$
18°	
2 000	18.7

LiOH

C	$10^6\kappa/C$
18°	
2 000	113.3
3 000	94.4
4 000	78.7
5 000	(65.3)
30°	
1 955	112.3
4 535	71.2
50°	
1 933	184.7
4 483	127.6
60°	
1 925	206.6
4 465	145.6

$LiClO_3$, 18°

C	$10^6\kappa/C$
2 000	46.9

$LiIO_3$, 18°

C	$10^6\kappa/C$
2 000	21.3
3 000	14.4

$LiCHO_2$, 18°

C	$10^6\kappa/C$
2 000	27.5
3 000	(19.9)
4 000	14.0

$LiC_2H_3O_2$, 18°

C	$10^6\kappa/C$
2 000	18.2
3 000	11.7
4 000	7.40

LiCNS, 18°

C	$10^6\kappa/C$
2 000	48.33
3 000	40.0

$\frac{1}{2}Li_2CrO_4$, 18°

C	$10^6\kappa/C$
2 000	37.4
3 000	29.8
4 000	23.3

$\frac{1}{2}Li_2Cr_2O_7$, 18°

C	$10^6\kappa/C$
2 000	47.6

NaOH

C	$10^6\kappa/C$
0°	
2 000	(84.0)
3 000	66.9
4 000	52.9
5 000	40.7
6 000	30.5

NaOH.—(*Cont'd*)

C	$10^6\kappa/C$
7 000	22.6
8 000	16.3
9 000	11.9
10 000	8.60
11 000	6.30
12 000	4.55
13 000	3.40
14 000	2.60
15 000	2.00
16 000	1.65
17 000	1.34
18 000	1.10
19 000	0.900
18°	
2 000	129.4
3 000	104.2
4 000	86.7
5 000	68.9
6 000	54.2
7 000	43.0
8 000	33.85
9 000	26.3
10 000	20.5
11 000	16.3
12 000	12.9
13 000	10.48
14 000	8.70
15 000	7.35
16 000	6.37
17 000	5.60
18 000	4.95
19 000	4.40
50°	
2 000	(218.2)
3 000	184.9
4 000	158.2
5 000	133.9
6 000	112.9
7 000	94.8
8 000	80.4
9 000	67.9
10 000	57.5
11 000	49.2
12 000	42.4
13 000	36.8
14 000	32.6
15 000	29.3
16 000	26.7
17 000	24.3
18 000	22.2
19 000	20.5
100°	
2 000	(347)
3 000	304.4
4 000	276.0
5 000	247.0
6 000	220.2
7 000	196.6
8 000	175.7
9 000	156.9
10 000	140.6
11 000	126.6
12 000	115.1

NaOH.—(*Cont'd*)

C	$10^6\kappa/C$
13 000	104.9
14 000	96.2
15 000	88.7
16 000	82.3
17 000	76.4
18 000	77.5
19 000	67.7

$NaClO_3$, 18°

C	$10^6\kappa/C$
2 000	51.7
3 000	43.5
4 000	36.1

$NaClO_4$, 18°

C	$10^6\kappa/C$
2 000	54.97
3 000	46
4 000	38.70

$NaBrO_3$, 18°

C	$10^6\kappa/C$
2 000	44.0

$\frac{1}{2}Na_2S$

C	$10^6\kappa/C$
0°	
2 000	58.8
3 000	47.5
4 000	37.0
18°	
2 000	89.7
3 000	73.5
4 000	60.5
25°	
2 000	103.2
3 000	86.0
4 000	71.0

$\frac{1}{2}NaHS$

C	$10^6\kappa/C$
0°	
2 000	35.9
18°	
2 000	56.6
25°	
2 000	65.7

NaN_3 (30, 194)

C	$10^6\kappa/C$
0°	
1 500	39.4
2 000	36.2
3 000	30.7
4 000	25.3
5 000	(20.6)
25°	
1 500	69.6
2 000	64.8
3 000	56.3
4 000	46.4
35°	
1 500	83.7
2 000	77.6
3 000	65.7
4 000	55.6

$\frac{1}{2}Na_2CO_3$, 18°

C	$10^6\kappa/C$
2 000	34.5
3 000	27.00

$NaHCO_2$, 18°

C	$10^6\kappa/C$
2 000	43.0
3 000	34.7
4 000	28.1

$NaC_2H_3O_2$, 18°

C	$10^6\kappa/C$
2 000	30.0
3 000	22.0
4 000	(15.6)
5 000	10.5

$NaC_2H_5CO_2$, 18°

C	$10^6\kappa/C$
2 000	24.8
3 000	16.63
4 000	10.89

NaCNS, 18°

C	$10^6\kappa/C$
2 000	59.7
3 000	50.7
4 000	43.64

$\frac{1}{2}Na_2SiO_3$

C	$10^6\kappa/C$
18°	
2 000	51.1
3 880	28.2
5 880	13.7
25°	
2 000	57.3

$\frac{1}{2}Na_2CrO_4$, 18°

C	$10^6\kappa/C$
2 000	46.6
3 000	37.8
4 000	30.6

KOH, 18°

C	$10^6\kappa/C$
2 000	160.6
3 000	140.4
4 000	122.0
5 000	105.6
6 000	(90.6)
7 000	77.1
9 292	51.4
10 690	39.3

$KHSO_4$, 18°

C	$10^6\kappa/C$
2 000	155.5

$\frac{1}{2}K_2S$, 18°

C	$10^6\kappa/C$
2 000	121.4
3 000	108.8
4 000	97.9
5 000	86.8
6 000	74.0
7 000	61.0
9 320	44.1
12 500	20.6

KN_3

C	$10^6\kappa/C$
0°	
2 000	56.8
3 000	53.3
35°	
2 000	108
3 000	99
4 000	92

$\frac{1}{3}KH_2PO_4$, 18°

C	$10^6\kappa/C$
2 000	17.7
3 000	16.3

$\frac{1}{3}K_2HPO_4$, 0°

C	$10^6\kappa/C$
1 500	22.3

½K_2CO_3, 18°

C	$10^6\kappa/C$
2 000	62.3
3 000	55.2
4 000	48.7
5 000	42.7
6 000	37.5
8 200	26.5
11 160	13.14

½$K_2C_2O_4$, 18°

1 293	70.7

½$KHCO_3$, 18°

1 032	36.0
2 132	32.2

$KC_2H_3O_2$, 18°

C	$10^6\kappa/C$
2 000	51.3
3 000	41.4
4 000	32.7
5 000	24.8
6 000	18.3
7 500	11.22
9 128	5.24

KCN, 18°

1 029	99.7

KCNS, 18°

2 000	86.7

⅓$K_3Fe(CN)_6$, 18°

C	$10^6\kappa/C$
2 000	75.3

¼$K_4Fe(CN)_6$, 18°

2 000	62.5

½K_2CrO_4, 18°

2 000	71.9
3 000	59.8

RbOH, 18°

2 000	168.6
3 000	148.8

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(For a key to the periodicals see end of volume)

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ELECTRICAL CONDUCTIVITY OF SATURATED SOLUTIONS OF SLIGHTLY SOLUBLE ELECTROLYTES

H. I. Schlesinger and Judith E. Wallen

Scope.—Electrolytes with solubilities less than 0.1 equivalent per liter.

Arrangement.—Table 1 gives both the conductance and the solubility computed therefrom. Table 2 gives the conductance only. In each part the arrangement is alphabetical with respect to the symbol of the cation, with organic cations at the end.

Units.—Conductivities in reciprocal ohms (*see* p. 230 for cell constant basis); solubilities in equivalents per liter.

Abbreviations and Symbols.—κ_W = specific conductance of the water used.

κ_S = specific conductance of the solution, corrected for κ_W in the case of salts, uncorrected in all other cases.

S = solubility of the electrolyte as computed from the relation $S = \frac{\kappa'_S \times 10^3}{\alpha \Lambda_0}$, in which Λ_0 is the value assumed for the equivalent conductance of the completely ionized electrolyte, α is the value assumed for the "degree of ionization" (Λ/Λ_0) of the electrolyte in the saturated solution, and κ'_S is the value of κ_S after correction (where possible and necessary) for the effects of hydrolysis. No calculation of S has been attempted in cases where the use of the above relation involves assumptions of doubtful validity. S has been calculated at round values of the temperature, only where the data justified interpolation.

Nature of Crystalline Phase.—Except as otherwise indicated, the crystalline phase was prepared by precipitation methods.

TABLE 1.—ELECTROLYTES FOR WHICH BOTH CONDUCTANCE AND SOLUBILITY ARE GIVEN

Crystalline phase	t, °C	$\kappa_W \times 10^6$	$\kappa_S \times 10^6$	Λ_0	α	$S \times 10^6$	Lit.
AgCl	1.55	0.75	0.297				(9)
	4.68	1.21	.393				
	5.00		.404	84.71	1.0	4.77	
	9.66	1.22	.594	97.02	1.0		
	10.00		.611	97.91	1.0	6.24	
	10.9	1.13	.663	100.29	1.0		
	15.00		.879	111.12	1.0	7.91	
	17.33	1.28	1.067	117.27	1.0		
	17.57	1.21	1.085	117.90	1.0		
	18.00	1.16	1.119	119.04	1.0	9.40	
	18	0.56	1.259	119.04	1.0		(12)
	19.95	1.31	1.329				(1)
	20.00		1.261	124.32	1.0	10.01	(9)
	25.00		1.794	137.53	1.0	13.04	
	25.86	1.21	1.899	139.80	.999		
	33.68	2.03	3.007	160.45	.999		
AgCl.—(*Cont'd*)	34.26	1.21	3.188	161.98	0.999		(9)
	50.00	≦0.8	7.892	217	.998	36.4	(12)
	100.00	≦0.8	57.840	395.$_8$	.993	146	
	100.00	2.82	56.640	395.$_8$	.993	144	(2)
AgBr	19.96	1.23	0.057	126.36	1.0	0.42	(1)
	21.1	1.21	.075	129.42	1.0	0.54$_5$	(9)
	100.0	2.30	7.393	400.0$_4$	.999	18	(2)
$AgBrO_3$	19.94	0.93	663.24	105.9	0.954	6 564	(1)
AgI	20.8	1.14	0.002	127.45	1.00	0.013	(9)
$AgIO_3$	9.43	1.05	6.850			97.1	(9)
	10.00		7.031	71.94	0.995	98.3	
	15.00		9.828	81.72	.995	121.0	
	18.00	1.16	11.890	87.58	.995	137.0	
	18.37	1.27	12.160				
	19.95	1.32	14.04				(1)
	20.00		13.55	91.49	.994	149.0	(9)
	25.00		18.20	101.27	.993	181	
	26.60	1.60	20.00				
AgSCN	19.96	1.019	0.096	115.3	1.00	0.78	(1)
	100.0	2.43	13.89				(2)
$BaSO_4$	0.77	0.77	1.125				(9)
	5.00		1.330	85.85	0.995	15.6	
	10.00		1.664	100.14	.995	16.7	
	15.00		2.072	114.43	.995	18.3	
	17.90	1.25	2.389				
	18.00	1.25	2.398	123.0	.994	19.5	
	18.00		2.229	123.0			(12)
	20.00		2.539	128.72	.994	19.8	
	25.00		3.072	143.01	.993	21.6	
	25.00	0.68	2.997	143.01			
	25.00	1.3	2.7	143.01			(4)
	26.75	1.43	3.345				(9)
	50.00	0.8	6.44	229	.99	28.4	(12)
	100.00	.8	13.99	434	.99	32.6	
Barite	3.35	1.40	1.453	81.13			(9)
	5.00		1.576	85.84	.995	18.5	
	10.00		1.978	100.13	.994	19.9	
	15.00		2.440	114.43	.994	21.5	
	17.65	1.40	2.706	122.00			
	18.00	1.40	2.747	123.00	.994	22.4	
	20.00		2.951	128.72	.994	23.1	
	25.00		3.517	143.01	.993	24.8	
	33.27	1.40	4.680	166.64			
$BaC_2O_4.?H_2O$	2.46	2.5	32.09				(9)
	5.00		36.73	80.4	.922	495	
	10.00		47.53	94.2	.917	550	
	15.00		60.39	107.8	.912	614	
	17.38	2.5	68.35				
	18.00	2.5	70.13	116.0	.909	665	
	20.00		74.82	121.5	.907	679	
	25.00		91.62	135.1	.902	752	
	33.73	2.5	127.9				

(40) Costachescu and Apostoi, *177*, **7**: 101; 11. (41) Davis, Hughes and Jones, *7*, **85**: 513; 13. (42) Davis and Jones, *7*, **81**: 68; 13. (43) Dede, *93*, **125**: 28; 22. (44) Dhar, *93*, **85**: 44; 14. (45) Dhar, *93*, **85**: 198; 14. (46) Dittrich, *7*, **29**: 449; 99. (47) Doroschewskii and Dworzaneyk, *53*, **46**: 371, 455, 1686; 13. (47.1) Doroschewskii and Fridmann, *53*, **47**: 617; 15. (48) Dutoit, *42*, **11**: 650; 13. (49) Engér, *147*, **6**: No. 5; 25.

(50) Euler and Blomdahl, *19*, **4**: 1; 13. (51) Glover, *4*, **99**: 379; 11. (52) Goldschmidt, *7*, **70**: 627; 10. (53) Goldschmidt and Thuesen, *7*, **81**: 30; 13. (54) Goldschmidt and Weissmann, *9*, **18**: 380; 12. (55) Hägglund, *42*, **10**: 207; 11. (56) Hammond, *78*, **45**: 219; 24. (57) Hantzsch, *93*, **25**: 332; 00. (58) Hardt, *Diss.*, Braunschweig, 1901. (59) Harkins and Paine, *1*, **41**: 1155; 19.

(60) Harkins and Pearce, *1*, **38**: 2679; 16. (61) Hartley, Thomas and Applebey, *4*, **93**: 538; 08. (62) Heyrovsky, *135*, **125**: 198; 22. (63) Heyrovsky, *4*, **117**: 1013; 20. (64) Hümi, *Diss.*, Zürich, 1910. *10*, **1**: 487; 10. (65) Irvine and Steele, *4*, **107**: 1221; 15. (66) Jones and Davis, *152*, **No. 180**: 179; 13. (67) Jones and Guy, *152*, **No. 180**: 153; 13. (68) Jones and Hartmann, *78*, **30**: 295; 16. (69) Jones and Kreider, *152*, **No. 180**: 89; 13.

(70) Jones and Mahin, *7*, **69**: 389; 09. (71) Jones and Mahin, *152*, **No. 180**: 111; 13. (72) Jones and Schmidt, *152*, **No. 180**: 133; 13. (73) Jones and Stine, *152*, **No. 180**: 11; 13. (74) Joyner, *93*, **77**: 103; 11. (75) Kaiser, *Diss.*, Utrecht, 1914. *10*, **4**: 977; 14. (76) Kameyamu, *78*, **40**: 131; 21. (77) Kasanecki, *53*, **46**: 1125; 14. (78) Kendall and Andrews, *1*, **43**: 1545; 21. (79) Kreider and Jones, *11*, **45**: 282; 11.

(80) Kremann and Brassert, *57*, **31**: 195; 10. (81) Kremann and Hönel, *57*, **34**: 1469; 13. (82) Miles, *68*, **35**: 188; 15. (83) Millar, *7*, **85**: 129; 13. (84) Noyes, Boggs, Farrell and Stewart, *1*, **33**: 1650; 11. (85) Noyes, Hall and Beattie, *1*, **39**: 2526; 17. (86) Öholm, *60*, **55**: No. 5; 13. (87) Ordeman, *152*, **No. 260**; 18. (89) Philip and Courtman, *4*, **97**: 1261; 10.

(90) Pissarjewsky and Lemcke, *7*, **52**: 479; 05. (91) Polack, *83*, **10**: 177; 15. (92) Powell, *4*, **107**: 1335; 15. (93) Pratolongo, *22*, **22 I**: 87; 13. (94) Quartaroli, *36*, **43 I**: 97; 13. (95) Richardson and Taylor, *78*, **20**: 179; 11. (98) Rieger, *9*, **7**: 863, 871; 01. (97) Rimbach and Neizert, *93*, **52**: 397; 07. (98) Rosenheim and Bertheim, *93*, **34**: 427; 03. (99) Rosenheim and Loewenstamm, *93*, **34**: 62; 03.

(100) Russo, *36*, **44 I**: 17; 14. (101) Russo, *36*, **45 I**: 6; 15. (102) Sachanov, *53*, **46**: 88; 14. (103) Sachanov and Goncarov, *53*, **47**: 1252; 14. (104) Sandonnini, *36*, **46 II**: 205; 16. (105) Schilow, *93*, **133**: 55; 24. (105.1) Schwarz, *25*, **49**: 2538; 16. (106) Sluiter, *176*, **9**: 668; 11. (107) Stearn, *1*, **44**: 670; 22. (108) Stewart and Maeser, *1*, **46**: 2583; 24. (109) Tartar and Keyes, *45*, **13**: 1127; 21.

(110) Thompson and Hamilton, *78*, **17**: 291; 10. (111) Wagner, *57*, **34**: 931; 13. (112) Walker and Hambly, *4*, **71**: 61; 97. (113) Washburn and Strachan, *1*, **35**: 681; 13. (114) Wintgen, *93*, **74**: 281; 12. (115) Woitaschowski, *53*, **45**: 429; 13.

TRANSFERENCE NUMBERS OF ELECTROLYTES IN AQUEOUS SOLUTION

K. G. FALK

In the following tables the values given are in all cases the transference numbers of the cation multiplied by 10^3, and except as otherwise noted are with respect to water as the reference substance. Concentrations, C, are in equivalents per liter except those marked "Wt. N" which are in equivalents per kg H_2O. For theoretical discussion of the numbers and methods of weighting results obtained by the gravimetric method, *see* Noyes and Falk, *1*, **33**: 1436; 11.

Les valeurs données dans les tables suivantes sont dans tous les cas, les nombres de transport des cations multipliés par 10^3 et, à moins d'une autre indication, se rapportent à l'eau comme substance de référence. Les concentrations, C, sont exprimées en équivalents par litre, à l'exception de celles marquées "Wt. N" qui sont exprimées en équivalents par kg H_2O. Pour la discussion théorique des nombres et des méthodes d'appréciation des résultats par la méthode gravimétrique, *voir* Noyes and Falk, *1*, **33**: 1436; 11.

In den folgenden Tabellen stellen alle angegebenen Werte die Überführungszahlen des Kations multipliziert mit 10^3 dar. Sie gelten, stets, wenn nicht etwas anderes bemerkt, in Bezug auf Wasser. Die Konzentrationen, C, sind in Äquivalenten pro Liter angegeben, mit Ausnahme der Stellen, wo die Bezeichnung "Wt. N" steht, welche Äquivalente pro kg Wasser bedeutet. Die theoretischen Besprechungen der Zahlen und der Methoden zur Abschätzung der Ergebnisse nach der gravimetrischen Methode, findet man in der Abhandlung von Noyes and Falk, *1*, **33**: 1436; 11.

I valori riportati nelle tabelle seguenti rappresentano sempre il numero di trasporto del catione moltiplicato per 10^3, e, salvo indicazioni contrarie, si riferiscono all'acqua. Le concentrazioni, C, sono in equivalenti per litro, eccettuati i casi contrassegnati con "Wt. N" nei quali le concentrazioni sono espresse in equivalenti per kg di acqua. Per la discussione teorica dei numeri e circa l'apprezzamento dei risultati ottenuti col metodo gravimetrico, *vedi* Noyes and Falk, *1*, **33**: 1436; 11.

TABLE 1.—GRAVIMETRIC METHOD

Electrolyte	t, °C	$10^3 n_k$	$C \times 10^3$	Lit.
Uni-univalent electrolytes				
HF	*v.* Table 2 (7)			
HCl	*v.* Table 2 (2, 14, 22, 24, 43, 44, 45, 47, 48, 56)			
HI	25	825	60– 80	(55)
		828	80– 150	
		825	150– 250	
HNO_3	*v.* Table 2 (2, 24, 44)			
NH_4Cl	*v.* Table 2 (2, 24)			
TlCl	22	484	8– 15	(2)
$AgClO_3$	25	499	15– 25	(30)
$AgClO_4$	25	486	15– 25	(30)
$AgNO_2$	25	481	2– 8	(13)
		461	8– 15	
$AgNO_3$	*v.* Table 2 (2, 24, 25, 26, 29, 30, 41)			
$AgC_2H_3O_2$	0, 24, 28, 46, 96°C, *v.* (2, 30, 41)			
LiCl	18	*v.* Table 2		(24, 47)
	25	324	40– 60	(2)
		276	1.25 Wt. N	(59)
	97	390	40– 60	(2)
NaOH	25	201	25– 40	(2)
NaCl	*v.* Table 2 (2, 22, 24, 59, 60)			
NaBr	*v.* Table 2 (2, 24)			
$NaNO_3$	19	371	40– 60	(2)
KCl	*v.* Table 2 (2, 24, 47, 53, 56, 59)			
KBr	*v.* Table 2 (24)			
KI	25	495	40– 60	(2)
$KMnO_4$	23	441	40– 60	(2)
RbCl	22	485	40– 60	(2)
CsCl	20	492	40– 60	(2)
	25	485	1.1 Wt. N	(60)
Uni-bivalent electrolytes				
H_2SO_4	*v. also* Table 2 (2, 24, 57, 61)			
	96	696	40– 60	(2)
Tl_2SO_4	*v.* Table 2 (2, 15)			
$Ag_2S_2O_6$	0–30	396	15– 25	(30)
Ag_2SiF_6	22	525	25– 40	(30)
Na_2SO_4	*v.* Table 2 (24)			
K_2SO_4	*v.* Table 2 (24, 42)			
$Pb(NO_3)_2$	*v.* Table 2 (15)			

TABLE 1.—(*Continued*)

Electrolyte	t, °C	10^3n_k	$C \times 10^3$	Lit.
$CdCl_2$	*v. also* Table 2 (24)			
	8	433	250– 400	(2)
	25	431	40– 60	(2)
	96	525	40– 60	(2)
$CdBr_2$	*v.* Table 2 (24)			
CdI_2	*v.* Table 2 (24)			
$CuCl_2$	23	405	40– 60	(2)
$CuBr_2$	25	445	150– 250	(8)
$MnCl_2$	18	387	40– 60	(2)
$CoCl_2$	18	404	40– 60	(2)
$CoBr_2$	25	409	150– 250	(8)
$MgCl_2$	21	385	40– 60	(2)
$Ca(OH)_2$	25	214	25– 40	(2)
$CaCl_2$	*v. also* Table 2 (2, 53)			
	49	445	8– 15	(2)
	96	470	8– 15	(2)
		426	80– 150	(2)
		451	150– 250	(2)
$Ca(NO_3)_2$	18	450	2– 8	(53)
$SrCl_2$	20	433	250– 400	(2)
$BaCl_2$	*v.* Table 2 (2, 22, 24, 42)			
$Ba(NO_3)_2$	*v.* Table 2 (42)			
Cu $(C_7H_5O_3)_2$, Salicylate	25	626	10– 30	(20)
$AgC_{10}H_7SO_3$	25–30	612	8– 25	(30)
$AgC_9H_{11}SO_3$, Pseudo-cumenesulfonate	0	727	15– 25	(30)
	24	707	15– 25	(30)
	29	705	15– 25	(30)
$AgC_2H_5SO_4$	25	616	2– 8	(30)
		613	15– 25	(30)
$AgC_6H_5SO_3$	25	653	15– 25	(30)
Cobaltammine complex salts	15–20		8– 40	(31)
$(Na_2O)_x(SiO_2)_y$				(21)
Bi-bivalent electrolytes				
$CdSO_4$	*v.* Table 2 (24)			
$CuSO_4$	*v. also* Table 2 (24)			
	0	385	8– 15	(2)
		389	80– 150	
	11	316	600– 800	(22)
		304	800–1000	(2)
	50	393	80– 150	
$MgSO_4$	*v.* Table 2 (2, 22, 24)			
$CaSO_4$	18	441	2– 8	(53)

TABLE 2.—GRAVIMETRIC METHOD, BEST VALUES
For literature, *v.* Table 1

Electrolyte	t, °C	$C \times 10^3$								
		5	10	20	50	100	200	300	500	1000
HF	25			860	845	821	787	763	732	694
HCl	0	847	846	844	839	834				
	10	840	840	841						
	18	832	833	833	834	835	837	838	840	844
	30		822	822	822					
	50		801							
	76					781				
	96		748							
HNO_3	20	839	840	841	844					
NH_4Cl	0		489	489						
	18		492	492	492					
	30		495	495						
$AgNO_3$	0			461						
	18		471	471	471	471				
	25		477	477	477					
	30	481	481	481	481	481	481	481	481	
LiCl	18		332	328	320	313	304	299		
NaCl	0	387	387	387	386	385				
	18	397	397	396	393	390	385	380	374	365
	30	404	404	404	404	403				
	96				442	442	442			
NaBr	18	395	395	395						
KCl	0	493	493	493	493	492	491			
	10		495	495	495	495				
	18	496	496	496	496	495	494	493	492	490
	30	498	498	498	498	497	496			
KBr	18		495	495						
H_2SO_4	8			835	835	835				
	20			822	822	822	820	818	816	812
	32			808	808	808				
$Pb(NO_3)_2$	25				487	487				
Tl_2SO_4	25				478	476				
$CdCl_2$	18	430	430	430	430	430				
$CdBr_2$	18	430	430	430	430	429	410	389	350	222
CdI_2	18	445	444	442	396	296	127	46	3	
$CaCl_2$	20	440	432	424	413	404	395	389		
	25				418	409				
$BaCl_2$	0	439	437	432						
	16					420	408	401	391	
	25				438	427	415			
	30	445	444	443						
	50		475							
$Ba(NO_3)_2$	25				456	456	456			
Na_2SO_4	18		392	390	383					
K_2SO_4	18		494	492	490					
	25				496	494	493			
$CdSO_4$	18		389	384	374	364	350	340	323	294
$CuSO_4$	18			375	375	373	361	348	327	
$MgSO_4$	18	388	385	381	373					
	30		388	386	380					

TABLE 3.—MOVING BOUNDARY METHOD (9, 10, 11, 12, 33, 34, 34.5, 35, 36, 37, 39, 50, 51, 52)

$C \times 10^3$ / Electrolyte	20	50	100	50	100	200
	Values of 10^3n_k, 18°C			Values of 10^3n_k, 25°C		
HCl	835		835	828	832	
HNO_3*	846		855	840	844	849
NH_4NO_3					513	
NH_4Cl	492		489		490	
NH_4Br	483		481			
NH_4I	489		484			
$AgNO_3$:				466	469	
NaOH			158			
NaCl		387	383		386	
NaBr		381	376			
NaI		381	376			
$NaNO_3$					410	
KOH			257			
KCl	493		492		492	490
$KClO_3$	534		536		537	
$KClO_4$			523			
KBr	482		481		480	
					485	
$KBrO_3$	567		570		570	
KI	487		486		483	

TABLE 3.—(*Continued*)

$C \times 10^3$ / Electrolyte	20	50	100	50	100	200
	Values of $10^3 n_k$, 18°C			Values of $10^3 n_k$, 25°C		
KNO_3	502		502		501 512	
RbCl	497		494			
RbBr	495		492			
RbI	498		497			
CsCl	504		500			
CsBr	497		493			
CsI	497		497			
H_2SO_4	833		828			
$MgCl_2$		368	352			
$MgBr_2$	385	368	350			
MgI_2	388		350			
$CaCl_2$	413		398		396	
$CaBr_2$	409		396			
CaI_2	416		400			
$SrCl_2$	412		400		404	
$SrBr_2$	410		392			
SrI_2	416		393			
$BaCl_2$	435		419		416	
$BaBr_2$	422		408			
BaI_2	426		415			
K_2SO_4	488		485		479	

* 25°, $10^3C = 10$ or 20, $10^3 n_k = 838$.

TABLE 4.—ELECTROMOTIVE FORCE METHOD

Electrolyte	t, °C	$C \times 10^3$ 5	10	20	30	50	100	200	300	500	1000	Lit.
HCl	18	832	832	832	832	832	832	832				(16, 38)
	25				830							(19)
LiCl	25	341	334	327	323	318	311	304	299	293	286	(34)
NaOH	25		203	197	194	189	183	177	174	169	163	(18)
KOH	25				263	263	263	263	263	263	263	(27, 28)
KCl	25	496	496	496	496	496	496	496	496	496	496	(1, 6, 38)
KBr	25	496	496	496	496	496	496	495	491	488	485	(46)
	30	496	496	496	496	496	496	495	492	489	486	(46)
	35	496	496	496	496	496	496	495	493	491	489	(46)
H_2SO_4	25						813					(17)
$CuCl_2$	25		420	416	411	404	387	355	322	289	259	(32)
$SrCl_2$	25		424	417	412	405	393	376	360	343	306	(32)
$BaCl_2$	25		439	431	425	418	406	390	383	377	372	(32)

TABLE 5.—TRUE TRANSFERENCE NUMBERS AND RELATIVE HYDRATION VALUES

For critical review of the literature and some additional data, *see* (46.5)

Electrolyte	C, Wt. N	t, °C	Reference substance	$10^3 n_k$	Lit.
HCl	1.0–3.1	Room	Mannitol Resorcinol	844	(5)
HCl	1.0	18	Allyl alcohol	844	(56)
HCl	2.5	18		825	
KCl	0.5	18		502	
KCl	1.0	18		502	
KCl	1.4	18		498	
KCl	1.9	18		496	
KCl	2.5	18		492	
KCl	1.24	25	Raffinose	495	(59)
LiCl	1.28	25		304	
NaCl	1.21	25		383	
NaCl	1.12	25		377	(60)
CsCl	1.1	25		491	

Relative Hydration Values of the Ions

Average number of water molecules carried by the indicated ion combined as chloride as it moves through the solution.

HCl: $N_w^{H+} = 0.28 \pm 0.04 + 0.185 N_w^{Cl-}$.
CsCl: $N_w^{Cs+} = 0.67 \pm 0.01 + 1.03 N_w^{Cl-}$.
KCl: $N_w^{K+} = 1.3 \pm 0.2 + 1.02 N_w^{Cl-}$.
NaCl: $N_w^{Na+} = 2.0 \pm 0.2 + 1.61 N_w^{Cl-}$.
LiCl: $N_w^{Li+} = 4.7 \pm 0.4 + 2.29 N_w^{Cl-}$.

TABLE 6.—MIXTURES OF ELECTROLYTES

Electrolytes	C	Tr. No. $\times 10^3$	Lit.
KCl	0.2	Cl^-	(40)
K_2SO_4	0.2	289	
$FeCl_3$	0.14	Fe‴	(23)
HCl	0.06–0.19	384	
$FeCl_3$	0.44	Fe‴	
HCl	0.06–0.31	359	
$FeCl_3$	1.16–1.32	Fe‴	
HCl	0.50–0.60	297	
$FeCl_3$	0.16	Fe‴	
HCl	0.23	301	
$FeCl_3$	0.16	Fe‴	
HCl	0.22	313	
$FeCl_2$	0.17	Fe″	(54)
HCl	0.13	375	
$FeCl_2$	0.49	Fe″	
HCl	0.12–0.18	326	
$FeCl_2$	1.0	Fe″	
HCl	0.04–0.19	300	

Electrolytes, KCl, NaCl

Total salt concentration 0.2N; concentration ratios, KCl:NaCl	Tr. No. $\times 10^3$	Lit.	Total salt concentration 0.2N; concentration ratios, KCl:NaCl	Tr. No. $\times 10^3$	Lit.
4:1	K^+ 369 Na^+ 63	(4)	1:2	K^+ 159 Na^+ 246	(4)
3:1	K^+ 372 Na^+ 84		1:3	K^+ 129 Na^+ 239	
2:1	K^+ 337 Na^+ 109		1:4	K^+ 108 Na^+ 288	
1:1	K^+ 260 Na^+ 163				

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(For a key to the periodicals see end of volume)

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(40) Mackay, *1*, **33**: 308; 11. (41) Mather, *11*, **26**: 473; 01. (42) Noyes, *1*, **23**: 37; 01. (43) Noyes, *1*, **25**: 165; 03. (44) Noyes and Kato, *1*, **30**: 318; 08. (45) Noyes and Sammet, *1*, **24**: 944; 02. (46) Pearce and Hart, *1*, **43**: 2483; 21. (46.5) Remy, *237*, **19**: No. 2; 27. (47) Richter, *7*, **80**: 449; 12. (48) Riesenfeld and Reinhold, *7*, **68**: 440; 09. (49) Schneider and Braley, *1*, **45**: 1121; 23.

(50) Smith and MacInnes, *1*, **46**: 1398; 24. (51) Smith and MacInnes, *1*, **47**: 1009; 25. (52) Steele, *7*, **40**: 689; 02. (53) Steele and Denison, *4*, **81**: 456; 02. (54) Stepniczka-Marinkovic, *57*, **36**: 831; 15. (55) Strachan and Chu, *1*, **36**: 810; 14. (56) Straub, *Diss.*, Budapest, 1923. (57) Tower, *1*, **26**: 1039; 04. (58) Velišek, *362*, **20**: 242; 26. (59) Washburn, *1*, **31**: 322; 09.

(60) Washburn and Millard, *1*, **37**: 694; 15. (61) Whetham and Paine, *5*, **81**: 58; 08.

ELECTROLYTIC EMF

DUNCAN A. MACINNES, SPECIAL EDITOR

THE CHARACTERISTICS OF STANDARD CELLS AND OF PRIMARY CELLS

M. DEKAY THOMPSON

CONTENTS

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THE WESTON NORMAL CELL

$HgCd_{12.5\%} \mid CdSO_4.\frac{8}{3}H_2O \text{ satd.} \mid Hg_2SO_4 \text{ paste} \mid Hg$

Emf at 20°C.—(*a*) Value in **semi-absolute volts** at 20.00°C, that is, the potential which exists between the terminals of a resistance of one *international* ohm when carrying a current of one *absolute* ampere: 1.01825; average deviation of mean = 0.00002.

This value is the arithmetical mean of the results from the following references: (**1, 23, 25, 34, 50, 57, 62**).

(*b*) Value in **international volts,** when the current through the international ohm is determined by a silver coulometer, the electrochemical equivalent of silver being taken as 1.11800 milligram per coulomb as defined by the International Congress of 1908.

Value recommended by a special technical committee to the International Committee on Electrical Units and Standards: 1.0183 international volt at 20°C (**6**).

Best average value: 1.01827_4 international volt at 20°C; average deviation of mean = 0.000003.

This average value is the weighted mean from the following references, with assigned weights equal to the square root of the number of observations, since the authors do not compute the precision measure in all cases (**19, 25, 39, 40, 59, 67**); *cf.* (**58**).

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This average value is the weighted mean from the following references, with assigned weights equal to the square root of the number of observations, since the authors do not compute the precision measure in all cases (19, 25, 39, 40, 59, 67); *cf.* (58).

The Temperature Coefficient.—$E_t = E_{20} - 0.0000406(t - 20) - 0.00000095(t - 20)^2 + 0.00000001(t - 20)^3$. Adopted by the International Conference on Electrical Units and Standards at London, 1908 (76).

Construction.—Normal cells are nearly always constructed in the H-form proposed by Lord Rayleigh (17, 29, 55, 75). Recently circular forms have been constructed and studied (30, 56).

Heat of the Reaction in the Weston Cell.—$\text{Cd} + \text{Hg}_2\text{SO}_4 + \frac{8/3}{m - 8/3}\,\text{CdSO}_4.m\text{H}_2\text{O} \rightleftharpoons 2\text{Hg} + \frac{m}{m - 8/3}\,\text{CdSO}_4.8/3\text{H}_2\text{O}$, where m is the number of moles of water per mole of cadmium sulfate in the saturated solution.

The heat of this reaction is 47 561 g-cal_{15} according to thermochemical measurements, and 47 437 from the electromotive force and its temperature coefficient. These values refer to 12.5% Cd in the amalgam (8, 10).

Effect of Pressure on the Emf of the Weston Cell.—*v.* (13, 15).

Influence of Ultra-violet Light on the Emf of the Weston Cell.—*v.* (52).

Effect of Size of Grain of Mercurous Sulfate.—Weston cells made with finely divided mercurous sulfate (grain size of the order of magnitude of 5μ in diameter) have an electromotive force of 40 to 100 microvolt higher than those made with coarse mercurous sulfate (grain size 30 to 360μ). Hysteresis is greatest with coarse, white mercurous sulfate and is less for acid than for neutral cells (72); *cf.* (66, 75).

The Effect of Acidity on the Weston Cell.—For the purpose of making the Weston cell stable for a long time it is sometimes made up with 0.1N sulfuric acid (65). The emf is then 1.0182_5 international volt at 20°.

When the Weston cell is made up with acid the decrease in voltage = 0.000 855 × normality of acid (42).

TEMPERATURE COEFFICIENTS OF CELLS WITH DIFFERING AMOUNTS OF ACID

$$E = E_{20} + \alpha(t - 20) + \beta(t - 20)^2 \text{ (42)}$$

Acidity	0.07_8N	0.40_2N	0.56_6N	0.75_6N
$-10^6\alpha$	42.5	43.6	43.7	45.5
$-10^6\beta$	2.3	2.5	2.6	2.7

THE CONSTANCY OF ACID CELLS (42)

Emf at 20°C of the acid cell (standard: mean of 10 neutral cells, 1.01827 volt at 20°C)

Cell	Acidity: equivalents H_2SO_4 per liter	Date of construction	July 23, 1919	July 29	Aug. 1	Oct. 8	Nov. 4	Mar. 9, 1920	Mar. 25	Oct. 8
		1919	1.01+	1.01+	1.01+	1.01+	1.01+	1.01+	1.01+	1.01+
218	0.07_8	July 21	0.00840	0.00836	0.00830	0.00823	0.00822	0.00822	0.00822	0.00822
220	0.40_2	July 21	.00860	.00825	.00810	.00794	.00795	.00794	.00794	opened
221	0.56_6	July 21	.00807	.00802	.00783	.00781	.00780	.00781	.00780	.00780
222	0.75_6	July 21	.00777	.00782	.00772	.00763	.00763	.00761	.00762	.00763
223	0.75_6	July 21	.00732	.00738	.00733	.00761	.00763	.00761	.00763	.00761
226	0.40_2	July 25		.00818	.00809	.00797	.00798	.00794	.00795	.00794

Effect of Composition of the Amalgam on the Emf of Weston Normal Cells.—*v.* (12, 60, 61).

RELATION BETWEEN THE EMF AND THE CONCENTRATION OF THE AMALGAM IN THE WESTON CELL (64)

The emf = 1.01823 international volt + the correction given in the table. The corrections are expressed in hundred-thousandths of a volt.

t, °C	Percentage of cadmium in the amalgam							
	1	2	3	4	5	6	7	8
0	−1197	− 365	+ 35	34	35	35	36	36
5		− 580	− 32	35	36	36	37	37
10		− 798	− 246	29	29	30	30	30
15		−1024	− 464	− 79	17	17	18	18
20		−1250	− 684	− 291	− 1	− 1	0	0
25		−1483	− 910	− 507	− 186	− 24	− 24	− 23
30		−1717	−1132	− 729	− 407	−140	− 50	− 49
35		−1959	−1365	− 954	− 628	−362	− 94	− 80
40		−2202	−1594	−1184	− 853	−583	−315	−114
45		−2446	−1837	−1415	−1081	−804	−539	−296

t, °C	Percentage of cadmium in the amalgam								
	9	10	10.5	11	11.5	12	12.5	13	13.5
0	36	36	37	37	39	40	41	47	50
5	37	37	38	38	40	41	42	48	51
10	30	30	31	31	33	34	34	35	38
15	18	18	19	19	21	22	22	25	27
20	0	0	1	1	3	4	4	4	7
25	− 23	− 23	− 22	− 22	− 19	− 18	− 17	− 17	− 16
30	− 49	− 49	− 48	− 48	− 44	− 44	− 43	− 43	− 42
35	− 79	− 79	− 78	− 78	− 77	− 76	− 76	− 76	− 75
40	−114	−112	−111	−112	−112	−112	−112	−111	−111
45	−148	−146	−145	−145	−146	−145	−145	−144	−144

In the amalgams containing 14 to 20% of cadmium the initial and final values are given for each temperature.

t, °C	Percentage of cadmium in the amalgam							
	14	14.5	15	16	17	18	19	20
0	+238	330	696	486	1098	1290	1560	1610
0	249	457	673	560	1101	1295	1564	1613
5	120	329	537	428	969	1162	1419	1476
5	123	339	533	431	969	1163	1420	1476
10	59	205	390	288	830	1022	1270	1332
10	61	215	387	292	830	1023	1270	1333
15	47	89	239	149	683	870	1124	1187
15	63	115	214	244	643	870	1075	1188
20	13	19	55	72	488	717	922	1036
20	13	19	55	70	488	716	922	1035
25	− 15	− 13	0	0	327	557	760	876
25	− 15	− 13	0	0	327	555	760	877
30	− 42	− 41	− 31	− 40	162	376	594	712
30	− 42	− 41	− 32	− 40	159	372	592	710
35	− 74	− 73	− 71	− 72	− 6	204	423	539
35	− 74	− 73	− 71	− 72	− 7	197	223*	539
40	−111	−110	−108	−109	−108	30	244	361
40	−111	−110	−109	−110	−108	24	241	360
45	−145	−144	−144	−144	−144	−120	+ 60	170
45	−145	−144	−143	−144	−144	−130	+ 48	169

* *Sic!*

ELECTROMOTIVE FORCE OF THE CELL:

Cd amalg. (10%) |$CdSO_4.\frac{8}{3}H_2O$| Cd amalg. (dilute) (44, 45)

Percentage composition of the dilute amalgam	Emf at 29°C, volt	Temp. coeff., volt per °C
0.25	0.03420	+0.00051
0.50	0.02977_5	+0.00049
1.11	0.01945	+0.00045(?)
1.25	0.01612	+0.00046
1.73	0.01367	+0.00043
2.19	0.01083	+0.00043
2.83	0.00770	+0.00042
3.47	0.00511	+0.00042

Effect of Age on the Emf of the Weston Normal Cell (63).—Average change in 10 years: −0.000063 volt.

THE WESTON UNSATURATED CELLS

The unsaturated Weston cell is made with a solution saturated at 4°C. It has an average voltage of 1.0187 international volt and a temperature coefficient of less than 0.00001 volt per °C (73). Each cell is accompanied by a certificate stating its voltage.

UNSATURATED ACID WESTON CELLS

The measurements were made against three well-aged, very constant normal cells made at the National Physical Laboratory, Teddington, England. Their values were assumed to be such that the normal cells made for this investigation would have a value of 1.018054 volt at 25°C. The saturated solutions of cadmium sulfate were made with a 0.015 molal solution of sulfuric acid. The unsaturated solutions were made by adding the number of ml of this solution shown in the table to one liter of the saturated solution.

Composition of cadmium sulfate solutions, electromotive force, and temperature coefficients (71)

Solution number	Cells	Dilute acid added, ml	$CdSO_4$, per cent	Emf at 25°C, volt	$\Delta E/\Delta T$ in mmv per deg			
					15–25°	25–35°	35–40°	40–45°
1	16–20	None	43.22 ± 0.01	1.018270 ± 0.0_58	2.8	2.7	5.0	8.1
2	41–45	2.5	43.12 ± 0.03	1.018374 ± 0.0_57	2.1	2.0	4.7	7.1
3	32–25	5	43.06 ± 0.00	1.018548 ± 0.0_55	1.0	1.1	3.4	5.9
4	26–30	9	43.94 ± 0.01	1.018711 ± 0.0_413	0.1	0.0	2.5	5.4
5	31–35	11	43.90 ± 0.01	1.018788 ± 0.0_57	− 0.1	− 0.3	2.1	4.5
6	36–40	15	42.77 ± 0.04	1.018983 ± 0.0_56	− 1.3	− 1.4	0.7	3.5
7	46–50	22.5	42.63 ± 0.00	1.019343 ± 0.0_57	− 3.5	− 3.6	− 0.9	0.9
8	51–55	30	42.39 ± 0.01	1.019688 ± 0.0_414	− 5.5	− 5.5	− 3.2	−0.6
9	56–60	50	41.84 ± 0.02	1.02095 ± 0.0_43	−13	−13	−10	−8

Neutral cells did not give consistent results for temperature coefficients.

Cadmium Cells with Halide Electrolytes

Cells made in H-form. Measurements refer to an unsaturated Weston cell certified by the Reichsanstalt to have 1.0190 volt at room temperature (46).

1. Cells of the type: $HgCd_{12.5\,\%}$ | CdX_2 satd. | Hg_2X_2 paste | Hg

X	Electromotive force in volt
Cl	$E_t = 0.67180 - 0.000074(t - 18) - 0.0000015(t - 18)^2$
Br	$E_t = 0.55916 - 0.000366(t - 18) - 0.0000046(t - 18)^2$
I	$E_t = 0.41470 - 0.000362(t - 18) - 0.0000003(t - 18)^2$

2. Cells of the type: $HgCd_{12.5\,\%}$ | CdX_2 soln. | Hg_2X_2 paste | Hg

The emf of these cells can be represented by the formula

$$E_{18} = a \log N + b,$$

where N is the number of moles of CdX_2 per liter and a and b are constants:

X	a	b
Cl	−0.04306	0.7017
Br	−0.03953	0.58364
I	−0.03162	0.43338
$\frac{1}{2}SO_4$	−0.02501	1.05125

The Clark Cell

$HgZn_{10\,\%}$	$ZnSO_4.XH_2O$ satd. X = 7 below 39°; = 6 above 39°	Hg_2SO_4 paste	Hg

Emf at 15°C = 1.4328 int. volt (1, 3, 24, 29, 75).

The Chicago International Electrical Congress of 1893 adopted the value 1.434 international volt as the electromotive force of the Clark Cell at 15°C.

The Temperature Coefficient of the Clark Cell.—$E_t = E_{15} - 0.00119(t - 15) - 0.000007(t - 15)^2$ (31, 32).

Heat of the Reaction in the Clark Cell.—See (9, 51).

THE INFLUENCE OF PRESSURE ON THE EMF OF THE CLARK CELL (11, 13, 14, 15, 18)

t, °C	Emf at				
	1 atm.	500 atm.	1000 atm.	1500 atm.	
	First series				
25.0	1.41974	1.42608	1.43223	1.43820	$ZnSO_4.7H_2O$
30.0	1.41368	1.42019	1.42604	1.43168	
35.0	1.40625	1.41290	1.41892	1.42452	
38.0	1.40147	1.40812	1.41427	1.41987	
39.5		1.40566	1.41183	1.41748	
42.0			1.40772	1.41346	
42.5				1.41255	
45.0	1.39400	1.39938	1.40479	1.40983	$ZnSO_4.6H_2O$
50.0	1.38826	1.39387	1.39920	1.40436	
55.0	1.38213	1.38800	1.39338	1.39854	
	Second series				
35.0	1.40625	1.41271	1.41880	1.42452	$ZnSO_4.7H_2O$
42.5				1.41255	
45.0		1.39946	1.40479	1.40982	$ZnSO_4.6H_2O$
50.0	1.38820	1.39383	1.39910	1.40420	
55.0	1.38210	1.38780	1.39314	1.39839	

Temperature Coefficient of the Emf

For cells containing $ZnSO_4.7H_2O$

$P_{atm.}$

1.......... $E_1 = 1.43701 - 0.0_3221t - 0.0_4188t^2$

500.......... $E_{500} = 1.44105 - 0.0_4840t - 0.0_4206t^2$

1000.......... $E_{1000} = 1.44993 - 0.0_3263t - 0.0_4178t^2$

1500.......... $E_{1500} = 1.46025 - 0.0_3528t - 0.0_4140t^2$

For cells containing $ZnSO_4.6H_2O$

1.......... $E_1 = 1.42811 - 0.0_3407t - 0.0_578t^2$

500.......... $E_{500} = 1.43277 - 0.0_3418t - 0.0_572t^2$

1000.......... $E_{1000} = 1.44475 - 0.0_3681t - 0.0_546t^2$

1500.......... $E_{1500} = 1.44331 - 0.0_3429t - 0.0_570t^2$

The Helmholtz Cell

Zn | $ZnCl_2$ soln., sp. gr. 1.391 | Hg_2Cl_2 | Hg

The reaction is: $Zn + Hg_2Cl_2 = ZnCl_2$ in soln. + 2 Hg; $E_t = 1 + 0.000094(t - 15)$ volt (7, 27, 49).

The Mercury Oxide Cell

Zn | 10% soln. of $ZnSO_4$ | HgO | Hg

The reaction is probably: $Zn + HgO = ZnO + Hg$, which may be followed by secondary reactions; $E_t = 1.390 - 0.0002(t - 12)$ (7, 22).

The Lead Chloride Cell

HgZn | $ZnCl_2$ soln., sp. gr. 1.157 | $PbCl_2$ | Pb

The reaction is: $Zn + PbCl_2 = ZnCl_2$ in solution + Pb; $E = 0.5$ volt, temperature coefficient negligible (2).

The Cu-Hg Cell

$HgCu_{1.5\text{ to }6\%}$ | $CuSO_4.5H_2O$ satd. | Hg_2SO_4 | Hg (41)

$E_t = 0.3497_9 - 0.000635(t - 20) - 0.0000024(t - 20)^2$ volt

Total energy of the reaction from emf, 103.5 kj; from thermochemical data, 103.0 kj.

The same cell containing 10 to 12% copper in the amalgam, $E_t = 0.3500 - 0.00064(t - 20) - 0.0000025(t - 20)^2$.

Total energy change of the reaction from thermochemical data, 104.0; from emf, 104.1_5 kj (47).

The Pb-Hg Cell

Cells of the type:

$HgPb_{x\%}$ | $PbSO_4$ solid | Soluble sulfate | Hg_2SO_4 solid | Hg (37)

Soluble sulfate	x, %	Observed emf, volt at 25°	Average variation of single cell, volt
$Na_2SO_4.10H_2O$*....	3.08 to 3.23	0.96466	0.00002
K_2SO_4............	3.02	1.0300 to 1.0260	0.01
$Li_2SO_4.H_2O$........	2.98	0.9615 to 0.9620	0.001
$MgSO_4.7H_2O$......	2.84	0.9600 to 0.9610	0.001
$NiSO_4.7H_2O$.......	3.50	0.96466	0.00001
$CuSO_4.5H_2O$.......	3.16	0.3489	0.0003
$CdSO_4.\frac{8}{3}H_2O$.......	3.58	0.9520 to 0.9540	0.0012
$ZnSO_4.7H_2O$.......	3.56	0.96480	0.00001
$MnSO_4.5H_2O$......	3.39	0.96478	0.00001

* For other temperatures: $E_t = E_{25} + 0.000174(t - 25) + 0.00000038(t - 25)^2$. The total energy of the reaction is calculated to be 176.5 kj from electromotive force; 175.0_5 from thermochemical data.

Low-Voltage Normal Cells (43)

				$E_{20°}$, volt
(*a*) $HgCd_{10\%}$.....	$CdBr_2.4H_2O$	$PbBr_2$	$HgPb_{10\%}$	0.14506
(*b*) $HgCd_{10\%}$.....	$CdCl_2.2\frac{1}{2}H_2O$	$PbCl_2$	$HgPb_{10\%}$	0.14186
(*c*) $HgCd_{10\%}$.....	CdI_2	PbI_2	$HgPb_{10\%}$	0.09835
(*d*) $HgCd_{10\%}$.....	$CdSO_4.\frac{8}{3}H_2O$	$PbSO_4$	$HgPb_{10\%}$	0.08861
(*e*) Cd...........	$CdSO_4$		$HgCd_{10\%}$	0.05160
(*f*) Cd...........	CdI_2		$HgCd_{10\%}$	0.05156
(*g*) Cd...........	$CdCl_2$		$HgCd_{10\%}$	0.05135
(*h*) Cd...........	$CdBr_2$		$HgCd_{10\%}$	0.05012
(*i*) $HgCd_{10\%}$.....	$CdSO_4.\frac{8}{3}H_2O$		$HgCd_{0.5\%}$	0.02980

Temperature coefficient: $E_t = E_{20} + \alpha(t - 20) + \beta(t - 20)^2$, volt.

Combination	α	β
(*a*)	-0.00037_0	-0.00000_5
(*b*)	-0.00020_0	-0.00000_3
(*c*)	$+0.00024_5$	-0.00000_1
(*d*)	$+0.00054_8$	-0.00000_4
(*e*)	-0.00024_2	0
(*f*)	-0.00024_8	0
(*g*)	-0.00024_8	0
(*h*)	-0.00022_8	0
(*i*)	+0.00050	

Cells of the combinations (*b*) and (*c*) are most reproducible and are constant for a long period.

The LeClanché Dry Cell

Cells 2.5 × 6 in. (63 × 152 mm) are designated as No. 6. Smaller cells are designated as follows (5)

Designation*	Diameter, inches	Height, inches	Diameter, mm	Height, mm
A...............	$\frac{5}{8}$	$1\frac{7}{8}$	16	48
B...............	$\frac{3}{4}$	$2\frac{1}{8}$	19	54
C...............	$\frac{15}{16}$	$1\frac{13}{16}$	24	46
D...............	$1\frac{1}{4}$	$2\frac{1}{4}$	32	57
E...............	$1\frac{1}{4}$	$2\frac{7}{8}$	32	73
F...............	$1\frac{1}{4}$	$3\frac{7}{16}$	32	87

* Includes flat cells of equivalent capacity.

The voltage requirements are those in the following table when measured with a voltmeter of not less than 100 ohm per volt, and having not less than 50 divisions of its scale per volt.

Designation	Nominal dimensions of cell		Minimum voltage
	Diameter, mm	Height, mm	
No. 6...............			1.50
F...................	32	87	1.50
E...................	32	73	1.50
D...................	32	57	1.50
C...................	24	46	1.49
B...................	19	54	1.48
A...................	16	48	1.47

For additional data, *v.* (5).

The electromotive force of the manganese dioxide electrode of dry cells is determined by the hydrogen ion concentration, in the case of Caucasian, Brazilian, and domestic ores. For a tenfold increase in hydrogen ion concentration the electrode potential increases from 0.06 to 0.08 volt. Chemically prepared dioxide is apparently free from this concentration effect (28).

Assumed Reactions of the LeClanché Cell

Negative pole: $Zn + 2\mathbf{F} + 2Cl^- = ZnCl_2$.

Positive pole:

$$2NH_4^+ + 2MnO_2 = 2NH_3 + H_2O + Mn_2O_3 + 2\mathbf{F}$$
$$2NH_3 + ZnCl_2 = Zn(NH_3)_2Cl_2$$

Other oxides of manganese probably form.

Net reaction: $Zn + 2NH_4Cl + 2MnO_2 = Zn(NH_3)_2Cl_2 + Mn_2O_3 + H_2O$.

The reaction at the positive pole may also be considered to take place as follows (20, 36, 68):

$$MnO_2 + 2H_2O \rightleftharpoons Mn^{++++} + 4OH^-$$
$$Mn^{++++} = Mn^{++} + 2\mathbf{F}$$
$$Mn^{++} + 2OH^- = Mn(OH)_2$$

Net reaction: $MnO_2 + 2H_2O = Mn(OH)_2 + 2OH^- + 2\mathbf{F}$.

Effects of Temperature on Dry Cells (4)

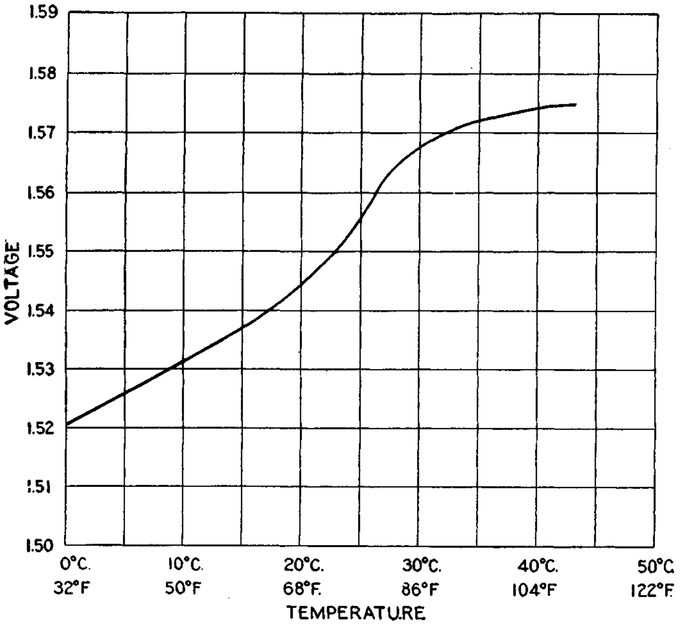

Fig. 1.—Effect of temperature on open-circuit voltage of dry cells.

Mean of measurements on 16 cells, No. 6 size, paper-lined construction, including four different brands. The cells were kept at fixed temperatures 24 hours before being measured.

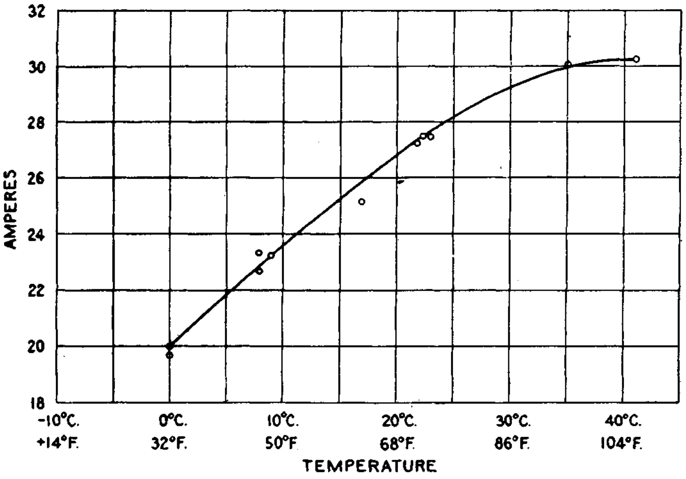

Fig. 2.—Effect of temperature on short-circuit current.

Mean values for a group of six cells maintained at each of the temperatures indicated for at least 24 hours prior to the measurements. The temperatures were taken in the following order; 22, 0, 22.5, 8, 0, 21.8, 35, 41, 8, 16.8, and 9°C.

Effect of Temperature on the Short-Circuit Current of Dry Cells Stored for 10 Weeks on Open Circuit (Pritz (53))

Temperature of storage, °C	Percentage decrease in short-circuit current at end of 10 weeks	Temperature of storage, °C	Percentage decrease in short-circuit current at end of 10 weeks
5	4.4	55	52.0
25	10.0	65	71.0
35	19.0	75	98.0
45	25.0		

Recent experiments show that the measurements of Pritz for cells stored at 25°C are approximately correct for dry cells when new, but the rate of decrease of short-circuit current becomes less as the age of the cell increases; the total decreases during a year at room temperature being about 25%.

Hours of Service of No. 6 Dry Cells Discharged to 0.5 Volt at Various Rates and Temperatures (48, 53)

Temp., °C	Service at various resistances of external circuit in ohms			
	2 ohm, hr	4 ohm, hr	8 ohm, hr	16 ohm, hr
0	40	80	270	560
25	60	94	260	700
50	70	160	350	650
75	65	158	315	615

Hours of Service of Dry Cells, No. 6 Size, Discharged to 0.6 Volt at Fixed Rates of Current and at Various Temperatures

Average of results of tests made on three standard makes of dry cells of paper-lined construction

Temp., °C	Service at various rates of discharge in ampere				
	0.1 amp., hr	0.25 amp., hr	0.50 amp., hr	0.75 amp., hr	1.00 amp., hr
0	136	40	14	7	5
25	220	64	24	13	9
40	300	94	31	18	11

Initial Working Voltage of No. 6 Dry Cell (21)

Ohm resistance of circuit	Corresponding ampere drain	Initial working voltage	Ohm resistance of circuit	Corresponding ampere drain	Initial working voltage
0.00	42.9*	0.00*	4	0.370	1.48
.01	32.0*	.32*	8	.185	1.48
.02	26.5*	.53*	16	.092	1.48
.04	18.5*	.74*	32	.046	1.48
.08	12.0*	.96*	64	.023	1.49
$\frac{1}{8}$	8.8	1.10	128	.0117	1.50
$\frac{1}{4}$	5.1	1.28	256	.0059	1.52
$\frac{1}{2}$	2.76	1.38	512	.0030	1.52
1	1.45	1.45	∞	.0000	1.53
2	0.735	1.47			

* Estimated by extrapolation.

LeClanché Dry Cell.—(*Continued*)

HOURS OF SERVICE FOR NO. 6 PAPER-LINED DRY CELL AT ROOM TEMPERATURE, THROUGH CONSTANT RESISTANCE (21)

Figures in parentheses are interpolated

Cell discharged	Cut-off voltage	Total life in hours for various ohms resistance of circuit, ohm														
		$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{2}$	1	2	4	8	16	32	64	128	256	512	1024	1792
Continuously (1)	1.2		0.02	0.13	0.70	2.2	9.1	47	115	390	1 050	2 780	4 220	6 350	7 850	9 120
	1.0	0.01	.21	.95	3.7	11.1	32.5	89	233	650	1 560	3 200	4 800	6 850	9 720	10 740
	0.8	.14	.76	2.3	7.4	20.7	53.0	119	304	740	1 750	3 350	5 100	7 300	10 200	11 500
	.6	.50	1.9	5.1	12.5	36.3	75.0	184	383	805	2 470	3 500	5 220	7 550	10 570	11 800
	.4	1.4	3.8	8.5	21.4	49.8	100.0	227	462	890	2 530	3 650	5 350	7 700	10 970	12 100
30 minutes every hour (2)	1.2				1.0	4.0	15.0	40	210	550	1 370					
	1.0			(1.1)	5.5	13.0	37.0	120	320	810	1 570					
	0.8	(0.2)	(0.8)	(3.0)	9.0	26.0	61.0	190	375	920	1 630					
	.6	(0.7)	(2.0)	(5.6)	15.5	43.0	87.0	230	420	1 000	1 680					
	.4	(1.5)	(4.0)	(9.7)	25.0	58.0	120.0	280	470	1 040	1 750					
15 minutes every hour (3)	1.2				1.0	5.0	13.0	90	240	580	1 225					
	1.0		0.17	1.2	5.0	17.0	47.0	157	370	815	1 275					
	0.8	0.31	1.0	3.0	10.5	40.0	80.0	195	445	875	1 325					
	.6	.91	2.3	5.1	16.5	74.0	100.0	223	500	920	1 370					
	.4	2.0	4.3	11.0	29.0	89.0	122.0	264	560	965	1 420					
5 minutes every hour (4)	1.2			0.18	2.5	10.5	45.0	115	292	508						
	1.0		0.34	2.0	7.5	28.0	75.0	166	360	542						
	0.8	0.21	1.2	4.1	13.5	40.0	93.0	201	385	567						
	.6	.75	2.3	6.4	20.0	50.0	114.0	224	403	602						
	.4	1.9	4.3	11.0	33.0	62.0	128.0	236	416	625						
2 minutes every hour (5)	1.2			0.53	3.5	22.0	56.0	152	207	272						
	1.0	0.06	0.53	2.3	13.0	35.0	78.0	167	216	288						
	0.8	.28	1.3	5.4	19.5	44.0	90.0	194	224	307						
	.6	.72	3.0	10.0	28.0	59.0	103.0	209	231	333						
	.4	1.8	6.0	15.0	36.0	68.0	109.0	217	240							
½ minute every hour (6)	1.2			2.0	8.7	22.0	42.0	70								
	1.0		1.6	6.0	15.7	29.0	46.0	76								
	0.8	0.80	3.7	8.5	17.7	31.0	48.0	80								
	.6	1.9	6.5	12.0	20.0	33.0	50.0	82								
	.4	5.2	10.3	16.0	23.0	36.0	52.0	85								
5 minutes every 10 minutes (7)	1.2			0.14	1.5	5.0	20.0	40	220	530	1 280	2 550				
	1.0		0.42	1.3	6.0	14.5	45.0	115	340	795	1 580	2 800				
	0.8	0.45	1.5	3.3	9.5	28.0	70.0	170	410	930	1 670	2 850				
	.6	1.3	3.0	6.0	16.5	45.0	105.0	220	460	1 010	1 730	2 875				
	.4	2.3	4.8	9.0	26.0	60.0	135.0	270	520	1 100	1 810	3 000				
30 minutes every 6 hours (8)	1.2				1.3	15.0	40.0	107	309	460						
	1.0				9.5	29.0	75.0	137	353	505						
	0.8				17.0	40.0	93.0	186	367	545						
	.6				24.0	48.0	102.0	216	381	590						
	.4				30.0	56.0	111.0	228	395	625						
5 minutes every 6 hours (9)	1.2			0.2	4.1	17.0	56.0									
	1.0		0.24	2.9	11.2	32.0	61.0									
	0.8	0.34	1.7	6.7	16.3	37.0	63.0									
	.6	.9	3.5	10.2	21.0	42.0	65.0									
	.4	2.8	6.5	14.0	26.0	47.0	82.0									

The Féry Zinc-Carbon Cell

Similar to the LeClanché but contains no manganese dioxide. The carbon electrode is cylindrical and is made of specially prepared carbon. A horizontal plate of zinc is at the bottom of the carbon cylinder and is insulated from it. A test cell mounted in a vessel 10 cm square and 22 cm high, containing 1 liter of water + 125 g of ammonium chloride and a zinc plate weighing 160 g yielded 125 ampere hours (69).

Caustic Soda Cells

REACTIONS OF THE CAUSTIC SODA CELL (20)

Negative pole: $Zn + 2\mathbf{F} + NaOH + 2OH^- = NaHZnO_2 + H_2O$.

Positive pole: $2H^+ + 2CuO = H_2O + Cu_2O + 2\mathbf{F}$ (also: $Cu_2O + 2H^+ = H_2O + 2Cu + 2\mathbf{F}$).

Net reaction: $Zn + 2CuO + NaOH = NaHZnO_2 + Cu_2O$.

The following graphs show performance under different conditions of temperature and concentration of electrolyte (36.1).

Caustic Soda Cells.—(*Continued*)

CuO | 20 to 25% solution of NaOH covered with oil | Zn amalg.
This cell is made in capacities from 200 to 1000 ampere hours.

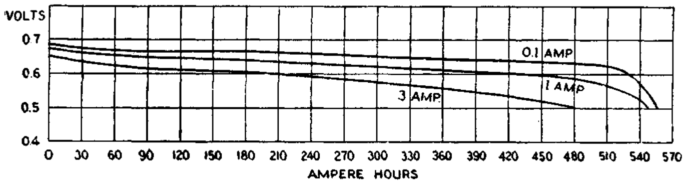

FIG. 3.—Graphs showing the voltage of a 500-ampere hour cell during discharge at 23°C. (Private Communication.)

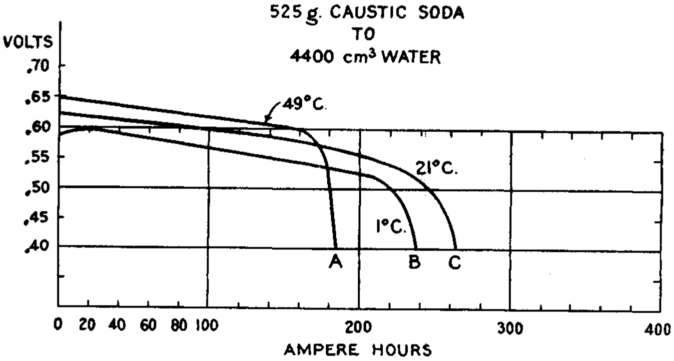

FIG. 4.—Performance of cell containing 525 g caustic soda to 4400 cm³ water. Current constant at 3 ampere.

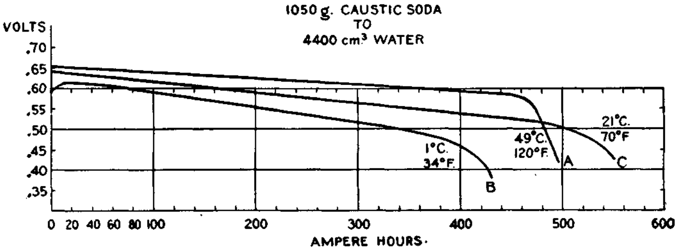

FIG. 5.—Performance of cell containing 1050 g caustic soda to 4400 cm³ water, the normal concentration. Current constant at 3 ampere.

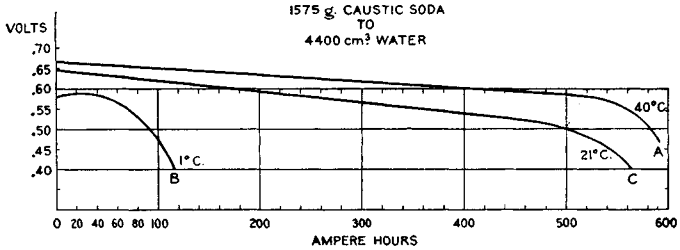

FIG. 6.—Performance of cell containing 1575 g caustic soda to 4400 cm³ water. Current constant at 3 ampere.

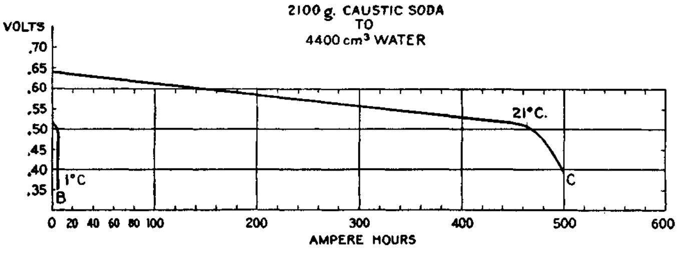

FIG. 7.—Performance of cell containing 2100 g caustic soda to 4400 cm³ water. Current constant at 3 ampere.

The Nyberg cell: Amalgamated Zn | 10% NaOH | Porous C

Voltage 1.00 to 1.18 for currents of 1 to 0.1 ampere. For a volume of 1000 cm³ and weight 1300 g the maximum capacity is 210 watt-hr (38).

The Daniell Cell

Zn | $ZnSO_4$ or H_2SO_4 soln. | $CuSO_4$ soln. | Cu

The two electrolytes are separated by a porous cup, or by difference in density in the "gravity" type of cell. *E* varies from 1.07 to 1.14 volt.

The reaction is: Zn + $CuSO_4$ in solution = $ZnSO_4$ in solution + Cu (16).

The Grove and Bunsen Cells

HgZn | 1 vol. H_2SO_4 to $12H_2O$ | Conc. HNO_3 | Pt

$E = 1.9$ to 2 volt. The two acids are separated by a porous cup.

The Bunsen cell is the Grove cell with platinum replaced by carbon.

The Poggendorff Cell

HgZn | Dil. H_2SO_4 | Conc. soln. of $Na_2Cr_2O_7$ or $K_2Cr_2O_7$ + H_2SO_4 | C

Reaction at negative pole: $3Zn + 6F + 3SO_4^{--} = 3ZnSO_4$ which is the same for all cells with zinc dipping into sulfuric acid.

At the positive pole: $Na_2Cr_2O_7 + H_2SO_4 = Na_2SO_4 + H_2O + 2CrO_3$.

$$2CrO_3 + 3H_2SO_4 + 6H^+ = 6H_2O + Cr_2(SO_4)_3 + 6F$$

Net reaction: $3Zn + 7H_2SO_4 + Na_2Cr_2O_7 = 3ZnSO_4 + Na_2SO_4 + Cr_2(SO_4)_3 + 7H_2O$.

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THE POTENTIALS OF ELECTRODE CELLS

CHARLES P. SMYTH

The term "electrode cell" as employed in this section signifies a cell whose emf is determined solely or chiefly by differences in concentration or physical condition of some atomic or molecular species in the electrode. The cells are arranged in alphabetical order of the symbols of the most important chemical element of the cell. In most instances the cell is given by literature reference only and only reversible cells have been included.

ABBREVIATIONS

Ac	Acetate radical.
E_t	Emf at t, °C.
mv	Millivolts.
M	Molal.
M_x	The element M in the amount x wt. % in the electrode.
N	Normal.
satd.	Saturated.

Le terme "electrode cell" tel qu'il est employé dans cette section, signifie une cellule dont la fem est déterminée uniquement ou principalement par les différences de concentration ou de conditions physiques d'une espèce atomique ou moléculaire, dans l'électrode. Les cellules sont arrangées dans l'ordre alphabétique des symboles de l'élément chimique le plus important de la cellule. Dans la plupart des cas, la cellule n'est donnée que par une référence bibliographique et les cellules reversibles ont seules été mentionnées.

ABRÉVIATIONS

Ac	Radical acétate.
E_t	Fem à t, °C.
mv	Millivolts.
M	Molal.
M_x	L'élément M dans la proportion x % poids dans l'électrode.
N	Normal.
satd.	Saturé.

Der Ausdruck "electrode cell," wie er in diesem Abschnitt verwendet wird, bezeichnet eine Zelle deren elektromotorische Kraft ausschliesslich oder hauptsächlich durch die Differenz in den Konzentrationen oder in den physikalischen Zustand einiger atomarer oder molekularer Stoffe in der Elektrode bestimmt ist. Die Zellen sind in alphabetischer Reihenfolge der Symbole des wichtigsten Elementes der Zelle, angeordnet. In vielen Fällen ist die Zelle nur durch die Literaturstelle angegeben und es werden nur reversible in Betracht gezogen.

ABKÜRZUNGEN

Ac	Acetat-Radikal.
E_t	Elektromotorische Kraft bei t, °C.
mv	Millivolt.
M	Molar.
M_x	Das Element M ist zu x Gew. % in der Elektrode vorhanden.
N	Normal.
satd.	Gesättigt.

Il termine "electrode cell" come viene impiegato in questo capitolo significa una cella la cui fem è determinata in modo esclusivo o per la massima parte, da differenze di concentrazione o di condizione fisica di qualche specie molecolare o atomica nell'elettrodo. Le celle sono disposte in ordine alfabetico del simbolo dell'elemento più importante delle celle stesse. Nella maggior parte dei casi la cella è indicata con la citazione bibliografica, e solo le celle reversibili sono state incluse.

ABBREVIAZIONI

Ac	Radicale acetico.
E_t	Fem a t, °C.
mv	Millivolts.
M	Molale.
M_x	L'elemento M nella quantità x in peso % nell'elettrodo.
N	Normale.
satd.	Saturo.

AQUEOUS SOLUTIONS

Ag

Ag | AgCl | 0.1*N* KCl | HgCl | Hg+
$E_{25} = 45.1 \pm 0.5$ mv; $10^3 dE/dP = (2.66 \pm 0.2)$ mv/atm. (99)
Ag(colloidal) | $AgNO_3$ | Ag(cryst.)+
$E_{25} = 25 \pm 5$ mv (92)
Ag(powder) | 0.1*N* $AgNO_3$ | Ag(compact) (62)
Ag_xPd | Ag_2SO_4 | Ag (61)
Ag_xSe or Te | *N*/7 $AgNO_3$ | Ag (68)
Ag_xSe | $AgNO_3$(satd.) | Ag (64)

Au

Au(var. treatments) | $AuCl_3$ | KCl | HgCl | Hg (28)
Au_xSn | $SnCl_4$ | $AuCl_3$ | Au (54)

Ba

Ba_xHg | $Ba(OH)_2$(satd.) | KCl | *N* KCl | HgCl | Hg (90)

Bi

$Bi_x(x = 1.6$ to $93.\dot{9}$ at. %)Hg | $Bi(NO_3)_3$ | Bi (66, 67)

Cd

Cd_xAg | *N* $CdSO_4$ | Cd (51, 90.5)
Cd_xAu | *N* $CdSO_4$ | Cd (88)
Cd_xBi | *N* $CdSO_4$ | Cd (29, 35)
Cd_xBi_yPb | *N* $CdSO_4$ | Cd (48)
Cd_xCu | *N* $CdSO_4$, *N* H_2SO_4 | Cd (68)
Cd_xHg | $CdSO_4$ | Cd_yHg

Precise determinations of E and dE/dt for a number of dilute amalgams (80, 81); *cf.* (9, 16, 38)

Cd_xHg | $CdSO_4 \cdot 8/3 H_2O$, Hg_2SO_4 | Hg (93)
v. p. 312
Cd_xHg | $CdSO_4 \cdot 8/3 H_2O$ | Cd_yHg
v. p. 312
Cd_xHg | *N* $CdSO_4$ | Cd (*v.* p. 312)
Cd_xHg | $CdSO_4$ | $Cd_{\alpha,\, \beta \text{ or } \gamma}$ (14, 15)
Cd_xPb | *N* $CdSO_4$ | Cd (29, 35)
Cd_xSb | $CdSO_4$ | Cd (44)
Cd_xSn | $CdSO_4$ | Cd (29, 35)
Cd_xTl | *M* $CdSO_4$ or TlCl(satd.) | Tl_yHg (50)

Ce

Ce_xFe | 0.3*N* $CeCl_3$, 0.2*N* $FeSO_4$ | *N* KCl | HgCl | Hg (10)
Ce_xFe | 0.3*N* $CeCl_3$, 0.2*N* $ZnCl_2$ | *N* KCl | HgCl | Hg (10)

Co

Co_xM | *N* $CoSO_4$ | Co (20, 21, 22, 23, 24, 26)
M = Ag, As, Bi, Cu, Pb, Sb

Cu

Cu_xAg | *N* $CuSO_4$ | Cu (35)
Cu_xAu | 0.5*M*[$CuSO_4$ or $Cu(NO_3)_2$] | Cu (95)
Cu_xHg | $CuSO_4$ | Cu_yHg (82, 83)
Cu_x ($x = 1$ to 16%)Hg | $CuSO_4$(satd.), Hg_2SO_4 | Hg+
$E_{25} = 347.2 \pm 0.2$ mv (11)
+$Cu_{12\%}$ Hg | $CuSO_4$(dil.) | Cu
E (mv ± 1) = 6.5 at 0°; = 5.5 at 25° (11)
Cu_xP | *N* $CuSO_4$ | Cu (37)
Cu_xPd | 0.5*M* $CuSO_4$ | Cu (61)
Cu_xSe | $CuSO_4$ | Cu (64)
Cu_xTe | *N* $CuSO_4$ | Cu (68)

Fe

Fe(var. treatments) | $FeSO_4$ | *N* KCl, HgCl | Hg

Other similar cells (1, 28, 76, 77). A magnetic field has a negligible effect upon the potential of Fe, but lowers the potential of hydrogen occluded in Fe, the amount of the lowering being approximately proportional to the intensity of the magnetic field and to the amount of the hydrogen overvoltage (84); *cf.* (74, 103).

H_2

$H_2(p)$ | 0.1N HCl | HgCl | Hg+ (33)

$p_{atm.}$	E(mv)	$p_{atm.}$	E(mv)	$p_{atm.}$	E(mv)
1.0	399.0	439.3	480.4	754.4	490.3
37.9	445.6	556.8	484.4	862.2	493.2
51.6	449.6	568.8	485.0	893.9	493.8
110.2	459.6	701.8	489.1	974.5	496.3
204.7	468.3	717.8	489.9	1035.2	497.5
386.6	478.4	731.8	489.3		

In

In_xHg | $In_2(SO_4)_3$ | In_yHg

Dilute amalgams; E ± 0.005 mv at 0 and 30° (86, 87)

Na

Na_xHg | 0.5N NaOH | Na_yHg

Dilute amalgams; values of E_{25} ± 0.08 mv and of dE/dt (78)

Ni

Ni_xCu | N $NiSO_4$ | Ni (100)

Ni_xCu | yN $NiSO_4 + (1 - y)N$ $CuSO_4$ | N KCl | HgCl | Hg (31)

Pb

Pb_xM | N $Pb(NO_3)_2$ | Pb

M = Ag, As, Bi, Cu, Hg, Pd, Pt, Sb, Te (66, 67, 68, 70, 71, 72, 73)

Pb_xBi | $PbCl_2$(satd.) | Pb

Dilute and concentrated alloys; E ± 0.2 mv at room temp. (91)

Pb_xHg | $PbAc_2$, HAc | Pb_yHg

Dilute amalgams; E ± 0.01 mv at 0 and 30° (82, 83)

Pb_xHg | $PbCl_2$ | 0.5N NaCl, 0.5N HCl | HgCl | Hg

E ± 0.1 mv at 0.2, 15.5 and 29.2° (2)

$+Pb_{5\%}$ Hg | $M_?$ [$PbAc_2$ or $Pb(ClO_4)_2$] | Pb

E_{25} = 5.7 ± 0.1 mv; dE/dt = 0.02 mv/°C (30)

Pb_xHg | $PbCl_2$(satd.) | HgCl | Hg+ (I)
$+Pb_xHg$ | $PbCl_2$(satd.) | Pb (II)
$+Pb_{1\%}Hg$ | $PbCl_2$(satd.) | $Pb_{30\%}Hg$ (III)
} (98)

x, %	Type	°C	E, mv	±	10^3dE/dP, mv/atm.
30	I	15	529.8_5	0.2	3.96 ±0.16
30	I	25	530.6_2	0.2	3.90 ±0.16
1	I	25	525.6	0.1	2.98 ±0.2
30	II	25	24.2	1	1.0 ±0.2
	III	25	7.5	0.5	0.7_2 ±0.1

Pb_xSe | $Pb(NO_3)_2$(satd.) | Pb

Also with $PbCl_2$(satd.) (64)

Sb

Sb(expl.) | $SbCl_3$ | Sb(ord.)+

E_{15} = 18 ± 1 mv (18)

Sb_xCu | $SbCl_3$, HCl | Sb (3)

Sb_xSe | 0.1N $SbCl_3$, 2N HCl | Sb (53)

Sb_xSe | $SbCl_3$, HCl | Sb

Effect of light on Sb_xSe (63, 65)

Sn

Sn(gray) | $(NH_4)_2SnCl_6$ | Sn(white) (12)

Sn_xAg | $SnCl_2$(satd.) | Sn (35)

MSn_x | N H_2SO_4 or KOH | Sn

M = Ag, As, Au, Bi, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Te, or Cu + Ag (68, 69, 70)

Sn_xBi | $SnCl_2$ | Sn (91)

Sn_xCo | N $CoSO_4$ | Co (25)

Sn_xHg | 0.5N $SnCl_2$ | Sn_yHg

0 and 30°; E ± 0.005 mv (86, 87); *cf.* (36)

Sn_xNi or Sb | $SnCl_2$ | Sn (69, 70)

Sn_xPb | Pb and Sn salts | HgCl | Hg (60)

Tl

Tl_xBi | TlCl(satd. at 15°) | Tl (50)

Tl | TlCl(satd.) | N KCl | HgCl | Hg+

E_{25} = 729.0 ± 0.1 mv; dE/dt = 0.75 mv/°C (39)

$Tl_{55\%}Hg$ | TlCl(satd.) | N KCl | HgCl | Hg+

E_{25} = 726.2 ± 0.3 mv; dE/dt = 0.71 mv/°C (39)

Tl_xHg | Tl_2SO_4 | Tl_yHg

Accurate values 0, 15, 20, 30° for wide variation of x and y (79, 85, 86, 87); *cf.* (2)

Tl_xPb | TlCl(satd.) | Tl (4, 50)

Also with Sb and Sn

Zn

MZn_x | $ZnSO_4$ | Zn

M	Lit.	M	Lit.	M	Lit.
Ag	(35, 45, 68)	Co	(27)	Ni	(101)
Ag + Pb	(45)	Cd	(68)	Pb	(29, 46)
Au	(68)	Cu	(89)	Pb + Sn	(47)
Bi	(29, 35, 49)	Fe	(102)	Sb	(35, 69)
Bi + Sb	(49)	Hg	*v. infra*	Sn	(29, 35)

Zn_xCu | N $Na_2SO_4 + yN$ $ZnSO_4 + (1 - y)N$ $CuSO_4$ | N KCl | HgCl | Hg (94)

Zn_xHg | $ZnSO_4$ | Zn_yHg

Accurate values at 0, 0.2, 12.1, 15, 25, 35, 50°; wide range of x and y (13, 19, 34, 59, 82, 83)

$+Zn_{0.6\%}Hg$ | $ZnSO_4$ / $ZnCl_2$ | $Zn_{1.2\%}Hg$

E (mv) = $6.96_4(1 + 0.00443t)$; range, t = 10 to 50° (9)

$Zn_{10\%}Hg$ | $ZnSO_4.7H_2O$, Hg_2SO_4 | Hg+

E_{25} = 1419.99 ± 0.05 mv; 10^3 dE/dP = −12.2 ± 0.3, mv/atm. (17)

$Zn_{7\%}Hg$ | $ZnCl_2$ (p %), MCl | M+ (99)

M	p, %	E_{25}, mv	±	10^3 dE/dP, mv/atm.
Ag	35.03	958.72	0.05	−1.22 ±0.2
Ag	65.59	846.6_6	0.1	−2.66 ±0.2
Hg	35.03	1005.61	0.05	+1.54 ±0.15
Hg	65.59	892.8	0.2	+0.04 ±0.03

NON-AQUEOUS LIQUIDS

$Ca_{0.0546\%}Hg$ | CaI_2 in pyridine / $CaCl_2$ in alcohol | $Ca_{0.11\%}Hg$ (5)

For similar cells in CH_3OH at 80°C, *v.* (6)

Ca_xHg | CaI_2 | $AgNO_3$ | Ag

In pyridine (7)

Cd_xBi | $CdCl_2$ in LiCl + KCl + KOH | Cd

E ± 2 mv at 431, 479, 533 and 577°; same with Sn (97)

$+K_{0.2216\%}Hg$ | KI in ethylamine | K

E_{25} = 1048.1 ± 0.3 mv; dE/dt = ± 0.272 (56)

$+Li_{0.0144\%}Hg$ | LiCl in pyridine | $Li_{0.025\%}Hg$

$E_?$ = 16.9 ± 0.2 mv; LiCl almost satd. (82, 83)

$+Li_{0.035\%}Hg$ | LiI in pyridine | Li

E_{25} = 950.2 ± 1 mv; dE/dt = 0.322; LiCl almost satd. (57)

Mg_xHg | 0.35M $MgCl_2$ | 0.35M $MgCl_2$ | HgCl | Hg

In methyl alcohol at −80°C (8)

Mg_xHg | MgI_2 | $AgNO_3$ | Ag in pyridine (8)

$+Na_{0.206\%}Hg$ | NaI in ethylamine | Na

E_{25} = 845.6 ± 0.1 mv; dE/dt = 0.0408 (58)

Na_xHg | 0.1N NaI in pyridine | Hg (41)

Na_xHg | NaOH in 95% alcohol | Hg_2O | Hg (32)

Pb_xHg | $PbBr_2$(solid) | Pb_yHg, 263 to 403°K (40)

Pb_xZn | y $ZnCl_2 + (1 - y)$ $PbCl_2$ | $PbCl_2$ | Pb, 515° (75)

$+Rb_{0.217\%}Hg$ | RbI in $C_2H_5NH_2 + NH_3$ | Rb

E_{25} = $1074._5$ ± 1 mv (55)

$Sn_xHg \mid SnCl_2$ in pyridine $\mid Sn_yHg$
    $E \pm 0.4$ mv at 25 and 50°; x, $0 - 100\%$ (36)
$Zn_xCd \mid ZnCl_2$ in $LiCl + KCl + KOH \mid Zn$
    $E \pm 0.2$ mv at 436, 464, 541 and 572° (97)
$Zn_xCu \mid ZnCl_2 \mid Zn$ (89)
$Zn_xSb \mid ZnCl_2 \mid$ Glass $\mid Zn$ (96)
$Zn_xSn \mid ZnCl_2$ in $LiCl + KCl + KOH \mid Zn$
    $E \pm 0.2$ mv at 431, 466, 537, 570° (97)

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THE EMF OF CONCENTRATION CELLS

H. S. HARNED

For the purpose of defining the scope of this section a concentration cell will be defined as one whose emf serves as a measure of the free energy change corresponding to a definite change in the activity of a molecular (or ionic) species *in the solution.*[1]

The section is divided into two parts as follows:

Part I. True concentration cells

These include all cells whose total emf is a direct measure of the free energy change. These are of two types as follows:

Type 1. Cells without transference

Example:

$$\left.\begin{matrix} H_2 \mid HCl(c_1) \mid AgCl \mid Ag \\ H_2 \mid HCl(c_2) \mid AgCl \mid Ag \end{matrix}\right\} \qquad (1)$$

or by combining

$$Ag \mid AgCl \mid HCl(c_2) \mid H_2 \mid HCl(c_1) \mid AgCl \mid Ag \qquad (2)$$

The cell reaction of cell (2) represents per faraday, the transfer of one equivalent of HCl from c_2 (activity a_2) to c_1 (activity a_1).

The equation for this cell is, $E = (RT/F) \log_e a_2/a_1$.

Type 2. Cells with transference

Example:

$$H_2 \mid HCl(c_1) \mid HCl(c_2) \mid H_2$$

The equation for this type is, $E = (nRT/F) \log_e a_1/a_2$, where n is the number of equivalents transferred from activity a_1 to a_2 per faraday.

Part II. Cells with salt bridges

Each cell listed in this group is composed of one of the standard reference electrodes joined (usually by a salt bridge) to a half cell containing the ion-species whose activity is sought. If from the total emf of such a cell, the emf of the reference electrode plus the emf's at the liquid junctions be subtracted, the result is a measure of the activity of the given ion species under the conditions which prevail in the other half of the cell.

Since the correction for liquid junction potentials is in most cases a matter of considerable uncertainty in the present state of our knowledge, these cells are listed by literature reference only.

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[1] For cells whose emf is a function of the activity of a molecular species *in the electrode*, *v.* p. 319.

ELECTRICAL AND OPTICAL PROPERTIES OF SILICA

ROBERT B. SOSMAN

Dielectric Constant (12, 16, 27, 28.1, 38, 67, 76, 79, 81, 85)

	Most probable value	Limits between which the true value certainly lies
Quartz, axis ‖ to direction of field.	4.6	4.5 and 5.0
Quartz, axis ⊥ to direction of field.	4.5	4.2 and 4.7
Difference (‖) − (⊥)............	+0.1	+0.1 and +0.4
Vitreous silica....................	3.75	3.2 and 3.9

Electrical Resistivity

Unit, ohm-cm (1, 7, 12, 16, 22, 26, 35, 39, 67, 68, 84, 86, 90)

t, °C	Quartz		Vitreous silica†			
	‖ to axis*	⊥ to axis	t, °C	ohm-cm	t, °C	ohm-cm
20	0.1×10^{15}	20×10^{15}	20	10×10^{18}	700	10×10^{6}
100	0.8×10^{12}		100	1×10^{18}	800	4×10^{6}
200	70×10^{9}		200	10×10^{15}	900	2×10^{6}
300	60×10^{6}		300	0.2×10^{12}	1000	1×10^{6}
1000	50×10^{3}	100×10^{3}	400	5×10^{9}	1100	0.7×10^{6}
1300	5×10^{3}	10×10^{3}	500	0.3×10^{9}	1200	0.5×10^{6}
			600	60×10^{6}	1300	0.4×10^{6}

* This is natural quartz, whose axial conductance is due mainly to impurities; the true axial resistivity of pure quartz is not known.

† *Cf.* Seemann (*2*, **31**: 119; 28), who finds lower values

Piezoelectric Constants of Quartz (14, 15, 18, 33, 63, 69, 73, 74)

Pressure in baryes (dynes per cm²); charge in absolute electrostatic units per cm²

d_{11} (principal coefficient).............	-69×10^{-9}
d_{14}..............................	$+17 \times 10^{-9}$

See also p. 211.

Magnetic Susceptibility (13, 41, 89, 94)

Quartz *in vacuo*, at 20°C

Volume-susceptibility, $10^6\kappa$		Mass-susceptibility, $10^6\kappa_1$	
‖ to axis	⊥ to axis	‖ to axis	⊥ to axis
−1.21	−1.20	-0.45_7	-0.45_2

Optical Constants (5, 10, 20, 25, 28, 50, 55, 64, 78, 91, 93)

Room temperature

		Low-quartz	Low-tridymite	Low-cristobalite	Vitreous silica
Indices of refraction for sodium light	$n\alpha$	1.544 (n_ω)	1.469	1.484	
	$n\beta$		1.47	Near 1.487	
	$n\gamma$	1.553 (n_ϵ)	1.473	1.487	1.459 (n)
Birefringence for sodium light ($n\gamma - n\alpha$)........		0.009	0.004	0.003 or higher	0
Constringence, ν..........		For o, 69.9 For e, 68.7			67.6
Optical character.........		Positive	Positive	Negative	
Optical orientation.......		c = $n\gamma$			
Optical character of elongation................		Positive	Negative		
Optic axial angle, $2V\gamma$....		0	35 to 43°	>90°	
Apparent optic axial angle, $2E\gamma$................		0	56 to 66°	>90°	
Optical rotatory power, α_D		21.72° per mm			0.000°

Refractive Index

AT 18°, IN AIR AT SAME TEMPERATURE (6, 9, 19, 24, 29, 30, 34, 47, 48, 49, 51, 55, 58, 60, 61, 70, 71, 76, 87, 92)

Radiating element	Wave-length in air at 15°, mμ	N_ω, quartz	N_ϵ, quartz	N, vitreous
Al......................	185.467	1.67578	1.68997	1.57436
Al......................	193.583	1.65999	1.67343	1.55999
Au......................	200.06	1.64927	1.66227	
Zn......................	202.55	1.64557	1.65842	1.54727
Au......................	204.448	1.64288	1.65562	
Au......................	211.07	1.63432	1.64671	
Cd......................	214.439	1.63039	1.64262	1.53386
Cd......................	219.462	1.62497	1.63698	1.52907
Cd......................	226.503	1.61818	1.62992	1.52308
Cd......................	231.288	1.61401	1.62559	1.51941
Au......................	242.796	1.60525	1.61650	
Au......................	250.329	1.60032	1.61139	1.50745
Cd......................	257.304	1.59622	1.60714	1.50379
Al......................	263.155	1.59309	1.60389	
Cd......................	274.867	1.58752	1.59813	1.49617
Au......................	291.358	1.58098	1.59136	
Sn......................	303.412	1.576955	1.58720	1.48594
Au......................	312.279	1.57433	1.584485	
Cd......................	325.253	1.570915	1.58095	
Cd......................	340.365	1.56747	1.577385	1.47867
Al......................	358.68	1.563915	1.573705	
Ca......................	396.848	1.55813	1.56772	1.47061
Hg......................	404.656	1.557156	1.56671	1.46968
H.......................	410.174	1.556502	1.566031	
H.......................	434.047	1.553963	1.563405	1.46690
Hg......................	435.834	1.553790	1.563225	1.46675
Cd......................	467.815	1.551027	1.560368	1.46435
Cd......................	479.991	1.550118	1.559428	1.46355
H (solar line "F")........	486.133	1.549683	1.558979	1.46318
Cd......................	508.582	1.548229	1.557475	1.46191
Mg (solar line "b_1")......	518.362	1.547651	1.556877	
Cd......................	533.85	1.546799	1.555996	1.46067
Hg......................	546.072	1.546174	1.555350	1.46013
Hg......................	579.066	1.544667	1.553791	
He......................	587.563	1.544316	1.553428	
Na (mean)..............	589.29	1.544246	1.553355	1.45845
Au......................	627.82	1.542819	1.551880	
Cd......................	643.847	1.542288	1.551332	1.45674
H (solar line "C")........	656.278	1.541899	1.550929	1.45640
He......................	667.815	1.541553	1.550573	
Li......................	670.786	1.541466	1.550483	
He......................	706.520	1.540488	1.549472	1.45517
He......................	728.135	1.539948	1.548913	
K.......................	766.494	1.539071	1.548005	
Rb......................	794.763	1.538478	1.547392	1.45340
O.......................	844.67	1.537525	1.54640	
	1000.00	1.53503	1.54381	
Hg......................	1014.06	1.53483	1.54360	
He......................	1083.03	1.53387	1.54260	
	1200.00	1.53232	1.54098	
	1300.00	1.53102	1.53962	
	1400.00	1.52972	1.53826	

Refractive Index.—(*Continued*)

Radiating element	Wave-length in air at 15°, mμ	N_ω, quartz	N_ϵ, quartz	N, vitreous
Hg	1529.61	1.52800	1.53646	
	1600.00	1.52703	1.53545	
	1800.00	1.52413	1.53242	
He	2058.20	1.51998	1.52814	
	2500.00	1.51156	1.5195	
	3000.00	1.49962	1.5070	

Change of the Refractive Indices of Quartz (per Degree, for Range 20 to 100°C) (56)

Approximate wave-length, mμ	Change of absolute index		Change of index in air	
	$10^6\Delta n_\epsilon$	$10^6\Delta n_\omega$	$10^6\Delta N_\epsilon$	$10^6\Delta N_\omega$
202	+1.29	+1.84	+2.67	+3.21
206	+0.63	+1.19	+1.98	+2.53
210	+0.08	+0.59	+1.45	+1.93
214	−0.49	−0.07	+0.83	+1.24
219	−1.05	−0.57	+0.27	+0.74
224	−1.79	−1.13	−0.48	+0.17
226	−2.04	−1.36	−0.75	−0.08
228	−2.22	−1.55	−0.93	−0.27
231	−2.41	−1.80	−1.12	−0.52
257	−3.89	−3.09	−2.65	−1.86
274	−4.44	−3.55	−3.23	−2.35
288	−5.06	−3.99	−3.85	−2.79
298	−5.34	−4.29	−4.15	−3.11
313	−5.68	−4.65	−4.50	−3.48
325	−5.87	−4.69	−4.69	−3.52
340	−6.17	−5.08	−5.01	−3.93
361	−6.40	−5.32	−5.25	−4.18
441	−7.05	−5.87	−5.93	−4.75
467	−7.15	−5.96	−6.01	−4.85
480	−7.22	−6.10	−6.10	−4.99
508	−7.29	−6.25	−6.16	−5.14
589	−7.54	−6.50	−6.42	−5.39
643	−7.64	−6.60	−6.53	−5.49

Change of Refractive Index of Vitreous Silica per Degree, for Range 20 to 100°C (52)

Radiating element	Approx. wave-length	Change of absolute index, $10^6\Delta n$	Change of index in air, $10^6\Delta N$
Al	185	23.19	24.61
Al	186	22.71	24.13
Al	193	20.80	22.17
Al	198	19.65	21.00
Zn	206	18.32	19.64
Zn	210	17.50	18.81
Cd	214	17.28	18.57
Zn	215	17.01	18.30
Cd	219	16.66	17.94
Cd	224	15.70	16.97
Cd	226	15.90	17.16
Cd	231	16.99	18.24
Cd	232	15.26	16.51
Cd	257	13.74	14.95
Cd	274	13.01	14.20
Cd	288	12.32	13.49
Cd	298	12.25	13.41
Cd	325.5	11.99	13.14
Cd	346	11.41	12.55
Cd	361	11.27	12.40
Cd	441	10.41	11.51
Cd	480	10.20	11.29
Cd	508	10.21	11.29

Vitreous Silica at Various Temperatures; Absolute Index of Refraction Calculated from Data of Rinne (71)

Temp., °C	He, blue	He, green	He, yellow	He, red
	λ = 471.315mμ	501.568	587.563	667.815
− 160	1.4635	1.4617	1.4581	1.4559
− 64	1.4641	1.4624	1.4586	1.4563
+ 18	1.4649	1.4629	1.4592	1.4569
130	1.4660	1.4642	1.4604	1.4579
235	1.4675	1.4654	1.4616	1.4591
365	1.4692	1.4672	1.4633	1.4608
475	1.4708	1.4689	1.4649	1.4625
590	1.4722	1.4703	1.4663	1.4639
1000		1.4772	1.4729	1.4706

See further p. 343.

Dispersion

Constants in the Formula: $n^2 = m + \frac{m_1\lambda^2}{\lambda^2 - \lambda_1^2} - k\lambda^2$; λ and λ_1 in μ at 18°, *in vacuo* (53, 54)

	m	m_1	λ_1	k
Quartz, n_ϵ	1.43813	0.95014	0.106692	0.01723
Quartz, n_ω (1904)	1.42919	0.93173	0.105805	0.01635
Quartz, n_ω (1906)	1.40090	0.95650	0.10495	0.01093
Vitreous, n	1.36112	0.74655	0.107044	0.01350

Effct of Temperature, Change per Degree C (54)

	$10^6\Delta m$	$10^6\Delta m_1$	$10^6\Delta\lambda_1$ in μ	Δk
Quartz, n_ϵ	67.838	−80.195	6.3200	0
Quartz, n_ω	69.390	−80.048	6.3200	0
Vitreous silica	69.400	−41.832	6.3200	0

Optical Rotation

Quartz at 20°C (2, 6, 8, 23, 31, 32, 36, 37, 45, 46, 48, 80, 82); *see also* Vol. II, p. 336

Radiating element	Wave-length in air at 15°, mμ	Deg., α/mm
Cd	226.503	201.9
Cd	231.288	190.5
Au	242.796	166.9
Au	250.329	153.9
Cd	274.867	121.10
Sn	303.412	95.02
Cd	340.365	72.45
Fe	348.534	68.585
Ca	396.848	51.115
Hg	404.656	48.945
H	410.174	47.495
H	434.047	41.924

Continued on p. 343

Refractive Index.—(*Continued from p. 342*)

QUARTZ AT VARIOUS TEMPERATURES, AS MEASURED BY RINNE AND KOLB (72) AND RECALCULATED AS ABSOLUTE INDICES

Extraordinary index, n_ϵ

Solar line	Wave length, mμ	−140°	−45°	+23°	115°	212°	305°	410°	550°	580°	650°	765°
G′ (H_γ)	434.047		1.5633	1.5634	1.5629	1.5623	1.5615	1.5598	1.5551	1.5503	1.5521	1.5532
(d)	466.8		1.5609	1.5608	1.5603	1.5597	1.5588	1.5572	1.5526	1.5478	1.5492	1.5506
F	486.133	1.5594	1.5594	1.5593	1.5589	1.5581	1.5573	1.5558	1.5512	1.5464	1.5475	1.5490
(c)	495.75		1.5587	1.5587	1.5582	1.5576	1.5567	1.5552	1.5503	1.5456	1.5468	1.5481
b_2	517.27		1.5574	1.5574	1.5568	1.5562	1.5553	1.5538	1.5488	1.5442	1.5454	1.5469
D_2	588.997	1.5541	1.5539	1.5537	1.5532	1.5526	1.5515	1.5499	1.5451	1.5405	1.5417	1.5431
α	627.8	1.5526	1.5525	1.5522	1.5517	1.5510	1.5500	1.5486	1.5437	1.5389	1.5403	1.5416
C	656.278		1.5516	1.5513	1.5508	1.5502	1.5491	1.5475	1.5427	1.5380	1.5393	1.5406
B	687.2	1.5506	1.5506	1.5504	1.5499	1.5492	1.5481	1.5466	1.5419	1.5369	1.5383	1.5397
a	718.9		1.5499	1.5495	1.5490	1.5483	1.5472	1.5458	1.5408	1.5362	1.5375	1.5388

Ordinary index, n_ω

Solar line	Wave length, mμ	−140°	−45°	$+23^{c}$	115°	212°	305°	410°	550°	580°	650°	765°
G′ (H_γ)	434.047		1.5539	1.5540	1.5536	1.5531	1.5523	1.5510	1.5469	1.5425	1.5439	1.5454
(d)	466.8		1.5515	1.5514	1.5511	1.5506	1.5498	1.5483	1.5442	1.5400	1.5414	1.5429
F	486.133	1.5504	1.5501	1.5500	1.5497	1.5491	1.5483	1.5469	1.5426	1.5385	1.5399	1.5414
(c)	495.75		1.5494	1.5494	1.5491	1.5485	1.5477	1.5465	1.5421	1.5379	1.5393	1.5406
b_2	517.27		1.5481	1.5481	1.5476	1.5472	1.5463	1.5452	1.5407	1.5363	1.5377	1.5392
D_2	588.997	1.5449	1.5448	1.5446	1.5441	1.5437	1.5428	1.5414	1.5370	1.5329	1.5341	1.5356
α	627.8	1.5434	1.5434	1.5431	1.5427	1.5422	1.5413	1.5401	1.5357	1.5314	1.5328	1.5340
C	656.278		1.5425	1.5423	1.5418	1.5414	1.5405	1.5390	1.5349	1.5304	1.5319	1.5331
B	687.2	1.5417	1.5416	1.5414	1.5410	1.5405	1.5395	1.5382	1.5337	1.5296	1.5309	1.5321
a	718.9		1.5408	1.5405	1.5401	1.5396	1.5386	1.5374	1.5327	1.5288	1.5301	1.5313

Optical Rotation.—(*Continued from p. 342*)

Radiating element	Wave-length in air at 15°, mμ	Deg., α/mm
Hg	435.834	41.548
Cd	467.815	35.601
H (solar line "F")	486.133	32.761
Cd	508.582	29.728
Hg	546.072	25.535
Na (mean)	589.29	21.724
Cd	643.847	18.023
Li	670.786	16.535
He	728.135	13.924
Rb	794.763	11.589
Hg	1014.06	6.976
	1200.00	4.889
Hg	1529.61	2.930
He	2058.20	1.527
	2500.00	0.972

CHANGE OF THE ROTATORY POWER OF QUARTZ WITH TEMPERATURE

Ratio of the measured rotation at temperature *t* to the measured rotation of the same plate at 0°C (2, 3, 31, 40, 42, 43, 57)

t, °C	α_t/α_0	*t*, °C	α_t/α_0	*t*, °C	α_t/α_0
−200	0.979	200	1.031	600	1.164
−100	0.988	300	1.050	700	1.166
0	1.000	400	1.071	800	1.167
+ 50	1.007	500	1.100	900	1.169
100	1.014	573	1.132 1.163	1000	1.171

Reflectivity

Wave-lengths of the maxima of reflection by quartz, as given by various observers (11, 44, 59, 65, 75, 77.1, 88)

Observer	Quartz, ω							
Nichols (1897)	8.42		8.80					
Rubens and Nichols	8.50		9.02				20.75	
Rosenthal (1899)	8.49		9.03					
Coblentz (1906)	8.48				12.5			
Coblentz (1908)	8.3–8.5		9.02					
Reinkober (1910)	8.40*		9.02†	9.20‡	12.52	14.55		
Trowbridge and Wood	8.41		8.90					
Liebisch and Rubens							21.0	26.0
	Quartz, ε							
Reinkober (1910)	8.40*	8.70	9.02†		12.87			
Liebisch and Rubens							19.7	27.5
	Vitreous silica							
Coblentz (1908)	8.3		8.8					
Reinkober (1910)	8.30		8.90		12.6	14.6		
Liebisch and Rubens							21.2	26.8

* Center of mass of two maxima, one at 8.35, and one at 8.50 (weak).

† Center of mass of two maxima, one at 8.90, and one at 9.05.

‡ Weak.

Verdet Constant

SODIUM LIGHT AT ROOM TEMPERATURE

Values of $10^3\omega$. $\omega = \alpha/lH$. α in minutes, *l* in cm, *H* in gilbert per cm.

Quartz, 17; vitreous, 15. Temperature coefficient about +0.01% per degree C (4, 45, 83).

DISPERSION OF THE VERDET CONSTANT

Source	Wave-length, mμ	Quartz, Verdet constant, $10^3\omega$ (4)	
		At 20°	At 96°
Cd, 25	219.462	158.66	
Cd, 18	257.304	107.90	
Cd, 9	361.25	46.17	
Cd, 6	467.815	27.50	27.72
Cd, 5	479.991	25.74	
Cd, 4	508.582	22.57	
D	589.29	16.64	16.82
Cd, 1	643.847	13.68	13.79

DISPERSION-RATIOS FOR VERDET CONSTANT OF QUARTZ

Radiating element	Wave-length, mμ	Ratio to D line			
		(4)	(21)	(45)	(37)
Cd_{25}	219.462	9.534			
Cd_{18}	257.304	6.484			
Cd_9	361.25	2.775			
Hg	404.656		2.137		
Hg	435.834		1.852	1.912	
Cd_6	467.815	1.653			
Cd_5	479.991	1.547		1.477	
Hg	491.60		1.456		
Cd_4	508.582	1.356		1.372	
Hg	546.072		1.171	1.175	
	549.5				1.158
Hg	579.066		1.041		
D	589.29	1.000	1.000	1.000	1.000
	600				0.963
Cd_1	643.847	0.822			
H	656.278		0.800		
Li	670.786			0.760	
	700				0.690
	800				0.529
	900				0.415
	1000				0.330
	1100				0.269
	1200				0.224
	1300				0.1915
	1400				0.1663
	1500				0.1444
	1600				0.1266
	1700				0.1125
	1800				0.0987
	1900				0.0869
	2000				0.0761
	2140				0.0627

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(For a key to the periodicals see end of volume)

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(50) Mallard, *191*, **13**: 161; 90. (51) Martens, *8*, **6**: 603; 01. **8**: 459; 02. (52) Martens, *88*, **6**: 308; 04. (53) Martens, *B76*, **VI.** (54) Martens and Micheli, *88*, **6**: 311; 04. (55) Merwin, *12*, **32**: 429; 11. (56) Micheli, *149*, **13**: 217; 02. *8*, **7**: 772; 02. (57) Molby, *2*, **28**: 57; 09. **31**: 291; 10. (58) Müller, *Publ. Astrophys. Obs. Potsdam*, **4**: 149; 85. (59) Nichols, *2*, **4**: 297; 97. *8*, **60**: 401; 97.

(60) Paschen, *8*, **35**: 1005; 11. (61) Pérard, *51*, **3**: 252; 22. (63) Pockels, *536*, **39**: 1; 94. (64) Ramdohr, *189*, **1920**: 33. (65) Reinkober, *8*, **34**: 343; 11. (67) Richardson, *5*, **92**: 41; 16. (68) Richardson, *5*, **92**: 101; 16. **107**:101; 25. (69) Riecke and Voigt, *8*, **45**: 523; 92.

(70) Riedel, *7*, **46**: 408; 03. (71) Rinne, *190B*, **39**: 388; 14. (72) Rinne and Kolb, *190*, **1910 II**: 138. (73) Röntgen, *8*, **18**: 213; 83. (74) Röntgen and Joffé, *8*, **41**: 449; 13. (75) Rosenthal, *8*, **68**: 783; 99. (76) Rubens, *8*, **54**: 476; 95. (77) Rubens, *76*, **1915**: 4. (77.1) Rubens and Nichols, *8*, **60**: 418; 97. (78) Schaller, *U. S. Geol. Sur., Bull.*, **640**: 125; 16. (79) Schmidt, *8*, **9**: 919; 02.

(80) Schönrock, *243*, **21**: 150; 01. (81) Schulze, *8*, **14**: 384; 04. (82) Soret and Sarasin, *149*, **8**: 5, 97, 201; 82. (83) Stierlin, *242*, **52**: 382; 07. (84) Tegetmeier and Warburg, *8*, **32**: 442; 87. (85) Thornton, *5*, **82**: 422; 09. (86) Thornton, *3*, **19**: 390; 10. (87) Trommsdorff, *Diss.*, Jena, 1901. (88) Trowbridge and Wood, *3*, **20**: 898; 10. (89) Voigt and Kinoshita, *188*, **1907**: 123. *8*, **24**: 492; 07.

(90) Warburg and Tegetmeier, *8*, **35**: 455; 88. (91) Washburn and Navias, *38*, **5**: 565; 22. (92) van der Willigen, *502*, **2**: 153; 69. **3**: 34; 74. (93) Wilson, *105*, **2**: 177; 18. (94) Wistrand, *Thesis*, Upsala, 1916.

MAGNETISM

ATOMIC AND MOLECULAR DATA IN RELATION TO THEORIES OF MAGNETISM

S. J. Barnett

A body can be magnetized either by placing it in a magnetic field or by rotating it in a neutral region (p. 347). The magnetization acquired in a magnetic field results from the superposition of two effects, either of which may practically vanish: (1) A *magnetic* effect, consisting in an alignment, more or less parallel to the applied magnetic field, of the axes of certain permanent, or approximately permanent, *magnetic elements* constituting parts of the molecules; and (2) a *diamagnetic* effect, fundamentally identical with the induction of an electric current in a conductor (88). In *diamagnetic* substances χ is negative, small, independent of H and, in many cases, independent of temperature and certain other physical conditions. *Magnetic* substances, for which χ is positive, are either *paramagnetic* or *ferromagnetic*. In *paramagnetic* substances χ is small and independent of H at ordinary temperatures and in weak fields. In *ferromagnetic* substances χ is relatively large and depends upon H, unless H is very small. When its temperature is sufficiently increased, every ferromagnetic substance becomes transformed into a paramagnetic substance. The temperature at which this change occurs is called the *temperature of transformation* or *Curie point* (Θ) for the substance. The data given in this report refer chiefly to paramagnetic and diamagnetic substances, because only a few pertinent quantitative atomic and molecular data are available for ferromagnetic substances.

SYMBOLS AND UNITS

Unless another is indicated, the basic unit in every case is the appropriate cgsm unit. Symbols which are frequently used throughout the Tables are defined in Vol. I, p. 16; those used in only a single section will be defined where used.

A	Atomic weight.
a	Constant in Langevin's equation (p. 350).
B	Number of Bohr magnetons per basal unit; $[\mu] = B[\mu]_B$.
e	Electric charge; usually, but not necessarily, it is numerically equal to the "electronic charge," $\mathbf{e}$.
H	Intensity of magnetic field.
j	Angular momentum of the body, or system, under consideration.
M	Molecular weight.
m	Mass.
$\mathbf{m}_0$	Electronic mass at low velocity.
N_0	Avogadro's number.
R	Gas constant per gram-mole.
R_0	$2\mathbf{m}_0/\mathbf{e}$.
r	Radius.
T	Absolute temperature, °K.
W	Number of Weiss magnetons per basal unit; $[\mu] = W[\mu]_W$.
Z	Atomic number.
Θ	Curie point. Temperature-constant in Weiss's relation.
$[\mu]$	Magnetic moment of the system under consideration.
$[\mu_0]$	Magnetic moment of elementary magnetic unit.
Σ	Sign of summation.
σ	Specific magnetization = magnetic moment per unit of mass.
σ_∞	Value of σ when axes of all the elementary magnetic moments are parallel.
χ	Specific susceptibility = susceptibility divided by density.

Subscripts: $_a$, $_m$ indicates the quantity is referred to the gram-atom, gram-mole. $_B$, $_W$ indicates the quantity is expressed in the Bohr magneton, the Weiss magneton, as unit moment.

Magnetons or Magnetic Elements

The term *magneton* has been applied both to the complete magnetic element within the atom or molecule, and to the ultimate magnetic units of which the element may be constituted. Of the various magnetons which have been proposed, four will be considered here; the first three are based upon theory, the fourth entirely upon experiment.

Spinning Electron (1, 32, 63, 97, 115).—The element is the rotating spherical electron. The ratio of the angular momentum (j) to the magnetic moment $[\mu]$ is $(j/[\mu])_s = m_s/e$ if the charge is distributed uniformly over the surface, and $(j/[\mu])_v = 5m_v/7e$ if the charge is distributed uniformly throughout the volume; m_s and m_v are the inertias of the electron in the two cases. If r = radius of the electron, $m_s = 2e^2/3r$. $m_v = 4e^2/5r$.

Bohr Magneton (104).—The electron is revolving in a fixed orbit; $j/[\mu_0] = 2m_0/e(\equiv R_0) = -1.13 \times 10^{-7}$ for a negative electron. On Bohr's theory, the least value of j is $\mathbf{h}/2\pi$, and the corresponding value of $[\mu_0]$ is Bohr's magneton $[\mu_0]_B = \mathbf{eh}/4\pi\mathbf{m}_0 = 9.23 \times 10^{-21}$. The Bohr gram-magneton $[\mu_g]_B$ is defined as $N_0[\mu_0]_B = 5593$ (28, 104); if there is but one such electron orbit per atom, $[\mu_g]_B = [\mu_a]_B$.

Sommerfeld Magneton (104).—On Sommerfeld's spectroscopic theory, the atomic moment of an atom is $[\mu] = gj_1[\mu_0]_B$, where g is Landé's "splitting factor," and the angular momentum of the atom is $j = j_1\mathbf{h}/2\pi$. The quantities j and g are derived from spectroscopic data, and the product gj_1 is known as the spectroscopic magneton number of the atom in the given state.

The magnetic moment of the free neutral atom of a metal may be determined directly from the effect of an intense and non-uniform magnetic field upon a high velocity stream of the vaporized metal in the atomic state (method of Gerlach and Stern) (45, 46, 47, 68, 92, 110, 137). The experimental error in the magneton number ($[\mu]/[\mu_0]_B$), so determined, ranges from 0.02 to 0.3 or 0.4.

TABLE 1.—COMPARISON OF MAGNETON NUMBERS (B) OBTAINED BY DIFFERENT METHODS (45, 46, 47, 68, 92, 110, 137)

$[\mu] = B[\mu_0]_B$; B_{GS}, B_S = value of B obtained by the Gerlach and Stern, and by the spectroscopic method, respectively

Atom....	H	Na	K	Cu	Ag	Au	Zn	Cd	Hg
B_{GS}......	1	1	1	1	1	1	0	0	0
B_S......	1	1	1	1	1	1	0	0	0

Atom..........	Tl	Sn	Pb	Sb	Bi	Te	Ni	Fe
B_{GS}..........	$\frac{1}{3}$	0	0	0	(?)	0	$\gtrless 2$	0
B_S..........	$\frac{1}{3}$	0	0	0	(?)	(?)	5	*

* Large.

Weiss Magneton (11, 50, 89, 93, 120, 126).—At very low temperatures, χ_a, for both Fe and Ni, approaches asymptotically a definite maximum as the intensity of the field is increased and the temperature is decreased. The limiting values are 1123.6×11 for Fe, and 1123.3×3 for Ni. The value 1123.5 is the magnetic moment of the gram-magneton of Weiss, $[\mu_g]_W$. At very low temperatures, the atoms of Fe and Ni contain, respectively, 11 and 3 Weiss magnetons. The moment of the elementary Weiss magneton is defined as $[\mu_0]_W = 1123.5/N_0 = 1.854 \times 10^{-21}$. Within less than the experimental error, the magnetic moments of the Weiss magnetons are ⅕ as great as those of the corresponding Bohr magnetons.

TABLE 2.—ATOMIC AND MOLECULAR MAGNETIC MOMENTS $[\mu]$ OF FERROMAGNETIC SUBSTANCES AT LOW TEMPERATURES: METHOD OF WEISS

$[\mu] = W[\mu_0]_W$

	Fe	Fe*	Fe†	Ni‡	$FeNi_2$
W.........	11.00	11.00	10.00	3.00	20.0
Lit.........	(120, 126)	(90)	(93)	(90, 120, 126)	(90)

	Fe_3Ni_2	Fe_2Ni	Co*	Co†	Fe_2Co
W.........	27.0	27.0	8.92	8.97	36.1
Lit.........	(90)	(90)	(11)	(93)	(93)

* By extrapolation from data for Ni alloys.

† By extrapolation from data for Fe-Co alloys.

‡ *See also* p. 351.

Molecular Gyromagnetic Effects

Magnetization by Rotation (Barnett) (3, 7).—In effect, each magneton is a gyrostat with a magnetic moment parallel to the axis of rotation; when a body containing magnetons is rotated, the directions of their magnetic moments tend to become parallel to the axis of rotation of the body. For a circular cylinder making n rotations per sec about its axis of figure, the resultant magnetic moment (M), so produced parallel to the axis, is $M = C\lambda n = CH$, where C is a constant, $\lambda = 2\pi j/[\mu]$, and H is the intensity of the axial magnetic field that would produce the same moment (M) without rotation; $\lambda (= H/n)$ is called the specific magnetic intensity of rotation for the substance of the rod. On the classical theory, if the magneton is an electron in a Bohr orbit, $\lambda = 2\pi j/[\mu_0] = 4\pi \mathbf{m}_0/e = 2\pi R_0 = -7.10 \times 10^{-7}$ gauss/rotation per sec. If the magneton is a spherical electron with uniform surface charge (Lorentz) spinning about a diameter, $\lambda = -3.55 \times 10^{-7}$ gauss/rotation per sec. Results of experiments are given in Table 3.

TABLE 3.—MAGNETIZATION BY ROTATION

λ = specific magnetic intensity of rotation $= 2\pi j/[\mu]$. For Bohr magneton, $j/[\mu] = R_0$; for spinning electron with surface charge, $j/[\mu] = R_0/2$. $2\pi R_0 = 4\pi \mathbf{m}_0/e = -7.10 \times 10^{-7}$ gauss/rotation per sec; unit of $\lambda(\equiv H/n) = 10^{-7}$ gauss/rotation per sec.

Material	Notes	$-\lambda$	Material	Notes	$-\lambda$
Steel	*	3.6	Heusler alloy	‡	3.62
Steel	†	3.4	Permalloy	80% Ni‡	3.78
Iron	6 rods‡	3.79	Ni-Fe	25% Ni‡	3.63
Steel			Co-Fe	35% Co‡	3.83
Nickel	2 rods‡	3.69	Co-Ni	54% Co‡	3.83
Cobalt	‡	3.84			

Weighted mean of observations (‡) of 1923, 3.76 ± 0.07.
Hence $j/[\mu] = (3.76/7.10)R_0 = 0.529R_0 = 1.06\mathbf{m}_0/e$.

* Observations of 1914, method of electromagnetic induction (3).
† Observations of 1915, method of 1914 (3).
‡ Observations of 1923, magnetometer method (7), error about 2%.

Rotation by Magnetization (Einstein and de Haas (40); *cf.* (9, 30, 39, 96, 105, 108, 109)).—This is the converse of the Barnett effect. A ferromagnetic rod is given an angular momentum about its axis by altering a magnetic field, parallel to the axis, impressed on the rod by means of a solenoid which may be either fixed to the earth or wound rigidly on the rod. The measurements permit the calculation of the ratio $j/[\mu]$ on the basis of the classical theory and the assumption that the momentum acquired by the rigid system which includes the rod is equal and opposite to the momentum given to the magnetons. For the results of the most reliable experiments, *see* Table 4.

TABLE 4.—ROTATION BY MAGNETIZATION

The value of $(j/[\mu])/R_0$ to be expected on the classical theory is unity for a Bohr magneton, and 0.5 for a spinning electron with surface charge.

Material	$(j/[\mu])/R_0$	Method*
Iron	0.50+	Bal (30)
	0.53	ACD (9)
	0.50+	ACN (109)
	0.52	ACN$_R$ (6)
Nickel	0.50+	Bal (30)
	0.57	ACD (9)
	0.50	ACN (109)
Cobalt	0.5	ACN (108)
Permalloy	0.52+	ACN$_R$ (6)
Magnetite	0.5	ACN (108)
Heusler alloy	0.50	ACN (109)

* Bal = ballistic; ACD = alternating current, deflection; ACN = alternating current, null; ACNR = alternating current, null, solenoid wound on rod; ACN$_R$ = both ACN and ACNR. Excepting ACNR, solenoid is fixed to earth. Data from (6) are preliminary.

Magnetism and Structure; *v. also* (108, 109)

Effect of Number of Electrons (*v. also* (19, 61, 62)).—(*a*) Pascal's Relation.—Pascal (82) found that for homologous elements in the 3 families of metalloids, $\chi_a(\equiv A\chi) = -Ce^{\alpha A}$, where C and α are experimental constants; later (85) he found the relation to apply to nearly all the other diamagnetic elements; *see* Fig. 1.

(*b*) Kossel's Relation (16, 64, 104).—For atoms and ions having 18 to 29 electrons external to the nucleus, Kossel observed that the magnetic moment depends primarily upon the number of electrons external to the nucleus; *e.g.*, A, K^+, and Ca^{++} have 18 such electrons each, and their moments are essentially identical (Fig. 2); removing 2 electrons from the neutral Ca atom ($Z = 20$) changes its moment to that of A ($Z = 18$). This illustrates Kossel's "displacement law." Meyer found the same relation for atoms and ions having 57 to 71 extranuclear electrons (Fig. 3).

Effect of Distribution of Electrons and Electron Orbits.—(*a*) Langevin's Theory.—On Langevin's (65) electron theory of magnetism, an ion, atom, or molecule with a completely symmetrical arrangement of electron orbits should be diamagnetic, as exemplified by the rare gases and Cu^+, Ag^+, Au^+; while an unsymmetrical arrangement should produce paramagnetism, as exemplified by Na, K, Ag, Cu, etc.

(*b*) Kossel's and Sidgwick's Theory.—On the theory of Kossel (64) and Sidgwick (102) the electropositive atoms of a saturated compound have lost all the electrons they will part with readily, and the electronegative atoms have taken up all they will take up, and in practically all cases the resulting orbital arrangement is symmetrical, and the compounds are diamagnetic. In a few cases, as in cupric compounds, the arrangement is not symmetrical, and the compound may be paramagnetic. Similarly, unsaturated compounds of diamagnetic elementary substances may be either diamagnetic like oxides of bivalent Pb and Sn, or paramagnetic like NO; *v. also* (10).

(*c*) Lewis's Theory.—On the magnetochemical theory of G. N. Lewis (69), those electrons in a molecule which are paired with one another produce a diamagnetic effect, while an unpaired electron gives a magnetic moment to the molecule, thus producing paramagnetism. In the case of solids and liquids the exact molecular state is in general unknown; but in the case of gases and dilute solutions it can be predicted that every substance with an odd number of electrons in the molecule will be paramagnetic, as exemplified by the following (111): The two odd molecules NO and NO_2 are paramagnetic, while the nitrogen oxides with even molecules are diamagnetic; ClO_2, which is odd, is paramagnetic even in dilute solution in CCl_4; the odd compound α-naphthyldiphenylmethyl in benzene solution is paramagnetic (the first case of paramagnetism in an organic compound); for additional data, *see* (111, 133).

(*d*) Welo and Baudisch's Theory.—On the theory of Welo and Baudisch (127, 128); *cf.* (10), the diamagnetism of certain salts of magnetic elements is due to the fact that the atoms of the magnetic element have, by sharing with, and transfer from, neighboring atoms, gained a sufficient number of electrons to attain the symmetrical electron configuration of a rare gas. Thus $K_4Fe(CN)_6$ is diamagnetic because each K atom contributes one electron to the Fe atom by transfer, and each CN group contributes one by sharing. Thus the Fe atom, originally possessing 26 non-nuclear electrons, gains 10 more, and assumes the structure of Kr with 36 electrons.

Effect of Crystal Structure.—Though numerous experiments, including the recent ones of Ingersoll and de Vinney on magnetic and non-magnetic Ni films (55); *cf.* (80), indicate clearly that ferromagnetism occurs only in crystalline masses, the type of crystal appears to have little significance (52, 129, 130). Thus α-, β- and δ-iron are all body-centered cubic, while γ-iron is face-centered cubic. At ordinary temperatures, Ni is face-centered cubic; Co

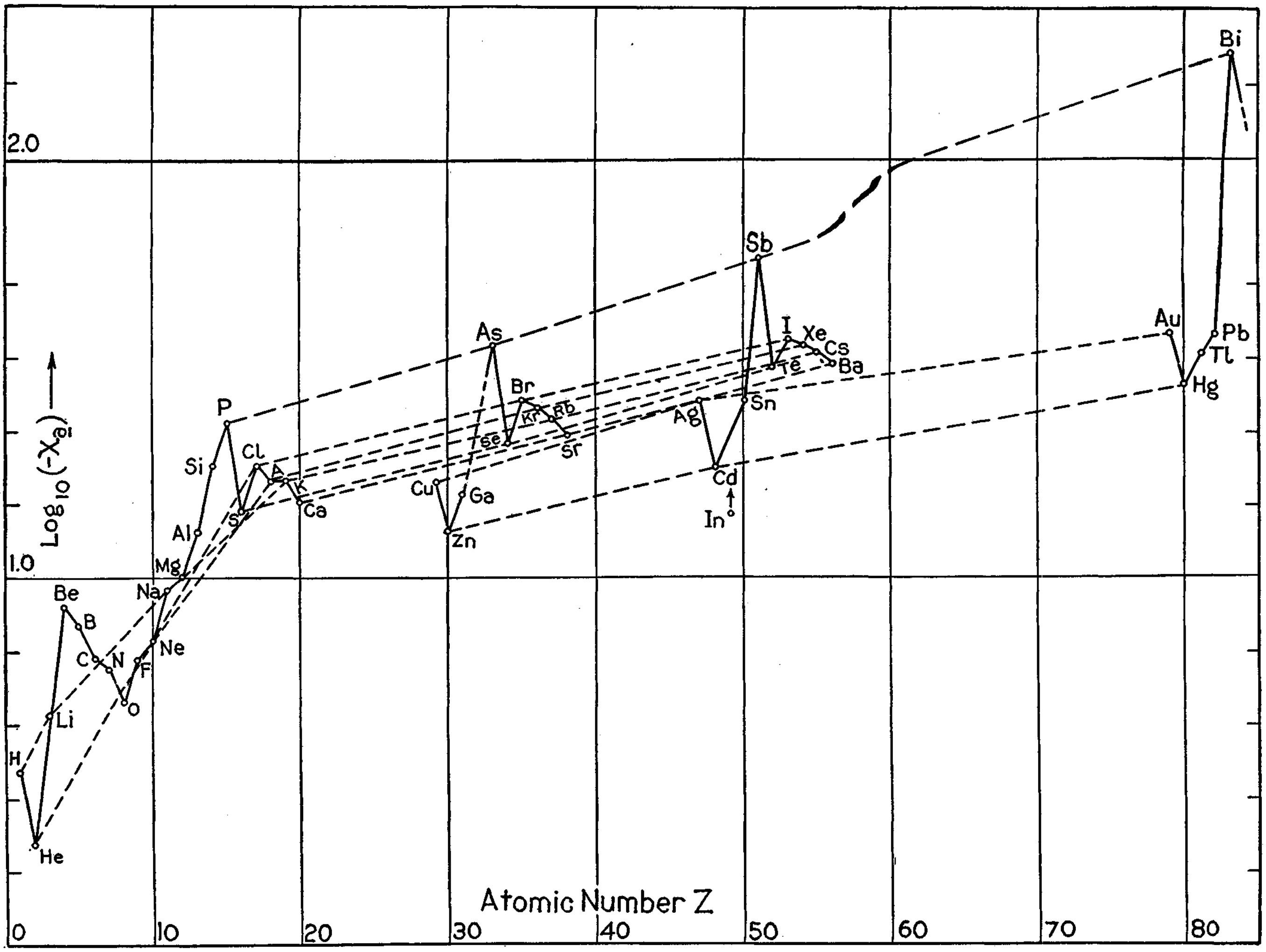

FIG. 1.—Relation between atomic susceptibility (χ_a) of diamagnetic elements and atomic number (Z) (Pascal's relation with A replaced by Z). Data for rare gases ($^{49, 134}$); *cf.* (^{10}), others from Pascal; calculations and interpolations ($^{15, 19, 32}$). Dashed (– – –) lines connect homologous elements and, for $Z > 14$, are nearly straight, as demanded by Pascal's relation (p. 347).

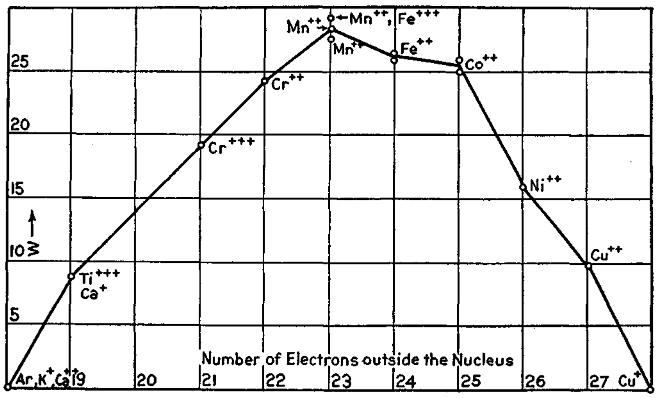

FIG. 2.

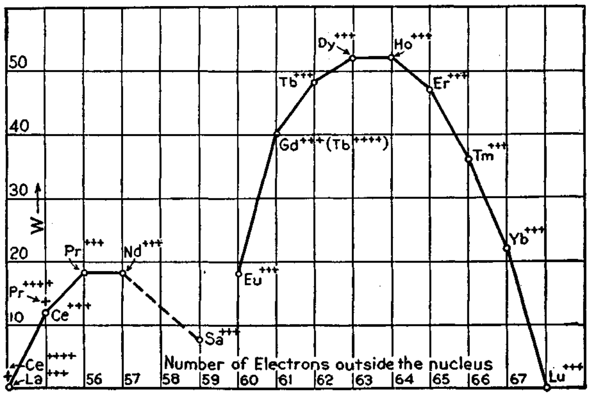

FIG. 3.

FIGS. 2, 3.—Relation between magnetic moment ($[\mu]$) of atom or ion and the number (N) of electrons external to the nucleus (Kossel's relation). $[\mu] = W[\mu_0]_W$, *i.e.*, W = number of Weiss magnetons per atom or ion. In Fig. 2, data from (^{104}); in Fig. 3, ° from (^{18}), + from (^{74}) computations assume the Langevin-Weiss theory (p. 350).

is hexagonal or face-centered cubic; pyrrhotite (Fe_7S_8), hexagonal; magnetite (Fe_3O_4), cubic; and hematite (Fe_2O_3), rhombohedric. Thermomagnetic changes in Heusler alloy are not accompanied by any change in the X-ray diffraction pattern ([139]), and the pattern of Fe-Ni alloys does not change when the composition passes through that of the extremely permeable permalloy ([2]). Paramagnetic and diamagnetic solids have a great variety of crystal forms, though in certain groups homologous elements have the same crystal structure ([10]). Magnetization may produce no change in the crystal structure ([138]); *e.g.*, Laue photographs of crystals of magnetite and of hematite are unchanged by a field of 1000 gauss ([34]), and those of Heusler alloy are unchanged by 3500 gauss ([139]), and the X-ray spectra obtained by reflection from a crystal of magnetite are not affected in any way by subjecting the crystal to a strong magnetic field ([33]); *cf.* ([138]).

Additivity Relations

Simple Additivity.—The law of additivity may be written $m\chi = \Sigma m_i\chi_i$, where m_i is the mass of a constituent i of a compound or mixture (M) of mass $m = \Sigma m_i$, and χ and χ_i are the specific susceptibilities of M and the constituent i. The summation (Σ) is extended to all constituents. For many compounds and mixtures, this law appears to be valid; for many others, the departures from it are great.

TABLE 5.—ADDITIVITY RELATION AS APPLIED TO SOLID PARAMAGNETIC HYDRATES ([43])

Some data satisfy the relation $m\chi = \Sigma m_i\chi_i$, and some do not.

χ_o = observed specific susceptibility; χ_c = specific susceptibility calculated from data in last column by subtracting the (negative) susceptibility of the H_2O lost. Error $\lesseqgtr$ 1%; unit of $\chi = 10^{-6}$ cgsm unit.

H_2O	None		$1H_2O$		nH_2O	
Salt	χ_o	χ_c	χ_o	χ_c	n	χ_o
$CuSO_4$	8.6	9.6	8.6	8.6	5	5.9
$NiSO_4$	25.5	27.8	24.1	23.8	6	15.6
$CoSO_4$	60.8	60.0	53.6	53.2	7	3.5
$Sm_2(SO_4)_3$	3.43	3.39			8	2.6
$Gd_2(SO_4)_3$	92.6	92.7			8	74.7

As applied to solutions, the law of additivity requires that the molecular susceptibility of the solute be independent of the concentration; this is known as *Wiedemann's law.* In many cases of apparent failure of Wiedemann's law, it is probable that more than one type of each of certain constituents is present and that the relative amounts of these types change with the concentration. Hydrolysis furnishes an illustration of such changes. When a salt is hydrolyzed in a solution, the value of χ for the ion, as deduced from that for the solution on the assumption that the simple additivity relation holds, commonly differs from that deduced from observations taken under other conditions. In such cases, progressive reduction of hydrolysis by addition of acid enables one to extrapolate to the condition of no hydrolysis; this extrapolated value for the ion frequently agrees with that found under other conditions of no hydrolysis ([15, 23, 41, 94]).

As applied to molecules, the additivity relation requires that the molecular susceptibility $\chi_m (\equiv M\chi)$ shall be computable from the atomic (ionic) susceptibilities of the constituent atoms (ions). Pascal so applied it, and found that consistent results could be obtained in many cases, especially of saturated organic compounds. Weiss similarly applied the relation in determining the ionic susceptibilities of metals, from the observed susceptibilities of salts and solutions; *v.* ([118]).

TABLE 6.—ATOMIC AND ATOMIC-GROUP SUSCEPTIBILITIES ([82, 83, 84])

The values given below are in general use in determining ionic susceptibilities of metals, and assume that $m\chi$ for H_2O is 13.0×10^{-6}. $m\chi$ = atomic or atomic-group susceptibility; in the former case, m = atomic weight; in the latter, m = formula weight of the group; unit of $m\chi = 10^{-6}$.

Atom	Br	C	Cl	F	H	Hg	I	K	Na	O
$-m\chi$	30.6	6.0	20.1	6.3	2.93	33.4	44.6	18.5	9.2	4.6

Atom or atom group	P	S	Se	Te	H_2O	SO_4	NO_3	NH_3	CN
$-m\chi$	26.3	15.0	23.1	37.5	13.0	33.6	14.2	14.4	10.8

Pascal's Relation ([82, 83]).—In those cases in which the application to molecules of the simple additivity relation led to inconsistent results, Pascal employed the more general equation $M\chi = \Sigma n_iA_i\chi_i + \lambda$, or its equivalent $\chi_m = \Sigma n_i\chi a_i + \lambda$, in which n_i is the number of atoms of species i and atomic weight A_i that are contained in a molecule of molecular weight M, and λ measures the deviation from the law of additivity; λ depends upon the nature of the molecule. Frequently, λ has the same value for all those organic compounds which are of similar type. Thus, if unit of χ is 10^{-7},

$$(m\chi)_{(C_6H_5Cl)} - (m\chi)_{(C_6H_5Br)} = 103$$

and

$$(m\chi)_{(CH_2ClCO_2C_2H_5)} - (m\chi)_{(CH_2BrCO_2C_2H_5)} = 107$$

while

$$(m\chi)_{Cl} - (m\chi)_{Br} = 105;$$

also

$$(m\chi)_{(C_6H_5Br)} - (m\chi)_{(C_6H_5I)} = 138$$

and

$$(m\chi)_{(CH_2BrCO_2C_2H_5)} - (m\chi)_{(CH_2ICO_2C_2H_5)} = 148$$

while

$$(m\chi)_{Br} - (m\chi)_{I} = 140;$$

the differences for the compounds are uncertain by 8 or 10 units. For values of λ, *see* Table 7.

TABLE 7.—PASCAL'S λ FOR CERTAIN BONDS IN ORGANIC COMPOUNDS

$M\chi = \Sigma n_iA_i\chi_i + \lambda$. For the saturated C_nH_{2n+2} compounds, $\lambda = 0$; unit of $\chi = 10^{-6}$ cgsm unit

Bond	λ	Bond	λ
Benzene bond	−1.5	Polyethylene bond	+10.6
Naphthalene bond	−6.1	C = O	+ 8.2
Hexamethylene bond	+3.0	C ≡ N	+ 0.8
Ethylene bond	+5.5	C ≡ N	0

TABLE 8.—EFFECTIVE ATOMIC SUSCEPTIBILITY $(\chi_a)_O$ OF O IN ORGANIC COMPOUNDS

Assumes $\lambda = 0$; unit of $(\chi_a)_O = 10^{-6}$ cgsm unit

Type of bond	$(\chi_a)_O$
Singly bound to any two atoms, —O—	−4.6
Doubly bound to a single C not carrying another O	+1.7
Doubly bound to a single C carrying a second O	−3.4

Doubly bound to any single polyvalent atom: $(a\chi_O)$ is of the same sign as for the corresponding case in which the C is the polyvalent atom.

Theories of Diamagnetism

The Weber-Langevin Theory ([65, 116]).—On this theory the magnetic moment of a diamagnetic atom in a neutral region is zero because the electron orbits are such and so arranged that the vector sum of their individual moments is zero. The orbits are assumed to be rigid, independent of T, and in general unaffected by chemical and physical changes; but *the velocities of the electrons in the orbits are changed by the application of a magnetic field.* On this last the existence of diamagnetism depends. On this theory, for an isotropic substance, or for atoms oriented at random, χ_a =

$-(e^2N_0/12\pi m_0)\Sigma n_i a_i$; a_i = area of an orbit of type i; n_i = number of such orbits per atom. Variations in χ_a may result from a *paramagnetic* relative displacement of the orbits, from distortion, due to a molecular electric or magnetic field, when a change of state occurs (69, 81, 82, 83) (Oxley (81) attributes to such fields intensities of the order of 10^7 gauss, *cf. infra*), and in the case of conductors, possibly but not certainly (67), from the presence of free electrons (99, 135).

TABLE 9.—EFFECT OF LIQUEFACTION OF DIAMAGNETIC SOLIDS: ILLUSTRATIVE (81)

If $\delta\chi/\chi$ is positive, the liquid is more diamagnetic than the solid; unit of $\delta\chi/\chi$ = 1%

Substance		$\delta\chi/\chi$	Lit.
H_2O	Water	3+	(56)
Hg	Mercury	14	(81)
C_6H_6	Benzene	0	(81)
C_6H_7N	Aniline	5	(81)
C_7H_5ClO	Benzoyl chloride	−5	(81)
C_7H_8	Toluene	5	(81)
C_8H_{10}	*o*-Xylene	5	(81)

Pauli's Theory.—On this theory (4, 86) which is applicable only to monatomic gases, diamagnetism is due to a *rotation of the complete atom* (Larmor rotation) produced by the magnetic field. For random orientation, χ_a is just twice as great as on the *Weber-Langevin* theory, *i.e.*, $\chi_a = -(e^2N_0/6\pi m_0)\Sigma n_i a_i$.

Atomic Radii

From measurements of the susceptibility of a diamagnetic substance it is possible, on the basis of either of these theories, to compute the mean of the areas of the several electronic orbits in the atom and the radius (r) of this mean area, assumed to be circular. The value obtained for r depends upon the theory applied. By the use of Bohr's theory of the atom, it is possible, in certain cases, to derive from r the radius (r_m) of the outermost orbit (19, 62). The effective atomic radius can also be obtained from viscosity and other data. For numerical values of the several r's, *see* Table 10.

TABLE 10.—ATOMIC RADII

The radii are derived as follows:

$r_w[r_p]$	From mean area of the electronic orbits as given by the Weber-Langevin [the Pauli] theory (15, 19); $r_w = r_p\sqrt{2}$.
r_m	Mean radius of outer shell of electrons, as computed by Cabrera (19) from observations of Wills and Hector (49, 134); where 2 values are given (ions of A structure) they are based on slightly different assumptions.
r_v	From measurements of viscosity; computed by Jeans (60).
r_c	From crystal data by method of Fajans and Herzfeld (42); computed by Grimm (48).
r_l	From Landé's atomic model, cubical symmetry; computed by Schwendenwein (100).
r_b	Radius of combination, Bragg (12).

Unit of $r = 1\mu\mu = 10^{-6}\mu = 10^{-10}$ cm

(1)	r_w	r_p	r_m	r_v	r_c	r_l	r_b
A	85	60	85	181	87	109	105
Ca^{++}			69, 74		67		170
Cl	92	65		168			
Cl^-			98, 92		95		105
F^-			55		75		
H	146	103		177			
He	81	57	57	111			
Hg	55	39		105			
K	84	59		159			
K^+			76, 80		79		207
Kr			103	205	97	112	
Mg^{++}			39		39		
N	76	54		146			
N^{---}			77				
Na^+			43		52		
Ne	68	48	54	111	63	74	
O	65	46		146			
O^{--}			65		89		
P^{---}			137, 111				
S^{--}			113, 101		109		102
Xe			144	242	110	126	

Theories of Paramagnetism

χ is Independent of the Temperature.—No detailed theory has been developed; *see*, however (124).

χ Varies with the Temperature.—(*a*) Langevin's Theory.—Langevin has developed a fundamental theory for gases, and on this many other theories have been based (*see infra* and p. 352). His theory leads to the relation $\sigma_a/\sigma_{a\infty}$ $(=\sigma/\sigma_\infty) = \coth a - 1/a$, where $a \equiv \sigma_{a\infty}H/RT$. If a is small, the relation becomes σ_a/H $(\equiv \chi_a) = (\sigma_{a\infty})^2/3RT = C_a/T$; or, divided by A, $\chi = C/T$, which is Curie's law (36). Curie's law is valid for O_2 both at high temperatures and (83), if density corresponds to a pressure of 100 atm. at 290°K, within the ranges 170 to 290°K and 10 to 18 kilogauss, C being $(302.8 \pm 1.5) \times 10^{-4}$; it is also valid for certain solids and solutions of salts, *see infra* and Tables 11, 12, 14.

Proceeding on quite different assumptions, Weiss has shown that in certain cases Langevin's relation may be valid for solid bodies (119), and it has been established experimentally (Onnes, Oosterhuis, Woltjer) (75, 136) for solid gadolinium sulfate, $Gd_2(SO_4)_3 \cdot 8H_2O$, over the ranges 1.3 to 300°K and 3.3 to 22 kilogauss; a was varied from a small value to 7.0; Curie's law applies if $a < 0.7$.

(*b*) Weiss's Generalization of Langevin's Theory.—Weiss and Onnes independently observed that many series of data for which Curie's law fails satisfy the more general relation $\chi(T - \Theta) = C$ (Weiss's law), and Weiss has shown that Langevin's theory leads to this expression when the orientations of the elementary moments are modified by intense molecular fields; $C_a = (\sigma_{a\infty})^2/3R$, as in Langevin's theory when a is small. The intensities of the molecular fields necessary to account for the observed values of Θ exceed 10^6 gauss if assumed to be magnetic; some of the values, as estimated by Weiss (122), are, in this unit: Fe, 6.5; Ni, 6.4; Co, 8.9; magnetite, 14.3.

If the elementary magnetic moments were each accompanied by an electric moment having the same axis, the resultant molecular electrical field would produce the same effect as the molecular magnetic field at first assumed by Weiss (121). The required elementary electric moment is $\epsilon = 1.5\sqrt{RM\Theta/\pi dN_0}$ electrostatic units, where d = density of the substance, and other symbols have same significance as elsewhere. Thus if the unit of ϵ is 10^{-18} cgse unit, the values of ϵ for Fe, Co, and Ni are, respectively, 1.09, 1.25, and 0.85, if the atom is the basal element; if the basal element for Fe is 3 atoms and for magnetite is $0.5Fe_3O_4$, the corresponding values of ϵ are 1.90 for Fe and 1.74 for Fe_3O_4. All these values are very close to those (0.34 to 1.18) obtained by Debye (37, 73) for the moments of dipoles in insulators. The value given for Ni is much the most reliable.

An explanation of the existence of Θ in mixtures of oxygen and nitrogen (*cf.* Table 14) has been given in terms of polymerization (70, 89).

For solutions, experiments of Foëx (44) and of Cabrera and Duperier (21) have shown that in general Θ is not zero; and the results of the latter indicate that Θ is independent of the concentration and of the nature of the anion.

For substances which are ferromagnetic at ordinary temperatures, Weiss's theory interprets Θ as the temperature at which the substance becomes paramagnetic (Curie point, critical temperature). For pure Fe-Ni alloys ranging from Fe_2Ni (34.4% Ni) to 100% Ni, Weiss's law is followed exactly from temperatures near the Curie point to *ca.* 1200°C, and Θ is found (91) to be a little higher than the Curie point. From many series of observations at Zürich (120), the atomic magnetic moment $[\mu]$ for pure Ni above the Curie point, calculated on the basis of the Langevin-Weiss theory, has been found to be $[\mu] = (8.02 \pm 0.02)\ [\mu_0]_w$; *cf.* p. 346.

For other ferromagnetic substances at temperatures above the Curie point, Weiss's law is not certainly followed even over moderate ranges of T.

For most paramagnetic substances, it holds over a considerable range of T, but, in general, fails at very low temperatures. This failure constitutes the *cryomagnetic anomaly* of Onnes. For ions both of the iron group and of the rare earth groups, Cabrera (20) has shown that Θ in general decreases with increase of ionic magnetic moment, the relation for ions of a given class being linear.

Table 11.—Weiss's Law as Applied to Paramagnetic Solids: Values of Θ and Ranges of Validity; Illustrative

Weiss's law, $\chi(T - \Theta) = C$, usually fails at very low temperatures. Range of T = range over which the law holds good; T' = temperature below the range; a, m, s indicate whether χ and C refer to the atomic (metal atom), molecular, or specific magnetization. Error in Θ ranges *ca.* from <1 to 2°K; unit of χ = 1 cgsm; of T, T', and Θ = 1°K.

Substance	(2)	Range of T	Θ	C	$\chi(T' - \Theta)$	T'	Lit.
$Gd(C_2H_5SO_4)_3$.-$9H_2O$	a*	14.6–291.5	0	7.05			(58)
$CoSO_4$	m	77.3–289.5	− 45	3.22	4.27	14.8	(57)
$NiSO_4.7H_2O$	m*	169.6–292.2	+ 59	1.077	3.76	14.6	(57)
Pt†	s	325 –685	−1124	0.001663	0.001651	289	(44)
Pd†	s	479 –722	− 226	0.003043	0.002997	290	(44)
$Fe_2(NH_4)_2(SO_4)_4$.-$24H_2O$	m	14.7–290	0	8.50			(78)
Dy_2O_3	m	13.9–288.5	− 16	27.6			(76)

* Values have been corrected for diamagnetism of the anion and of the water of crystallization.

† Values have been corrected for diamagnetism of the metal atom.

Table 12.—Weiss's Law as Applied to Paramagnetic Solids: Variation of Θ with Molecular Constitution

$\chi(T - \Theta) = C$; mean error in Θ = 2°, maximum error = 7°K; unit of Θ = 1°K

Cation	Ni^{++}		Co^{++}		Fe^{++}		Fe^{+++}	
Anion*	Θ	Lit.	Θ	Lit.	Θ	Lit.	Θ	Lit.
SO_4	−79	(57)	−45	(57)	−12	(14)†	−66	(14)†
			−30‡	(112)	−31	(57)		
			−19§	(57)				
			−48	(101)				
$SO_4.7H_2O$	+59	(57)	−14	(57)	− 1	(57)		
$(NH_4)_2(SO_4)_4$							−12	(14)†
$(NH_4)_2(SO_4)_2.6H_2O$	− 4	(57)	−22	(57)	+ 3	(57)	0	(78)
Cl_2	+78‡	(112)	+47	(112)	+30	(14)†	− 3	(14)†
	+38§	(112)	+34	(14)†				

* For Fe^{+++} the salts are $Fe_2(SO_4)_3$, $Fe_2(NH_4)_2(SO_4)_4$, $Fe_2(NH_4)_2(SO_4)_4.24H_2O$, and $FeCl_3$.

† Computed from the data of (51, 56).

‡ At lower temperatures.

§ At higher temperatures.

Table 13.—Weiss's Law as Applied to Solutions and a Pure Liquid: Values of Θ and Ranges of Validity

$\chi(T - \Theta) = C$; errors in C range from 0.1% to 0.2%. Discrepancies in Θ for a given ion are probably accidental. Solvent is H_2O unless another is indicated. Conc. = concentration, grams of solute per 100 g of solution, except where otherwise indicated; unit of Θ = 1°K; T = absolute temperature, °K.

Table 13.—(*Continued*)

Solute	Conc.	Range of T	Θ	Lit.
$MnCl_2$	3.0	293–373	−28	(21)
	15.0	293–376	−25	(21)
	37.9	293–371	−24	(21)
$Mn(NO_3)_2$	6.4	293–373	−23	(21)
	36.9	293–372	−27	(21)
$FeCl_3$*	0.148	290–400	−11	(44)
	0.148	290–400	+ 2	(44)
	0.161	290–400	+ 1	(44)
	0.183	290–400	− 4	(44)
$Fe(NH_4)_2(SO_4)_2.6H_2O$†	0.0315	290–373	0	(44)
	0.0405	291–384	− 1	(44)
$CoCl_2$	7.9	283–413	−11.6	(29)
	14.8	283–413	−12.1	(29)
$CoSO_4$	4.1	283–413	−11.2	(29)
	9.8	283–413	−12	(29)
$Co(NO_3)_2$	9.4	283–413	−12.4	(29)
	0.076*	290–400	− 2	(44)
	0.139*	290–400	− 3	(44)
	0.139*	290–400	−17	(44)
$NiCl_2$	4.6	279–363	0	(123)
	4.6‡	292–329	0	(123)
	Satd.§	290–400	0	(44)
$Ni(NO_3)_2$	12.4	293–370	− 4.2	(21)
	44.4	293–375	− 1.4	(21)
$V_2O_2Cl_4.5H_2O$‖	100	194–326	−29	(88)
	100	194–326	−45	(88)

* Conc. = grams of metal per 100 g solution; limits of T only approximate.

† Conc. = grams of Fe per 100 g solution; solvent is mixture of H_2O and H_2SO_4.

‡ Solvent is H_2O + 6.8% NH_3.

§ Solution is saturated, concentration $\lessapprox$ 20% Ni; limits of T only approximate.

‖ A viscous liquid.

Table 14.—Weiss's Law as Applied to Mixture of O_2 and N_2 (89)

V_O = volume of O_2 contained in volume V at the same temperature and pressure. $\chi(T - \Theta) = C$. Mean error in Θ *ca.* 0.2°; unit of Θ = 1°K; of $\chi = 10^{-4}$ cgsm unit.

V_O/V	1 (8)	$\frac{3}{5}$	$\frac{1}{3}$	$\frac{2}{11}$	$\frac{1}{9}$	$\frac{1}{5}$	Mean C
C	315.8	315.3	314.7	315	315.3	315	315.2
Θ		−29.5	−16.5	−9.5	−4.5	−2.2	

Table 15.—Magnetic Moments $[\mu]$ of Molecules and Ions of Paramagnetic Substances

I. Molecules. Only O_2 and NO. Computation based on Langevin's theory (p. 350) and assumption of a single fixed moment.

II. Ions. Except where otherwise stated: For solutions, solvent is H_2O, Wiedemann's law is valid, and Curie's law is assumed without having been established. For solid salts, Weiss's law is valid within the "range" indicated. Computation is based on the Langevin-Weiss theory (p. 350).

In column (1) is named the ion or molecule considered and in (2), the molecule from which it is derived. The pure substance is a solid salt unless the contrary is indicated by g = gas, or l = liquid; $[\mu]$ refers to the gram-ion (-molecule) or to the individual ion (molecule) according as $[\mu]_W = [\mu_0]_W$ or $[\mu_0]_W$. $[\mu] = W[\mu]_W$. t = centigrade temperature, °C.

TABLE 15.—(*Continued*)

State of substance		Solution		Pure		
(1)	(2)	*W*	Lit.	Range of *t*	*W*	Lit.
O_2	O_2			*g*	14.1$_8$	(8, 120)
NO	NO			*g*	9.1$_8$	(8, 120)
Cu^{++}	Various	9.5 9.8	(24)			
	$CuCl_2$			+ 20 – +500	10.0	(51, 56, 118)
	$CuSO_4$			−120 – +700	9.96	(51, 56, 118)
Mn^{++}	$MnCl_2$	28.05*	(21)	−180 – +630	27.04	(51, 56, 118)
				+ 15 – +575	28.45	(112)
	$MnSO_4$			+ 9 – +270	29.04	(112)
				+280 – +550	29.04	(112)
	$MnSO_4.4H_2O$			− 68.6 – + 28.5	29.04	(44)
	$Mn(NO_3)_2$	28.07*	(21)			
Fe^{++}	$FeCl_2$			−182 – +200	25.9	(51, 56, 118)
	$FeCl_2.4H_2O$			−180 – + 20	26.0	(51, 56, 118)
	$FeSO_4$			−177 – +660	26.08	(51, 56, 118)
	$FeSO_4.7H_2O$	26.51	(125)	−173 – + 23	26.0	(51, 56, 118)
	$Fe(NH_4)_2$-$(SO_4)_2.6H_2O$	26.49	(125)	− 73 – + 16	25.97	(44)
Fe^{+++}	$Fe_2(SO_4)_3$			−180 – +660	29.00	(51, 56, 118)
				+ 16 – +575	28.95	(112)
	$Fe_2(NH_4)_2$-$(SO_4)_4$			−180 – +400	29.0	(51, 56, 118)
Co^{++}	$CoCl_2$	25.06*	(29)	+ 15.5 – +325	24.96	(112)
	$CoSO_4$	25.03*	(29)	+ 15 – +550	25.00	(112)
				−196 – + 16	25.2	(57)
	$CoSO_4$†	26.03*	(29)	+ 8 – +422	26.0	(101)
	$CoSO_4.7H_2O$			−209 – + 17	25.04	(57)
	$Co(NH_4)_2$-$(SO_4)_2.6H_2O$			−196 – + 17.5	24.75	(57)
	$Co(NO_3)_2$	25.02*	(29, 44)			
		25.54*	(44)			
Ni^{++}	$NiCl_2$	16.02*	(13, 25, 123)	−120 – +360	16.08	(51, 56, 118)
				+ 15 – +125	16.03	(112)
				+150 – +500	16.92	(112)
	$NiSO_4$	16.06	(25, 123)	−180 – +120	17	(51, 56, 118)
				−196 – + 16	16.9	(57)
	$Ni(NO_3)_2$	16.04	(25, 123)			
		15.96*	(21)			
	$NiCl_2 + NiSO_4 + Ni(NO_3)_2$‡	15.58*	(123)			
Cr^{++}	$CrCl_2$	23.72 23.89	(27)			
	$CrSO_4.7H_2O$	23.98	(27)			
Cr^{+++}	$Cr_2O_3.7H_2O$			−164 – + 19	19.07	(51, 56, 118)
	$CrCl_3$			−167 – + 18	18.87	(51, 56, 118)
				+250 – +550	18.87	(51, 56, 118)
	$CrCl_3.4H_2O$	18.72§	(41)			
	$CrCl_3.6H_2O$	18.77§	(41)			
	$Cr_2(SO_4)_3$	18.89	(22)			
	$Cr(NO_3)_3$‖	18.99	(22)			
V^{++++}	$V_2O_2Cl_4.5H_2O$¶	**		*l*	7.94	(88)
	$VOSO_4.3\frac{1}{2}H_2O$	**		− 79 – +100	8.95	(88)

Rare earths; salt of type $R_2(SO_4)_3.8H_2O$, except where noted (15, 18, 74, 131, 132)††

Ion^{+++}	La	Ce‡‡	Pr	Nd	Nd§§	Sa
W	0	11.89	17.89	18.00	18.05	7.64(?)
$\pm\delta W$		1.2	0.3	0.3	1	
δP		−1.1	−0.6	0.0	+0.3	

* Weiss's law found to be valid, value of Θ was found and used in computation.

† Anhydrous salt prepared by calcining $CoSO_4.7H_2O$.

‡ Solvent is $H_2O + xNH_3$.

§ Hydrolysis is very weak and value of *W* closely approaches 19.00 as hydrolysis is reduced by addition of HCl.

‖ Hydrolysis is very weak.

¶ A viscous liquid.

** Erculisse finds the same moments (W = 8 and 9) when V^{++++} occurs in aqueous solutions (88).

†† As Curie's law has been found to be valid for $Gd_2(SO_4)_3.8H_2O$ (*see* p. 350), Θ has been assumed to be 0 for the sulfates. δW = % uncertainty in *W*; δP = % departure of *W* from nearest integer.

‡‡ $Ce_2(SO_4)_3.5H_2O$.

§§ Oxide.

TABLE 15.—(*Continued*)

Ion^{+++}	Eu	Gd	Tb	Dy	Dy§§	Ho
W	17.92	40.07	47.92	52.25	52.00	52.00
$\pm\delta W$	0.1	0.2	0.4	0.3	0.3	0.2
δP	−0.4	+0.2	−0.2	+0.5	0.0	0.0

Ion^{+++}	Er	Er§§	Tm	Yb	Lu
W	46.98	47.09	35.85	21.74	0
$\pm\delta W$	0.3	1	0.1	0.2	
δP	−0.0	+0.2	−0.4	−1.2	

§§ Oxide.

(*c*) *Energy Quantization Theories.*—The most thoroughgoing of several investigations modifying Langevin's theory (p. 350) by introducing energy quantization, are those of Reiche (95) and Rotzahn (98). The theory so developed for gases leads to relations which frequently accord with the data for solids more satisfactorily than do those of Weiss and others, especially at very low temperatures. It accounts for the Θ in Weiss's law and permits the computation of the value of χ at 0°K, but it is consistent with only that type of cryomagnetic anomaly in which $d(\chi^{-1})/dT$ decreases with T. For the equations and their derivation, *see* (67, 69).

TABLE 16.—REICHE-ROTZAHN THEORY AS APPLIED TO PARAMAGNETIC SOLIDS: ILLUSTRATIVE

χ_0 = value of χ at 0°K; $\chi_{obs.}$, $\chi_{calc.}$ = observed (51, 76, 79), calculated from Reiche-Rotzahn theory by means of parameters derived from the observations. $\Delta = (\chi_{obs.} - \chi_{calc.})/\chi_{calc}$; Δ_m = mean value of Δ; $[\Delta]_m$ = mean of the absolute values of Δ (irrespective of sign); $[\mu]_R$ and $[\mu]_L$ = $[\mu]$ of the gram-molecule, as derived from the Reiche-Rotzahn and the Langevin theory, respectively. Range of T = range over which the theory accords with observations. $(\chi T)_l[(\chi T)_h]$ = value of χT at the lowest [highest] temperature of the range. Values of $[\mu]_R$ are from (5); unit of $\chi = 10^{-6}$; of Δ_m and $[\Delta]_m = 1\%$; of $[\mu]_R$ and $[\mu]_L = 10^{-20}$; T = absolute temperature, °K.

Solid	Range of T	$(\chi T)_l$	$(\chi T)_h$	Δ_m
$MnSO_4$	19.4–293.9	9 158	25 804	+0.50
$MnSO_4.4H_2O$	14.4–288.7	17 755	19 141	−0.47
$FeSO_4.7H_2O$	14.7–293.2	11 113	12 394	+0.17
$Fe_2(SO_4)_3$	64.0–289.8	11 334	15 446	+0.09

Solid	Range of T	$[\Delta]_m$	χ_0	$[\mu]_R$	$[\mu]_L$
$MnSO_4$	19.4–293.9	0.92	658	5.35	5.12
$MnSO_4.4H_2O$	14.4–288.7	0.88	7 294	5.45	5.13
$FeSO_4.7H_2O$	14.7–293.2	0.41	3 365	4.90	4.82
$Fe_2(SO_4)_3$	64.0–289.8	0.27	286	6.84	7.11

(*d*) *Spatial Quantization Theories* (87, 103, 104).—The Zeeman spectroscopic effects suggest a spatial quantization of the axes of the elementary magnets. Pauli (87) introduced this assumption into Langevin's theory for gases (p. 350). As modified by Sommerfeld it gives $\chi_a T(\equiv C_a) = \left\{\frac{[\mu]^2 N_0^2}{3R}\right\}\left\{\frac{j_1+1}{j_1}\right\}$, where $[\mu]$ and j_1 refer to the atom, and $[\mu] = g j_1 [\mu_0]_B$ (*see* p. 346). Hence $\sqrt{3RC_a}/N_0[\mu_0]_B (= 2.83\sqrt{C_a}) = g\sqrt{j_1(j_1+1)}$. In certain cases, g and j_1 can be determined with considerable certainty from chemical and spectroscopic data. The most conspicuous success in verifying the formula by such means has been obtained by Hund with the triply ionized rare earths, Z = 57 to Z = 71 (*see* Table 17). Similar attempts with ions of elements from Z = 18 to Z = 29 have been only partially successful, probably because at ordinary temperatures the atoms are not all in the state of excitation assumed to characterize the gas. For attempts at correlation between atomic constitution and magnetic moments, Z = 18 to 29, *see* (20, 38, 53, 66, 104). For discussion of other theories of spatial quantization, *see* (73).

Table 17.—Pauli-Sommerfeld Theory as Applied by Hund to the Rare Earths (53, 54)

This theory requires that $2.83\sqrt{C_a}$ ($\equiv 2.83\sqrt{\chi_a T}$) shall equal $g\sqrt{j_1(j_1+1)}$, where g and j_1 are numbers determined from spectroscopic and chemical data; $gj_1 = [\mu]/[\mu_0]_B \equiv B$. In the following it is supposed that the 4_{33} and lower shells are completed, and that the 5_1, 5_2, and 5_3 shells contain 2, 2, and 4 electrons, respectively. In columns (3), (4), and (5) are given the number of electrons in the shells 4_4, 4_{43}, and 4_{44}; in (6), the fundamental spectral term; in (9) $B_c \equiv W/5$ for solid salt (Table 15); in (10), $g\sqrt{j_1(j_1+1)}$, computed value of $2.83\sqrt{\chi_a T}$; in (11) and (12), values of $2.83\sqrt{\chi_a T}$ as determined by Cabrera (20) and Meyer (74). Columns (4), (5), and (9) are not given by Hund.

(1) Z	(2) Ion*	(3) 4_4	(4) 4_{43}	(5) 4_{44}	(6) Sp.	(7) j_1	(8) g	(9) B_c	(10) comp.	(11) obs.	(12) obs.
57	La..........	0	0	0	${}^1S$	0	$\frac{0}{0}$	0	0.00†	0	0
58	Ce..........	1	1	0	${}^2F$	$\frac{5}{2}$	$\frac{6}{7}$	2.38	2.54	2.39	2.77‡
59	Pr..........	2	2	0	${}^3H$	4	$\frac{4}{5}$	3.58	3.58	3.60	3.47
60	Nd..........	3	3	0	${}^4J$	$\frac{9}{2}$	$\frac{8}{11}$	3.60	3.62	3.62	3.51
61		4	4	0	${}^5J$	4	$\frac{3}{5}$		2.68		
62	Sa..........	5	5	0	${}^6H$	$\frac{5}{2}$	$\frac{2}{7}$	1.53	0.84	1.54(?)	1.32
63	Eu§........	6	6	0	${}^7F$	0	$\frac{0}{0}$	3.58	0.00†	3.61	3.12
64	Gd..........	7	6	1	${}^8S$	$\frac{7}{2}$	2	8.01	7.9	8.2	8.1
65	Tb..........	8	6	2	${}^7F$	6	$\frac{3}{2}$	9.58	9.7	9.6	9.0
66	Dy..........	9	6	3	${}^6H$	$\frac{15}{2}$	$\frac{4}{3}$	10.45	10.6	10.5	10.6
67	Ho..........	10	6	4	${}^5J$	8	$\frac{5}{4}$	10.4	10.6	10.5	10.4
68	Er..........	11	6	5	${}^4J$	$\frac{15}{2}$	$\frac{6}{5}$	9.4	9.6	9.5	9.4
69	Tm..........	12	6	6	${}^3H$	6	$\frac{7}{6}$	7.2	7.5	7.2	7.5
70	Yb..........	13	6	7	${}^2F$	$\frac{7}{2}$	$\frac{8}{7}$	4.4	4.5	4.4	4.6
71	Lu..........	14	6	8	${}^1S$	0	$\frac{0}{0}$	0	0.00†	0	0

* Elements are triply ionized.

† Assumes $g = 0$.

‡ Perhaps Pr^{++++}.

§ Discrepancy may be due to Gd as an impurity, or a considerable fraction of the Eu ions may not be in fundamental state.

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(For a key to the periodicals see end of volume)

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ATMOSPHERIC ELECTRICITY

W. F. G. SWANN

Potential Gradient.—*See* Tables 1, 2 and Figs. 1, 2, 3, 4. The values are supposed to represent the gradient as it would be if the effective surface of the earth were a true plane. The main sources of error lie in (*a*) an uncertainty of the correction for the non-planar form of the effective surface of the earth, and (*b*) errors due to leakage from the collector system (4). No precise limits of accuracy can be given without a precise study of each individual case, which is impracticable. As a result of the first (*a*) source of error, determinations on land have occasionally been unexpectedly found in error by as much as 50%. The importance of the second (*b*) source of error depends upon the speed of the collector; in a typical case in which it required one minute to obtain a reading within 1% of its final value, the error due to leakage resulting from atmospheric conductivity alone amounted to 1%.

From an analysis of the diurnal variation over the ocean, Mauchly (22) has concluded that this variation is primarily due to a 24 hour wave which progresses according to universal, rather than local, time; he finds the same 24 hour wave from land observations, but for these it is not so large a part of the entire effect.

TABLE 1.—POTENTIAL GRADIENT: LAND VALUES

For ocean values, *see* Table 2. Mean values over the interval indicated: Long. = longitude east of Greenwich, Pot. Grad. = potential gradient, potential increasing upwards. (*See also* Figs. 1 to 4.) Unit of Pot. Grad. = 1 volt/meter = $3.33_6 \times 10^{-5}$ cgse unit per cm.

Place	Lat.	Long.	Interval	Pot. Grad.	Lit.
Karasjok............	69.3° N.	25.6°	1 yr	139	(6)
Upsala..............	59.9 N.	15.2	2	70	(24)
Moscow..............	55.7 N.	37.6		112	(18)
Potsdam.............	52.4 N.	13.1	4	245	(6)
Kew.................	51.5 N.	359.7	15	304	(6)
Seeham..............	48.0 N.	13.1	12	84	(29)
Kremsmünster........	48.0 N.	14.1	10	107	(6)
Munich..............	48.1 N.	11.6	5	168	(6)
Davos...............	46.8 N.	9.8	2	64	(6)
Trieste.............	45.6 N.	13.8	2	73	(6)
Perpignan...........	42.7 N.	357.1	2	55	(30)
Tortosa.............	40.8 N.	0.5	7	114	(6)
Buenos Aires........	34.6 S.	301.6	1	126	(3)
Petermann I.........	65.2 S.	295.8	1	176	(14)

TABLE 2.—POTENTIAL GRADIENT, IONIC CONTENT AND CONDUCTIVITY OF THE ATMOSPHERE, AND AIR-EARTH CURRENT DENSITY: OCEAN VALUES

For land values, *see* Table 1, potential gradient; Table 3, ionic content; Table 4, conductivity and current density. Compiled from (4, 4.1); data are averages for the region, and are based on observations distributed over one or two weeks and taken near 10 A. M. local mean time. Long. = longitude east of Greenwich; Pot. Grad. = potential gradient, potential increasing upwards; n_+ [n_-] = number of + [−] ions per cm³ of air; λ_+[λ_-] = conductivity due to + [−] ions; i = current density of positive current from air to earth, $i = (\lambda_+ + \lambda_-) \times$ potential gradient. Dates are written thus: 3:20:15 = March 20, 1915. Unit of Pot. Grad. = 1 volt/meter = $3.33_6 \times 10^{-5}$ cgse unit (per cm); of λ_+ and λ_- = 10^{-4} cgse unit; of $i = 10^{-7}$ cgse unit (per cm³).

Region		Mean date	Pot. Grad.*	$\frac{n_+ + n_-}{2}$	$\frac{n_+}{n_-}$	$\lambda_+ + \lambda_-$	$\frac{\lambda_+}{\lambda_-}$	i
Lat.	Long.							
°N.	°E.							
12–31	283–293	12:18:15	117	490	1.03	1.70	1.18	5.8
2– 8	260–280	4:21:15	126	760	1.20	2.75	1.18	11.1
8–16	233–258	5: 5:15	115	860	1.05	2.90	1.24	10.4
17–21	204–230	5:16:15	109	920	0.93	3.28	1.05	12.1
22–36	199–201	4: 7:15	112	690	1.16	2.57	1.45	9.3
37–52	190–196	4:15:15	129	730	1.27	2.54	1.13	10.4
56–59	175–193	8:11:15	155	790	1.26	2.62	1.15	12.4
32–54	163–173	8:24:15	144	610	1.41	2.35	1.33	10.9
14–30	165–171	9: 8:15	115	880	1.16	3.19	1.22	12.0
2–14	162–166	9:23:15	102	820	1.19	3.18	1.18	10.7
1–19	158–163	10: 8:15	115	670	1.19	2.66	1.13	10.3
22–47	155–173	10:24:15	104	850	1.19	2.76	1.14	9.5
°S.	°E.							
46–56	175–198	12:11:15	109	840	1.28	2.63	1.25	10.0
59–60	209–271	12:24:15	145	660	1.30	2.50	1.34	11.7
54–59	280–327	1: 8:16	165	690	1.25	2.54	1.25	12.2
52–54	349–42†	1:26:16	114	630	1.15	2.10	1.23	7.9
36–52	47–93	2: 8:16	110	810	1.15	2.71	1.22	9.8
34–54	95–108	2:22:16	118	750	1.18	2.89	1.19	10.9
41–59	110–133	3: 8:16	138	820	1.26	3.02	1.25	14.2
45–57	135–173	3:26:16	122	870	1.18	2.83	1.14	14.1

* Deduced from observed change in potential of a conductor that is moved in the earth's field (4).

† Taken, of course, over the lesser portion of the small circle.

Ionic Content.—The numbers n_+ and n_-, of positive and of negative ions per cm³, are derived from $(n_+ + n_-)/2$ and n_+/n_- (Table 3). As the atmospheric potential gradient tends to decrease the rate at which negative ions enter the measuring instrument, the values of n_- are apt to be too low. The size of this error depends upon instrumental details and the effect of surrounding objects, and may exceed 20% (21, 23, 37, 38, 39). With the Ebert aspiration apparatus, the ions measured are mostly the so-called "small" ions, which, in laboratory experiments, have mobilities of 1.3 cm/sec per volt/cm for the +ions and 1.8

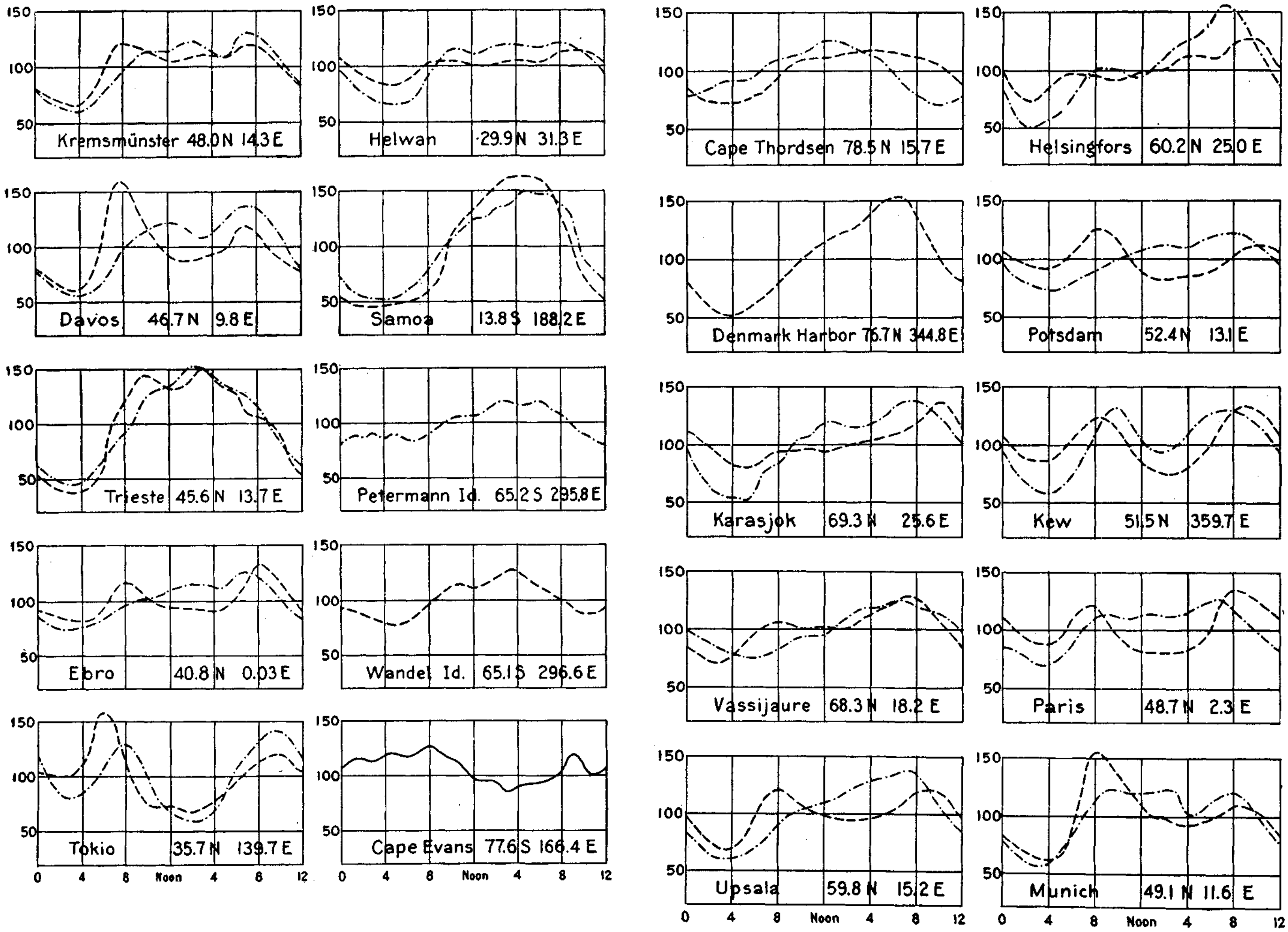

FIG. 1.—Diurnal variation of potential gradient (24).

Ordinates = percentage of the mean gradient for the season (summer, winter, or year), abscissae = local mean time. Summer – – – winter –. –, year —— .

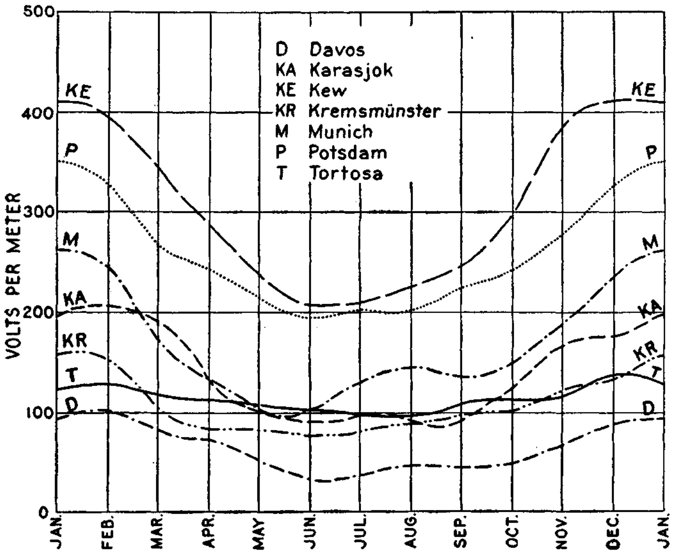

FIG. 2.—Annual variation of potential gradient: Northern hemisphere (6).

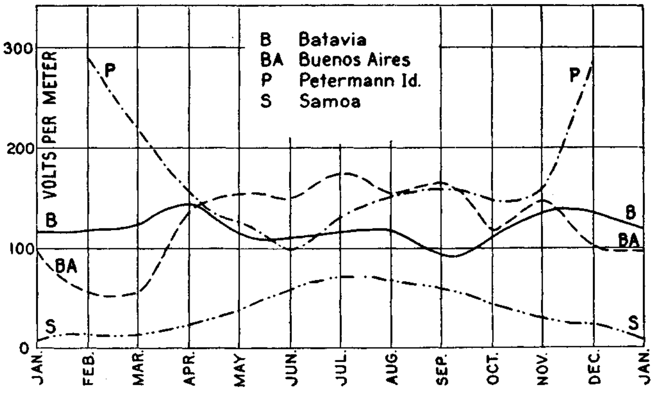

FIG. 3.—Annual variation of potential gradient: Southern hemisphere (6).

for the −ions. In addition to these, so-called "large" ions of mobility about 1/3000 cm/sec per volt/cm, and "intermediate" ions of mobility of the order 0.01 are to be found in the atmosphere. The numbers of these larger ions vary very widely. Representative ratios of large to small ions are: In Paris 50 (Langevin), in Swiss Alps and in Freiburg 2 to 3 (Gockel), in Dublin 200 (McClelland and Kennedy).

As determined on the fourth cruise of the Carnegie, the mobilities of the small ions over the Pacific and the sub-Antarctic Oceans averaged 1.3 cm/sec per volt/sec for both + and − ions. The large abnormalities in the mobilities of atmospheric "small" ions reported by some observers are probably attributable largely to experimental errors inherent in the methods used, the customary method with the Ebert apparatus leading in a large percentage of cases of observatory data to even a negative value of the mobility.

TABLE 3.—IONIC CONTENT OF ATMOSPHERE: LAND VALUES

For ocean values, *see* Table 2. These values have been reduced on the assumption that $e = 4.8 \times 10^{-10}$ es unit; most of them were obtained with Ebert's aspiration apparatus (18, 36). Values of n_+/n_- are apt to be too high, and of n_- too low. Dates are written thus: *8*: 19, 20; **05** = August 19, 20, 1905. Long. = longitude east of Greenwich. Unit of n_+ and n_- = 1 ion per cm.^{3}

Place	Lat.	Long.	Period	$\frac{n_+ + n_-}{2}$	$\frac{n_+}{n_-}$	Lit.
Karasjok	69.3° N.	25.6	1 yr	750	1.17	(31)
Kew	51.5 N.	359.7	**11** to **14**	330	1.40	(45)
Freiburg	50.9 N.	16.3	**04** to **05**	624	1.36	(12)
Munich	48.1 N.	11.6	*8*: 19, 20; **05**	994	1.24	(10)
Aibling	47.9 N.	12.0	**06,** summer	950	1.25	(8)
Aibling	47.9 N.	12.0	**06,** winter	913	1.19	(8)
Jachenau	47.6 N.	11.4	*8*: **05**	915	2.16	(10)
Barcelona*	41.4 N.	2.2	1 day	541	1.30	(10)
Seewalchen	N.		*8*: 6 to *9*: 20; **04**	862	1.18	(27)
Bolivia†	S.		*5*: to *9*: **09**	1980	1.08	(19)
Buenos Aires	34.6 S.	301.6	*5*: **11** to *4*: **12**	1980	1.04	(3)

* Barcelona harbor.

† In high Cordilleras.

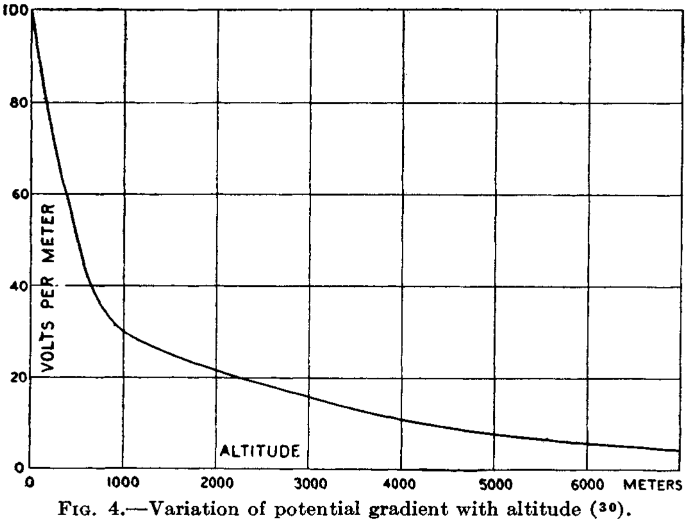

FIG. 4.—Variation of potential gradient with altitude (30).
Mean of results of various observers, each set reduced to correspond to 25 volt per meter at an altitude of 1500 meter.

Conductivity of Atmosphere.—(Tables 2 and 4.) The conductivity $(\lambda_+ + \lambda_-)$ of the atmosphere is the sum of the conductivities due to the presence of the + and of the − ions. For methods, *see* (18). Values of $(\lambda_+ + \lambda_-)$ obtained by the Gerdien apparatus are apt to be too low, owing to neglect of effect of rod supporting the central cylinder. This error may amount to 10% or 15% (35). In the ocean data recorded in Table 2, the measurements were taken in such a manner as to avoid this error. For land observations, the measured value of λ_+ is apt to be too high on account of the collection on the apparatus of radioactive material from the atmosphere. This error may amount to 5%.

Values obtained by Schering's method, which involves measurement of rate of flow of charge from a body (usually a long wire) exposed to the free air, are apt to be too low on account of effect of earth's electric field (34), unless that field near the apparatus is very small, as seems to be the case at Potsdam. When this effect is neglected the values obtained are 20% to 30% lower than those obtained with the Gerdien apparatus.

TABLE 4.—CONDUCTIVITY OF ATMOSPHERE, AND AIR-EARTH CURRENT DENSITY: LAND VALUES

For ocean values, *see* Table 2; for values at high altitude, *see* Table 5. Long. = longitude east of Greenwich; λ_+, λ_- = conductivity due to +ions, −ions; i = current density of positive current from air to earth, $i = (\lambda_+ + \lambda_-) \times$ potential gradient. Dates are written thus: *5*: **09**–*4*: **10** = May, 1909 to April, 1910; *4*: 1–17; **06** = April 1 to 17, 1906. Unit of λ_+ and $\lambda_- = 10^{-4}$ cgse unit; of $i = 10^{-7}$ cgse unit.

Place	Lat.	Long.	Period	$\lambda_+ + \lambda_-$	λ_+/λ_-	i	Lit.
Greenland*	73.0° N.		**07** to **08**	5.53	1.28	12.6	(6)‡
Edinburgh†	56.0 N.	356.9	*5–6*: **09**	0.72		8.4	(5)
Peebles†	55.7 N.	356.8	*9*: **06**–*10*: **07**	2.16		13.4	(42)
Potsdam§	52.4 N.	13.1	*5*: **09**–*4*: **10**	0.95	1.16	7.1	(17)
Göttingen*	51.5 N.	9.9	*4*: 1–17; **06**	2.22	0.98	8	(11)
Munich†	48.1 N.	11.6	*1–12*: **09**	0.98		6.1	(46)
Seeham§	48.0 N.	346.9	**08–20**	2.64	1.02	6.9	(29)
Davos§	46.8 N.	9.8	1 year	2.68	1.13	5.2	(9)
Simla†	31.2 N.	77.8	*11*: **09**	11.6		10.8	(33)
Samoa*	13.8 S.	188.2	*6*: **07**–*3*: **08**	4.5	1.04	7.0	(1)
Buenos Aires*	34.6 S.	301.6	*4, 6*: **12**	1.32	1.02	5.7	(3)
Petermann I*	65.2 S.	295.8	9 months	4.16	1.62	22.6	(6)‡

* By Gerdien's conductivity apparatus; values may be too low by 10 % or 15 %, *see* text.

† By C. T. R. Wilson's method. Values of $(\lambda_+ + \lambda_-) = 2\lambda_0$, λ_0 = directly observed λ; $i = 2\lambda_0 \times$ potential gradient.

‡ Vol. III, p. 123 (6); observed by Wegener.

§ By Schering's method; values may be too low, *see* text.

TABLE 5.—CONDUCTIVITY OF ATMOSPHERE AT HIGH ALTITUDES (41)

Results of 4 ascensions; in each, data are reduced to correspond with $(\lambda_+ + \lambda_-) = (1 \text{ to } 1.5) \times 10^{-4}$ cgse unit at earth's surface. Altitude = maximum altitude, tabulated values of $(\lambda_+ + \lambda_-)$ correspond to that altitude.

Ascension	1	2	3	4	Unit
$(\lambda_+ + \lambda_-)$	16.5	18.8	23.2	37.3	10^{-4} cgse
Altitude	5300	5385	8345	8865	meter

Miscellaneous Data.—The *air-earth current density* is computed from the potential gradient and the conductivity, and is usually expressed in cgs electrostatic units per cm^2 (=cgse units). *See* Tables 2 and 4.

Rate of Recombination of Atmospheric Ions.—As determined by laboratory experiments with artificial ionization, the coefficient α in $-\frac{dn\pm}{dt} = \alpha n_+ n_-$ has a value about 1.6×10^{-6} cm^3 per (ion sec) (*cf.* p. 110), but for atmospheric ions, α has, in general, been found to be of the order of (2 or 3) $\times 10^{-6}$. Recent work (25, 28) indicates that for atmospheric ions $-\frac{dn\pm}{dt} = \alpha n_+ n_- + \beta n_\pm$, where β is considerably more important than α.

Charge on Rain.—Rain may be charged either + or −. In Simla, Simpson (32) found that + precipitation occurred 2.5 times as frequently as − precipitation, and in a long series of observations the total + charge brought down was 3.2 times as great as the total − charge. The corresponding values found at Potsdam (26) by Schindelhauer (confirmed by Kähler) are 2.2 and 1.4, and at Le-Puy-en-Velay by Baldit (2) are 2.86 and 1.36, respectively. The charge on rain is generally less than 1 es unit per cm.[3]

Lightning.—Humphreys (16) estimates that the current associated with a lightning flash may, in certain cases, be of the order of 90 000 amperes. From a comprehensive series of experiments, C. T. R. Wilson (43) concludes that the average charge brought down in a lightning flash is of the order of 20 coulombs, and that the potential differences involved in the discharge are of the order of 10^9 volt.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Angenheister, *536*, **9**, No. 2; 11. *507*, **28**: 430; 11. (2) Baldit, *Soc météorol. France, Ann.*, **59**: 105; 11. *199*, **9**: 92; 12. (3) Berndt, *Veröff. deut Wiss. Ver. Buenos Aires*, No. **3**. Berlin, 1913. *507*, **30**: 363; 13. (4) Bauer, Peters, Fleming, Ault and Swann, *152*, No. **175**, **III**; 17. (4.1) Ault and Mauchly, *152*, No. **175**, V; 26. (5) Carse and MacOwan, *68*, **30**: 460; 10. (6) Chauveau, *Électricité atmosphérique.* Paris, Douin, 1922–1925. 3v. (7) Chree, *Encyclo. Brit.*, 11th ed., **2**: 860; 10. 13th ed., **1**: 257; 26. (8) Daunderer, *63*, **10**: 113; 09. (9) Dorno, *Studie über Licht und Luft der Hochgebirges.* Braunschweig, Vieweg, 1911.

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(30) von Schweidler and Kohlrausch, *B90*, Vol. 3. (31) Simpson, *62*, **205**: 61; 06. (32) Simpson, *62*, **209**: 379; 09. *5*, **83**: 394; 10. (33) Simpson, *3*, **19**: 715; 10. (34) Swann, *268*, **19**: 23; 14. (35) Swann, *268*, **19**: 81; 14. (36) Swann, *268*, **19**: 171; 14. (37) Swann, *268*, **19**: 205; 14. (38) Swann, *268*, **21**: 99; 16. (39) Swann, *2*, **21**: 449; 23.

(40) Swann, *Encycl. Brit.*, 1927. (41) Wigand, *268*, **19**: 93; 14. *199*, **11**: 204; 19. (42) Wilson, *5*, **80**: 537; 08. (43) Wilson, *62*, **221**: 73; 21. (44) Wilson, *B2*, Vol. 2. (45) *Observatories Year Book*, **1926**: 330. (46) Lutz, *213*, **1911**: 305.

TERRESTRIAL MAGNETISM

W. F. G. Swann

General Conclusions.—The magnetic field of the earth is roughly that of a uniformly magnetized sphere; at external points the field of such a sphere is equivalent to that due to a magnetic doublet placed at the center of the sphere. The axis of the doublet is inclined to the axis of rotation. If M is its moment, and M_p and M_e are, respectively, the axial and the equatorial components of M, then, according to an analysis by L. A. Bauer (4), $M = 8.04 (10)^{25}$, $M_p = 7.88(10)^{25}$, $M_e = 1.60(10)^{25}$ cgs magnetic unit; the axis of the doublet intercepts the northern hemisphere at latitude 78° 32′ N. and longitude 69° 08′ W.; and the average intensity of magnetization of the earth is 0.074 cgs magnetic unit.

The magnetic poles, defined as the places where the field is vertical, are not where the prolonged axis of the doublet intersects the earth's surface. From observations between 1903 and 1906, Amundsen placed the north magnetic pole at lat. 71° N, long. 96° W.; from data obtained on the "Discovery," 1902 to 1904, the probable position of the south magnetic pole is latitude 72° 50′ S., longitude 156° 20′ E.

From a harmonic analysis of the field, Gauss concluded that part of it is of external origin. Analyses by Schmidt (13) and by Bauer (4) lead these authors to conclude that a part of the field is not derivable from a potential; Bauer (4) concludes that about 3% of the field is of non-potential origin, and, of the remainder, 94% arises from internal, and 3% from external, causes. The non-potential portion would correspond, on classical electromagnetic theory, to vertical currents (*see* Table 1).

respectively. The charge on rain is generally less than 1 es unit per cm.^{3}

Lightning.—Humphreys (16) estimates that the current associated with a lightning flash may, in certain cases, be of the order of 90 000 amperes. From a comprehensive series of experiments, C. T. R. Wilson (43) concludes that the average charge brought down in a lightning flash is of the order of 20 coulombs, and that the potential differences involved in the discharge are of the order of 10^9 volt.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Angenheister, *536*, **9,** No. 2; 11. *507*, **28:** 430; 11. (2) Baldit, *Soc· météorol. France, Ann.*, **59:** 105; 11. *199*, **9:** 92; 12. (3) Berndt, *Veröff. deut Wiss. Ver. Buenos Aires*, No. **3**. Berlin, 1913. *507*, **30:** 363; 13. (4) Bauer, Peters, Fleming, Ault and Swann, *152*, No. **175, III**; 17. (4·1) Ault and Mauchly, *152*, No. **175**, V; 26. (5) Carse and MacOwan, *68*, **30:** 460; 10. (6) Chauveau, *Électricité atmosphérique.* Paris, Douin, 1922–1925. 3v. (7) Chree, *Encyclo. Brit.*, 11th ed., **2:** 860; 10. 13th ed., **1:** 257; 26. (8) Daunderer, *63*, **10:** 113; 09. (9) Dorno, *Studie über Licht und Luft der Hochgebirges.* Braunschweig, Vieweg, 1911.

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TABLE 1.—VERTICAL CURRENT DENSITIES AS COMPUTED FROM MAGNETIC DATA

Computed by Bauer (3) from magnetic data of 1920. The average value, regardless of sign, is about 10 000 times the atmospheric-electric current density, *see* p. 442. Dyson and Furner (8) conclude that such vertical currents are not indicated with any certainty, although there is some evidence for them. A + sign indicates an upward positive current; i_N [i_S] = current density in northern [southern] hemisphere. Unit of i_N and $i_S = 10^{-3}$ ampere/km^2 = 3.0×10^{-4} cgse (per cm^2).

Lat.	i_N	i_S
90° to 50°	+21	+18
50 to 45	+45	+34
45 to 40	− 6	−47
40 to 35	+18	−22
35 to 30	+ 8	−31
30 to 25	−29	+19
25 to 20	−37	+58
20 to 15	−19	+41
15 to 10	−33	−41
10 to 5	−53	+14
5 to 0	−18	+ 9

TABLE 2.—MAGNETIC ELEMENTS AT VARIOUS OBSERVATORIES: RECENT DATA (9)

D = declination (east or *west*); I = inclination or dip (north or *south*); H = horizontal intensity, Z = vertical intensity. *Italics* indicate that the quantity is to the south (latitude and I) or the west (longitude and D); in column "Yr," 24 indicates 1924; Long. = longitude east or *west* from Greenwich. Unit of H and $Z = 1\gamma = 10^{-5}$ gauss $= 10^{-5}$ cgsm.

Observatory	Lat.	Long.	Yr	D	I	H	Z
Matochkin Shar	73° 15′	56° 24′	24	20° 35′	80° 03′	9 520	54 270
Sodankylä	67 22	26 39	22	1 22.6	75 40.5	12 561	49 187
Pavlovsk	59 41	30 29	24	3 16.1	71 07.9	15 818	46 970
Sitka	57 03	*135 20*	22	30 29.1	74 22.4	15 560	55 631
Ekaterinburg	56 50	60 38	24	11 00.8	71 58.4	16 578	50 942
Rude Skov	55 51	12 27	21	*7 45.2*	69 01.2	17 105	44 607
Kasan	55 50	48 51	24	8 53.5	70 07.6	17 310	47 517
Eskdalemuir	55 19	*3 12*	20	*16 49.7*	69 39.5	16 706	45 062
Meanook	54 37	*113 20*	24	27 17.7	77 73.7	12 866	59 984
Stonyhurst	53 51	*2 28*	24	*15 05.3*	68 41.7	17 276	44 281
Wilhelmshaven	53 32	8 09	11	*11 28.2*	67 30.7	18 110	43 747
Potsdam	52 23	13 04	23	*6 56.9*	66 36.5	18 565	42 920
Seddin	52 17	13 01	22	*7 09.4*	66 32.8	18 614	42 905
Irkutsk (Zuja)	52 28	104 02	20	1 02.3	71 06.6	19 277	56 337
De Bilt	52 06	5 11	24	*10 38.3*	66 52.7	18 372	43 024
Valencia	51 56	*10 15*	20	*19 17.9*	68 05.3	17 840	44 353
Bochum	51 29	7 14	21	*10 10.4*			
Kew	51 28	*0 19*	20	*14 31.0*	66 57.9	18 410	43 297
Greenwich	51 28	0 00	23	*13 35.1*	66 51.9	18 431	43 137
Uccle	50 48	4 21	16	*12 28.4*	66 02.8	18 971	42 703
Hermsdorf	50 46	16 14	13	*6 58.2*			
Prague	50 05	14 25	21	*6 24.2*			
Val Joyeux	48 49	2 01	22	*12 31.5*	64 39.6	19 661	41 517
Munich	48 09	11 37	13	*9 06.2*	63 04.6	20 623	40 609
			21	*7 53.6*			
O'Gyalla	47 53	18 12	18	*5 21.9*		20 917	
Odessa	46 26	30 46	10	*3 35.9*	62 26.9	21 707	41 606
Pola	44 52	13 51	22	*6 28.0*	60 12.8	22 090	38 591
Agincourt	43 47	*79 16*	24	*7 05.8*	74 44.4	15 752	57 733
Tiflis	41 43	44 48	13	3 09.1	56 51.1	25 217	37 612
Capodimonte	40 52	14 15	14			24 166	
Ebro (Tortosa)	40 49	0 31	24	*11 20.2*	57 30.5	23 359	36 678
Coimbra	40 12	*8 25*	20	*15 21.5*	58 22.8	23 087	37 496
Cheltenham	38 44	*76 50*	22	*6 27.7*	70 57.6	19 020	55 115
Athens	37 59	23 42	08	*4 53.0*	52 11.7	26 197	33 613
San Miguel	37 46	*25 39*	20	*19 24.9*	60 26.0	23 123	40 759
San Fernando	36 28	*6 12*	24	*13 23.5*	53 46.8	25 016	
Kakioka	36 14	140 11	16	*5 17.6*	49 31.7	29 743	34 859
Tsingtau	36 04	120 19	20	*4 12.9*	52 07.0	30 817	39 610
Tucson	32 15	*110 50*	22	13 47.5	59 29.0	26 839	45 533
Lukiapang	31 19	121 02	20	*3 21.4*	45 30.7	33 175	33 773
Dehra Dun	30 19	78. 03	22	1 43.2	45 02.6	32 927	33 091
Helwan	29 52	31 20	19	*1 30.6*	41 09.6	29 947	26 175
Hongkong	22 18	114 10	24	*0 23.8*	30 42.8	37 294	22 155
Honolulu	21 19	*158 04*	22	9 57.1	39 24.5	28 794	23 658
Teoloyucan	19 45	*99 11*	22	9 09.9			
Toungoo	18 56	96 27	22	*0 29.7*	23 07.2	39 156	16 717
Alibag	18 38	72 52	22	0 12.6	25 05.0	36 967	17 303
Vieques	18 09	*65 27*	22	*4 00.9*	51 33.1	27 695	34 880
Antipolo	14 36	121 10	20	0 35.9	16 11.7	38 100	11 065
Kodaikanal	10 14	77 28	22	*1 58.7*	4 40.1	37 878	3 093
Batavia-Buitenzorg	*6 11*	106 49	24	0 52.9	*32 04.3*	36 821	23 072
St. Paul de Loanda	*8 48*	13 13	19	*14 49.0*			
Huancayo	*12 03*	*75 20*	24	8 01.7	0 54.6	29 755	395
Apia	*13 48*	*171 46*	24	10 19.2	*30 07.5*	35 249	20 453
Tananarive	*18 55*	47 32	14	*8 25.2*	*53 37.9*	22 484	30 532
Mauritius	*20 06*	57 33	23	*10 49.2*	*52 33.7*	22 982	30 018
Vassouras	*22 24*	*43 39*	23	*11 42.8*	*15 53.7*	24 407	6 950
Watheroo	*30 19*	115 53	24	*4 18.3*	*64 05.2*	24 750	50 941
Pilar	*31 40*	*63 53*	20	7 48.6	*25 41.2*	25 297	12 168
Toolangi	*37 32*	145 28	20	8 00.8	*67 55.1*	22 874	56 384
Christchurch	*43 32*	172 37	23	17 11.7	*68 12.0*	22 209	55 526
Orcadas	*60 43*	*44 47*	12	4 46.5	*54 26.0*	25 343	35 442

TABLE 3.—MAGNETIC ELEMENTS FOR EACH 10° OF LATITUDE AND LONGITUDE

Data obtained from charts (5) compiled at Royal Observatory, Greenwich, England, 1922. A ? indicates that the curves were too widely spaced to permit satisfactory interpolation. D = declination (east or *west*); I = inclination or dip (north-seeking pole down or *up*); H = horizontal intensity; *italics* indicate that D is to the west or that I is such that north-seeking pole is up. Unit of $H = 100\gamma = 10^{-3}$ gauss $= 10^{-3}$ cgsm.

Lat.	70° N.			60° N.			50° N.			40° N.			30° N.			20° N.			10° N		
Long.	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I	H	D	I
0° E.	?	*18.7°*	?	153	*16.3°*	72°	193	*13.5°*	65°	240	*11.8°*	57°	280	*11.0°*	43°	308	*11.1°*	26°	318	*12.6°*	5°
10 E.	?	*10.6*	?	157	*9.7*	71	197	*9.0*	64	244	*8.2*	55	286	*7.9*	42	316	*7.9*	23	325	*8.7*	2
20 E.	120	*3.3*	?	160	*3.4*	71	203	*3.7*	64	248	*4.2*	54	292	*4.5*	42	322	*5.0*	23	331	*6.2*	1
30 E.	120	2.6	?	163	2.1	71	208	1.0	64	253	*0.9*	54	299	*1.6*	41	330	*2.4*	22	337	*3.7*	2
40 E.	?	7.8	?	162	6.2	71	211	4.8	64	258	2.8	54	306	1.3	41	339	0.1	22	344	*1.3*	2
50 E.	?	13.0	?	160	10.0	71	212	7.2	65	265	4.8	55	313	3.2	42	344	1.8	23	352	0.8	3
60 E.	106	18.2	?	156	12.8	72	212	8.3	65	271	5.6	56	318	3.5	42	352	1.7	25	361	0.1	5
70 E.	98	?	?	150	14.1	73	212	8.8	66	275	5.7	56	324	2.8	43	361	0.4	26	372	*1.9*	5
80 E.	88	?	?	148	13.8	73	210	8.0	67	279	4.7	57	333	1.8	43	373	*0.6*	26	382	*2.5*	4
90 E.	80	?	80	137	10.7	74	210	6.2	67	282	?	57	342	?	43	383	*0.5*	26	395	*1.5*	4
100 E.	?	16.0	80	135	6.8	75	212	2.7	68	283	?	57	346	?	43	389	?	25	?	0.0	3
110 E.	?	10.0	80	137	0.4	75	216	*1.3*	68	284	*1.8*	57	344	*1.4*	43	384	?	25	?	1.2	3
120 E.	?	3.9	80	144	*5.9*	75	224	*6.1*	67	285	*5.0*	56	338	*2.9*	43	373	*0.4*	25	389	1.4	4

Table 3.—(*Continued*)

Lat.	70° N.			60° N.			50° N.			40° N.			30° N.			20° N.			10° N.		
Long.	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*
130 E.	83	*1.0*	80	157	?	74	232	*9.4*	66	285	*6.8*	55	326	*3.8*	42	360	*0.9*	26	379	1.5	5
140 E.	92	*4.8*	80	167	?	73	234	*9.4*	64	281	*6.6*	53	313	*3.6*	41	343	*0.5*	26	364	2.2	6
150 E.	100	0.0	?	174	*8.0*	72	235	*6.7*	62	274	*4.2*	52	300	*1.6*	41	325	1.0	26	348	3.7	7
160 E.	109	4.3	?	179	*2.3*	71	234	*2.2*	61	267	*0.4*	52	291	1.6	41	313	3.9	27	338	5.7	9
170 E.	114	10.2	?	182	2.6	70	230	2.6	61	261	3.9	52	283	5.5	42	304	6.8	29	330	8.0	12
180 E.	114	15.4	?	182	8.6	70	225	8.0	62	255	8.6	53	277	8.9	44	299	9.1	32	325	9.0	15
170 W.	110	21.2	?	177	15.0	71	220	13.5	63	250	12.5	55	274	11.3	46	296	10.2	35	324	9.0	18
160 W.	102	27.7	80	171	20.9	72	215	17.8	64	247	15.4	57	273	13.0	48	296	10.6	37	324	8.8	20
150 W.	93	35.0	80	163	26.0	73	208	21.4	66	245	17.7	59	275	14.1	50	299	10.9	38	325	8.8	22
140 W.	81	44.5	?	150	30.9	75	200	24.1	68	244	19.2	61	278	15.0	52	304	11.2	40	328	?	24
130 W.	67	54.6	?	130	35.6	77	190	25.9	70	240	19.8	62	282	15.2	53	310	11.6	41	332	9.1	25
120 W.	47	62.8	85	109	37.7	80	177	25.8	72	233	19.2	64	282	14.6	55	313	11.4	43	334	9.3	26
110 W.	33	70.0	?	87	32.6	82	156	22.3	75	221	16.8	67	280	13.3	57	314	10.7	44	336	9.3	28
100 W.	13	60.0	?	63	17.6	84	134	15.0	77	207	12.7	69	272	10.0	59	312	9.0	46	335	8.6	31
90 W.	19	*67.3*	?	47	*3.0*	85	121	2.1	78	192	5.0	71	259	6.2	62	304	6.4	49	329	7.1	33
80 W.	40	*74.0*	?	58	*30.0*	84	119	*13.6*	78	184	*4.4*	72	245	0.0	63	292	2.7	52	320	4.8	36
70 W.	58	*73.0*	85	76	*41.7*	82	127	*24.0*	77	185	*13.3*	71	235	*6.3*	63	275	*2.3*	52	305	0.7	38
60 W.	70	*67.7*	?	94	*44.4*	80	138	*31.0*	76	188	*19.6*	70	231	*13.0*	62	265	*8.0*	53	291	4.8	40
50 W.	82	*59.0*	?	111	*43.2*	78	152	*32.5*	74	195	*24.0*	68	233	*18.0*	60	264	*13.6*	51	286	*10.9*	40
40 W.	91	*50.0*	80	124	*39.5*	76	163	*31.3*	72	204	*24.8*	66	239	*20.6*	57	267	*18.0*	48	288	*16.2*	36
30 W.	100	*40.3*	?	134	*34.9*	75	173	*28.0*	70	215	*22.8*	63	248	*20.0*	54	277	?	43	?	*19.0*	28
20 W.	107	*33.6*	?	142	*28.8*	73	183	*23.3*	68	225	*19.7*	61	261	*18.1*	50	291	*18.0*	36	302	*19.5*	18
10 W.	?	*26.3*	?	148	*22.2*	72	189	*18.6*	66	233	*15.7*	58	273	*14.6*	46	301	*14.7*	30	311	*16.8*	10

Lat.	0°			10° S.			20° S.			30° S.			40° S.			50° S.			60° S.		
Long.	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*	*H*	*D*	*I*
0° E.	290	*16.1*	*17*	246	*20.4*	*33*	209	*25.1*	*44*	188	*28.0*	*51*	181	*28.2*	*55*	184	*25.2*	*59*	189	*22.1*	*62*
10 E.	294	*12.0*	*22*	245	*16.6*	*38*	205	*22.0*	*50*	180	*26.5*	*56*	169	?	*60*	169	*27.5*	*62*	178	*25.1*	*64*
20 E.	297	*8.2*	*23*	245	*12.9*	*41*	203	*18.4*	*52*	172	*23.7*	*59*	158	*27.7*	*62*	159	*29.0*	*65*	168	*27.3*	?
30 E.	303	*5.5*	*23*	250	*9.4*	*41*	204	*14.6*	*54*	168	*20.5*	*61*	150	*26.0*	*64*	153	?	?	160	*29.3*	?
40 E.	313	*2.2*	*22*	258	*5.7*	*41*	208	*10.7*	*54*	169	*17.0*	*61*	?	*24.4*	*65*	?	*29.8*	?	?	*32.3*	?
50 E.	325	*0.6*	*21*	270	*3.4*	*40*	220	*8.9*	*53*	176	*15.6*	*61*	150	*24.5*	*65*	?	*32.2*	?	?	*37.1*	?
60 E.	338	*2.0*	*19*	285	*5.0*	*38*	234	*10.3*	*52*	188	*18.0*	*61*	161	*27.1*	*65*	?	*36.0*	?	?	*41.6*	*70*
70 E.	350	*4.3*	*19*	301	*7.2*	*38*	247	*13.7*	*52*	203	*21.6*	*61*	175	*30.4*	*66*	161	*39.7*	*68*	?	*46.7*	*72*
80 E.	360	*4.6*	*20*	316	*8.0*	*38*	261	*14.0*	*52*	215	*22.5*	*62*	186	*32.5*	*67*	166	*42.5*	*70*	?	*51.1*	*74*
90 E.	373	*3.0*	*20*	330	*5.7*	*39*	276	*11.0*	*53*	224	*19.5*	*62*	188	*30.4*	*68*	162	*42.1*	*73*	141	*54.3*	*76*
100 E.	384	*0.6*	*20*	342	2.3	*38*	290	*6.5*	*53*	233	*13.3*	*63*	188	*24.6*	*70*	148	*38.6*	*75*	124	*54.7*	*78*
110 E.	389	1.4	*19*	353	0.4	*37*	303	*1.9*	*52*	244	*7.4*	*63*	188	*15.2*	*72*	135	*30.6*	*77*	105	*52.3*	?
120 E.	387	2.4	*17*	360	2.2	*36*	314	0.6	*51*	253	*2.4*	*63*	190	*7.3*	*72*	127	*18.5*	*78*	87	*43.2*	?
130 E.	382	3.0	*16*	364	3.5	*34*	325	3.1	*49*	265	2.0	*62*	197	*0.4*	*71*	128	*5.9*	*78*	?	*25.0*	?
140 E.	?	4.0	*14*	367	4.8	*32*	332	5.2	*48*	275	5.5	*61*	207	5.5	*70*	137	4.0	*77*	?	0.0	?
150 E.	?	5.3	*12*	?	6.3	*31*	336	7.1	*46*	284	8.2	*60*	219	9.7	*69*	151	12.1	*76*	86	14.4	?
160 E.	360	6.9	*10*	?	7.9	*28*	338	9.0	*44*	291	10.5	*58*	231	13.3	*67*	166	16.6	*75*	100	21.6	?
170 E.	355	?	*7*	?	8.9	*25*	339	10.2	*43*	295	12.3	*56*	242	15.5	*65*	182	19.2	*73*	118	26.9	*80*
180 E.	352	?	*4*	360	9.3	*23*	340	10.7	*40*	297	13.1	*54*	251	16.5	*63*	195	20.4	*71*	133	28.8	*78*
170 W.	349	?	0	?	9.4	*21*	338	11.0	*38*	300	13.5	*52*	258	16.7	*62*	204	20.7	*70*	145	29.6	*77*
160 W.	346	?	1	?	9.3	*19*	333	11.1	*36*	302	13.6	*50*	264	16.7	*60*	211	20.8	*68*	158	29.7	*75*
150 W.	?	?	3	344	9.3	*17*	327	11.1	*35*	303	13.6	*48*	268	16.8	*58*	218	20.9	*66*	169	29.8	*74*
140 W.	?	?	4	337	9.4	*16*	322	11.2	*33*	302	13.6	*46*	272	16.8	*57*	227	21.3	*65*	182	30.1	*72*
130 W.	?	?	6	333	9.5	*15*	318	11.3	*32*	301	13.8	*45*	274	17.1	*55*	237	22.0	*64*	196	31.4	*71*
120 W.	?	?	7	330	9.7	*13*	314	11.6	*30*	298	14.2	*43*	275	17.9	*53*	248	23.1	*62*	212	32.7	*69*
110 W.	341	9.1	9	324	10.0	*11*	309	12.0	*28*	294	15.2	*41*	276	19.2	*52*	255	24.4	*60*	226	33.1	*67*
100 W.	337	9.4	12	318	10.6	*8*	302	12.9	*25*	289	16.3	*38*	277	20.5	*48*	262	25.4	*57*	239	32.0	*64*
90 W.	330	8.8	15	310	10.5	*4*	292	13.2	*21*	282	16.6	*35*	?	20.5	*45*	268	24.4	*54*	250	28.8	*61*
80 W.	320	6.6	18	298	9.0	0	280	11.3	*16*	271	15.0	*30*	269	18.3	*41*	270	21.1	*50*	256	25.0	*58*
70 W.	308	2.7	23	286	5.0	6	270	7.4	*11*	259	10.3	*26*	260	13.6	*37*	265	16.6	*47*	257	20.0	*56*
60 W.	295	*3.8*	25	278	*0.9*	8	260	1.0	*8*	248	3.7	*22*	250	6.7	*34*	258	10.1	*44*	?	13.6	*53*
50 W.	291	*9.2*	25	272	*8.2*	8	250	*6.8*	*8*	237	*4.8*	*22*	239	*1.0*	*33*	250	3.1	*43*	249	7.0	*53*
40 W.	291	*15.3*	20	268	*15.1*	2	243	*14.5*	*12*	228	*12.3*	*26*	227	*9.1*	*35*	237	*4.6*	*44*	237	0.4	*53*
30 W.	290	*19 5*	11	263	*20.0*	*5*	236	*19.8*	*21*	218	*18.6*	*32*	214	*15.7*	*39*	224	*11.5*	*47*	224	*6.4*	*54*
20 W.	289	*21.1*	1	257	*22.6*	*15*	227	*23.7*	*30*	209	*23.6*	*38*	203	*21.0*	*45*	209	*17.0*	*51*	211	*12.7*	*57*
10 W.	289	*19.6*	*8*	250	*23.1*	*25*	218	*25.6*	*37*	198	*27.0*	*45*	192	*25.4*	*51*	197	*21.7*	*55*	199	*17.8*	*59*

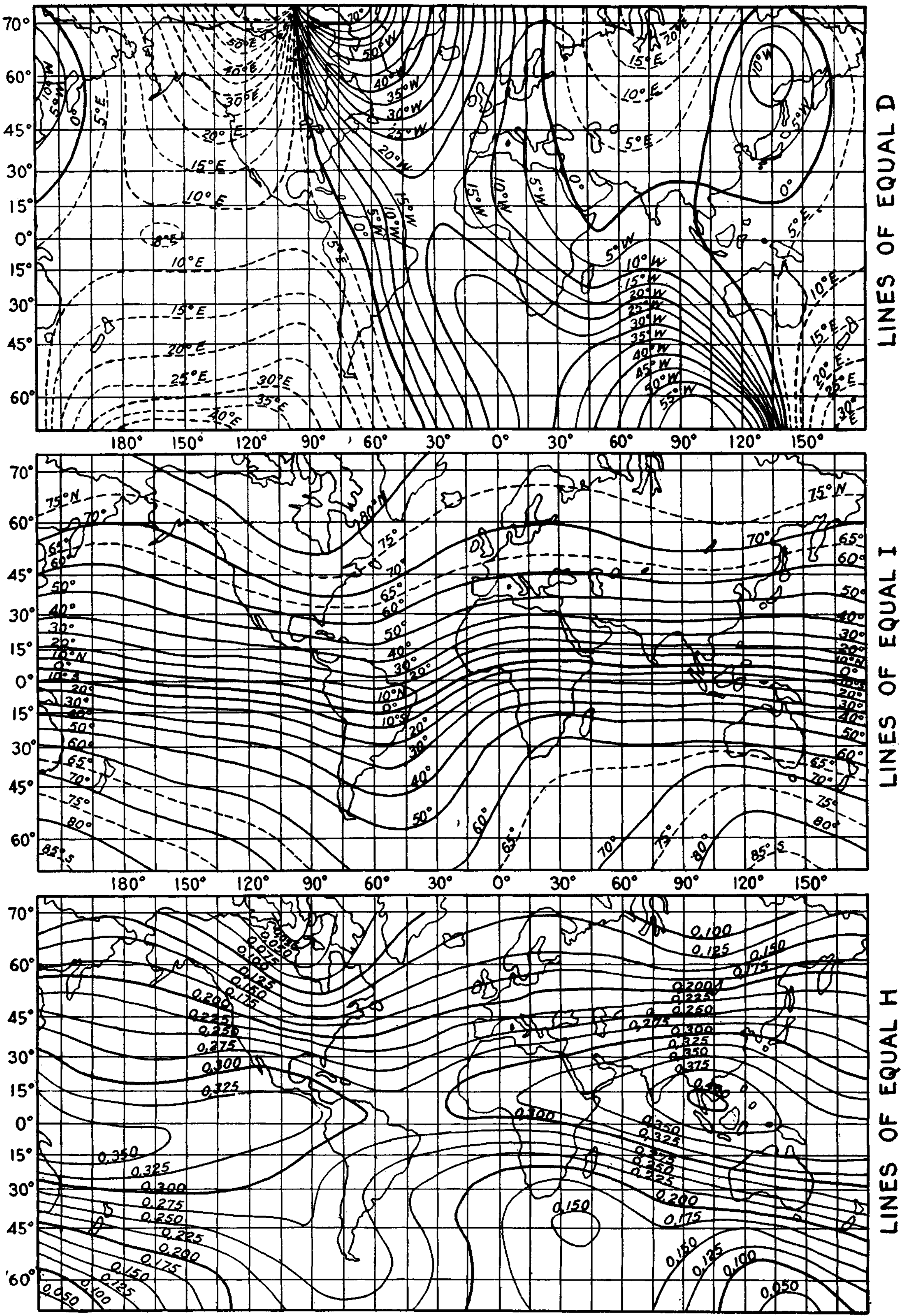

FIG. 1.—Curves of equal declination (*D*), of equal inclination (*I*), and of equal horizontal intensity *H*: for 1922 (6). Based on British Admiralty Charts for 1922. Values are marked on the curves; unit of *H* = 1 gauss = 1 cgsm unit.

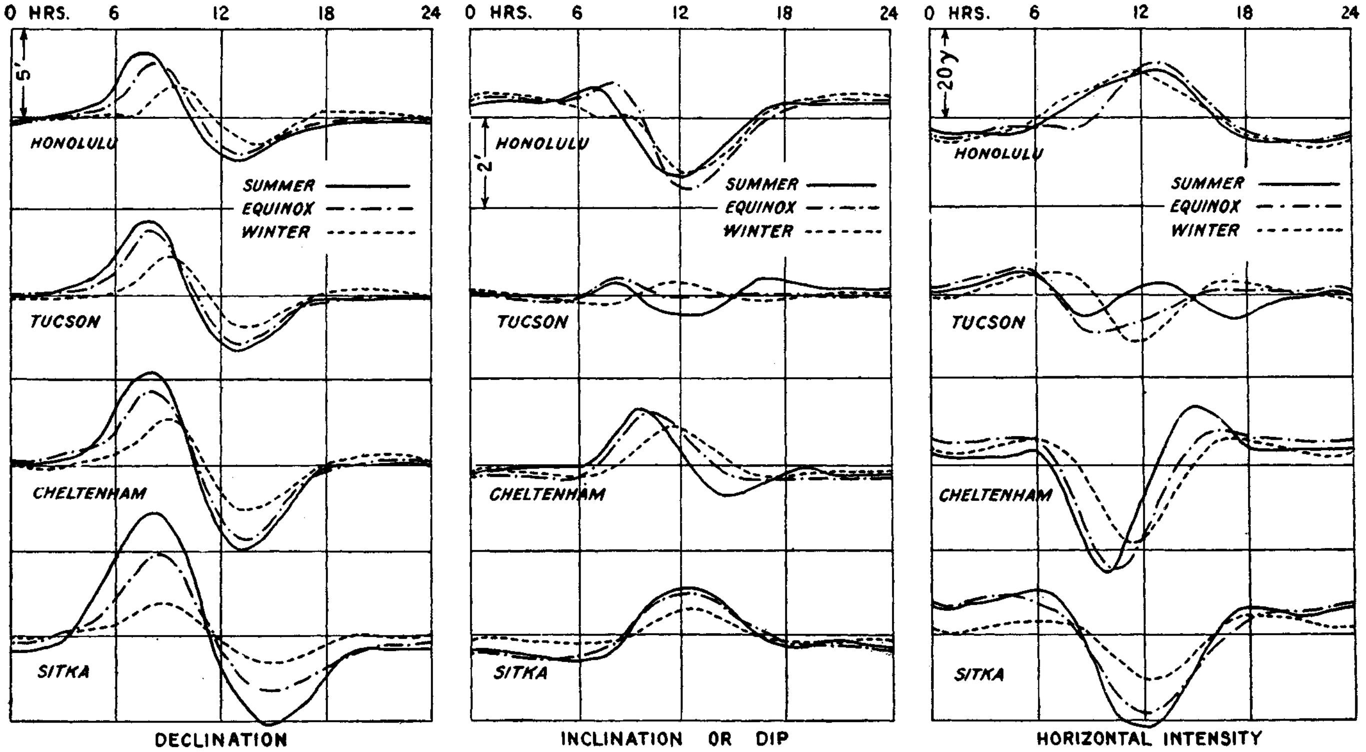

Fig. 2.—Diurnal variations at selected stations (¹⁰).

Data are based on average values for stormless days. Time is measured from local mean noon; 1γ = 10^{-5} gauss = 10^{-5} cgsm unit.

Table 4.—Secular Changes in Declination (D) at Various Places, and over Long Periods (¹⁰)

For recent variations, *see* Table 5; south and west values are printed in *italics*

Lat. Long.	51° 28′ *0 19*	44° 55′ *67 00*	37° 48′ *122 27*	23° 07′ *82 22*	14° 36′ 120 58	*12° 04′* *77 08*	*22° 54′* *43 10*	*33° 56′* 18 29
Place	London, England	Eastport, Maine	San Francisco, California	Havana, Cuba	Manila, P. I.	Callao, Peru	Rio de Janeiro, Brazil	Cape Town, S. Africa
Year	D							
1540	7.2°							
1560	9.6							
1580	10.9							
1600	10.1							1.0°
1620	7.3	*19.0°*						*1.5*
1640	3.3	*18.5*						*4.0*
1660	*0.6*	*17.5*					12.1°	*6.4*
1680	*3.9*	*16.0*					11.8	*8.9*
1700	*7.1*	*14.5*					11.3	*11.5*
1720	*11.0*	*13.1*		4.0°		6.7°	10.6	*14.0*
1740	*15.3*	*12.4*		5.0		7.7	9.7	*16.8*
1760	*19.6*	*12.2*		5.8	*0.1°*	8.6	8.5	*19.4*
1780	*22.7*	*12.4*	12.6°	6.3	0.0	9.4	7.1	*22.2*
1800	*24.1*	*13.2*	13.6	6.5	0.1	10.0	5.5	*25.0*
1820	*24.1*	*14.7*	14.6	6.3	0.2	10.4	3.5	*27.1*
1840	*23.2*	*16.3*	15.4	6.0	0.3	10.6	1.2	*29.0*
1860	*21.5*	*18.0*	16.1	5.2	0.5	10.5	*1.5*	*30.0*
1880	*18.7*	*18.8*	16.5	4.0	0.7	10.3	*4.4*	*29.8*
1900	*16.5*	*19.3*	16.9	3.1	0.9	9.9	*7.7*	*28.6*
1910	*15.7*	*20.0*	17.6	3.0	0.8	9.2	*9.5*	*27.5*
1920	*14.1*	*20.8*	17.9	3.4	0.7	8.5	*11.2*	*26.1*

Table 5.—Secular Changes in Magnetic Elements at Various Observatories: 1905 to 1925 (¹⁰)

Z = total intensity, D = declination (east or *west*), I = inclination (north-seeking pole down). West values are printed in *italics*. Δ = algebraic excess above value in column 1905; *e.g.*, at Sitka in 1915, Z = 58 797 − 659 = 58 138, D = 29° 59.1′ + 24.1′ = 30° 23.2′, I = 74° 43.2′ − 16.7′ = 74° 26.5′. Unit of Z = 1γ = 10^{-5} gauss = 10^{-5} cgsm unit.

Year		1905	1910	1915	1920	1925
Place		Value	Δ			
Sitka	Z	58 797	−371	−659	−997	−1 177
57° 03′ N.	D	29° 59.1′	+17.3′	+24.1′	+29.1′	+28.1′
135° 20′ W.	I	74° 43.2′	−11.0′	−16.7′	−21.1′	−21.0′
Greenwich	Z	47 274	−34	−171	−252	−424
51° 28′ N.	D	*16° 09.9′*	*−28.7′*	*−1° 13.4′*	*−2° 01.3′*	*−2° 59.9′*
0° 00′	I	66° 55.9′	−3.3′	−4.1′	−2.3′	−4.4′
Toronto	Z	61 730	−309	−935	−1 439	
43° 40′ N.	D	*5° 42.2′*	*+21.7′*	*+46.3′*	*+1° 03.2′*	
79° 24′ W.	I	74° 34.3′	+4.2′	+8.6′	+10.3′	
Cheltenham	Z	59 878	−282	−896	−1 380	−1 895
38° 44′ N.	D	*5° 17.8′*	*+23.6′*	*+46.2′*	*+1° 00.7′*	*+1° 21.4′*
76° 50′ W.	I	70° 25.4′	+10.0′	+21.4′	+30.0′	+35.1′
Tucson	Z	53 669	Values for 1910	−374*	−712*	−1 072*
32° 15′ N.	D	13° 25.8′		+16.7′*	+22.2′*	+19.5′*
110° 50′ W.	I	59° 19.6′		+5.1′*	+8.0′*	+11.0′*
Honolulu	Z	38 168	−258	−587	−827	−1 006
21° 19′ N.	D	9° 21.7′	+8.0′	+19.9′	+31.5′	+40.1′
158° 04′ W.	I	40° 05.0′	−17.8′	−35.9′	−39.9′	−39.1′
Vieques	Z	44 795	−61	−85	−213	
18° 09′ N.	D	*1° 38.3′*	*+42.3′*	*+1° 31.8′*	*+2° 07.8′*	
65° 27′ W.	I	49° 17.0′	+35.0′	+1° 28.9′	+2° 05.7′	

* Algebraic excess over value for 1910.

Earth Currents.—It is not practicable to do more than to indicate the order of magnitude of earth currents. At the observatory del Ebro, Tortosa, Spain, the horizontal electrical potential gradient in the earth was measured over a distance of 1.28 km in a north-south line, and over a distance of 1.40 km in a west-east line. The average of observations extending over 4 yr (1914–18) gave as the gradient along the N.-S. line 0.204 volt per km, current (+) from N. to S., and along the W.-E. line 0.114 volt per km, current (+) from W. to E.

Aurora.—Auroral activity is confined largely to two zones of the atmosphere situated at an angle of about 20° to the magnetic polar axis. The lower edge of the aurora is sharply bounded; the height of this boundary appears to vary from 70 to 300 km, with a maximum number at about 115 km.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Angenheister, *B95*, Vol. 15. (2) Auerbach, *B90*, Vol. 4. (3) Bauer, *268*, **25**: 145; 20. (4) Bauer, *268*, **28**: 1; 23. (5) British Admiralty Charts. (6) Bur. Central Magn. Terr. *Atlas magnétique.* Paris, Maurin, 1905. (7) Chree, *Encycl. Brit.*, 11th ed., **17**: 353; 10. (8) Dyson and Furner, *520*, *Geophys. Suppl.*, **1**: No. 3; 23. (9) Fleming, *Trans. Sect. Terr. Mag. Elec., Intern. Geophys. Union*, Madrid, 1925. Bull. 5.

(10) Hazard, *217*, No. **117**; 25. (11) Nippoldt, in Müller-Pouillets, *Lehrbuch der Physik und Meteorologie*, Vol. 4. 1914. (12) Schmidt, *Enzykl. math, Wiss.*, Vol. 6; 18. (13) Schmidt, *Z. Geophysik*, **1**: 281; 25. (14) Swann. *Encycl. Brit.*, 1927.

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ACOUSTICS

GEORGE WALTER STEWART, SPECIAL EDITOR

PHYSICAL ASPECTS OF AUDITION

H. FLETCHER

For general bibliography of speech and hearing, *see* (6)

SYMBOLS AND DEFINITIONS

d.v.	Double (or complete) vibration(s).
E	Physical intensity of a sound = power (energy per second) it transmits per a unit of area normal to direction of propagation.
N	Frequency = number of d.v. per unit of time.
P	Amount by which the r.m.s. pressure exceeds the static pressure; P_0 = threshold value of P for an average normal ear; it depends upon N; P_m = value of P required for audition in presence of a masking tone.
r.m.s.	Root-mean-square; r.m.s. pressure = square root of the time average of $(\text{pressure})^2$.
S	Sensation level.
sen	Sensation unit.
t	Time.
v.p.s.	Vibrations per second; 1 v.p.s. = 1 d.v. per sec.
φ	Phonic level.

Masking of a tone (A) by another (B) means the difficulty in distinguishing A when sounded simultaneously with B. It is expressed by the difference in phonic level between P_m and P_0, this equals $20 \log_{10} (P_m/P_0)$ sen. (*See* Figs. 2, 3, 4.)

Phonic level of P above the fixed datum corresponding to P' is $\varphi_P = 20 \log_{10} (P/P')$ sen. In this section P' is taken as 1 dyne cm^{-2}. (*Cf.* Sensation unit.)

Sensation level (S) measures the auditory intensity of sound; it is the excess of the phonic level above that of P_0. For a pure tone, $S = \varphi_P - \varphi_{P_0} = 20 \log_{10} (P/P_0)$ sen.

Sensation unit (sen) is defined as that fractional change in intensity which is just perceptible by the ear. Throughout the range of audition, it is found that if the sensation being experienced is that corresponding to $P = P_1$, then the smallest perceptible change is approximately $1/20$ of that caused by increasing P from P_1 to $10P_1$. Hence in the range P_1 to P_2 there are $20 \log_{10} (P_2/P_1)$ sen. It is convenient to regard this relation as extending indefinitely, irrespective of the range of audition, and to regard each value of P as corresponding to a phonic level of $20 \log_{10} (P/P')$ sen above some convenient fixed datum (P') which is independent of the auditor and audition. (*Cf.* (5).)

Sensitivity of the ear is inversely proportional to P_0; the unit is so chosen that the sensitivity $= 1/P_0$.

Threshold value (P_0) of P for any given auditor and tone is that least value of P, in the ear canal, which produces an audible sound of that tone.

TABLE 1.—SENSITIVITY OF THE EAR

See also Vol. I, p. 94

Absolute Sensitivity $= 1/P_0$.—*Differential sensitivity* is the reciprocal of the least perceptible fractional change ($\Delta E/E$, $\Delta N/N$) in E or N. Sensitivity in recognition of pitch may be taken as the reciprocal either of the time the tone must persist, or of the total number of d.v. that must reach the ear, in order that the tone shall be recognized.

Unit of N = 1 v.p.s.; of P_0 = 1 dyne/cm^2; of t = 1 sec; of S = 1 sen.

Limits of Audibility (6).—Lower limit varies from N = 8 to 40; upper, from N = 12 000 to 35 000.

LITERATURE

(For a key to the periodicals see end of volume)

(1) Angenheister, *B95*, Vol. 15. (2) Auerbach, *B90*, Vol. 4. (3) Bauer, *268*, **25**: 145; 20. (4) Bauer, *268*, **28**: 1; 23. (5) British Admiralty Charts. (6) Bur. Central Magn. Terr. *Atlas magnétique*. Paris, Maurin, 1905. (7) Chree, *Encycl. Brit.*, 11th ed., **17**: 353; 10. (8) Dyson and Furner, *520*, *Geophys. Suppl.*, **1**: No. 3; 23. (9) Fleming, *Trans. Sect. Terr. Mag. Elec., Intern. Geophys. Union*, Madrid, 1925. Bull. 5.
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Sensation level (S) measures the auditory intensity of sound; it is the excess of the phonic level above that of P_0. For a pure tone, $S = \varphi_P - \varphi_{P_0} = 20 \log_{10} (P/P_0)$ sen.

Sensation unit (sen) is defined as that fractional change in intensity which is just perceptible by the ear. Throughout the range of audition, it is found that if the sensation being experienced is that corresponding to $P = P_1$, then the smallest perceptible change is approximately $\frac{1}{20}$ of that caused by increasing P from P_1 to $10P_1$. Hence in the range P_1 to P_2 there are $20 \log_{10} (P_2/P_1)$ sen. It is convenient to regard this relation as extending indefinitely, irrespective of the range of audition, and to regard each value of P as corresponding to a phonic level of $20 \log_{10} (P/P')$ sen above some convenient fixed datum (P') which is independent of the auditor and audition. (*Cf.* (5).)

Sensitivity of the ear is inversely proportional to P_0; the unit is so chosen that the sensitivity = $1/P_0$.

Threshold value (P_0) of P for any given auditor and tone is that least value of P, in the ear canal, which produces an audible sound of that tone.

Table 1.—Sensitivity of the Ear

See also Vol. I, p. 94

Absolute Sensitivity = $1/P_0$.—*Differential sensitivity* is the reciprocal of the least perceptible fractional change ($\Delta E/E$, $\Delta N/N$) in E or N. Sensitivity in recognition of pitch may be taken as the reciprocal either of the time the tone must persist, or of the total number of d.v. that must reach the ear, in order that the tone shall be recognized.

Unit of N = 1 v.p.s.; of P_0 = 1 dyne/cm^2; of t = 1 sec; of S = 1 sen.

Limits of Audibility (6).—Lower limit varies from N = 8 to 40; upper, from N = 12 000 to 35 000.

Absolute sensitivity (9, 13, 20); *see also* Fig. 1.

N	64	128	256	512	1024	2048	4096
P_0	0.12	0.021	0.0039	0.0010	0.00052	0.00041	0.00042

Differential sensitivity for monaural reception of successive tones (12, 14).

$\Delta E/E$ depends upon both S and N, and is given by the empirical equation $\Delta E/E = (\Delta E/E)_\infty + \{(\Delta E/E)_t - (\Delta E/E)_\infty\} \times 10^{-rS/10}$, where $(\Delta E/E)_\infty = 126/\{80N^{0.5} + N\} + 0.000015N$, $(\Delta E/E)_t = 0.3 + 0.003N + 193/N^{0.8}$, and $r = 0.244 \times 10^6/\{358\,000N^{0.125} + N^2\} + 0.65N/\{3500 + N\}$.

$\Delta N/N$ varies with S about as $\Delta E/E$ does. For $S = 40$ sen, $\Delta N/N$ varies with N thus:

N, v.p.s.	64	128	256	512	768 to 4096
$\Delta N/N$, %	0.93	0.59	0.4	0.32	0.3

Pitch Recognition (1).—t and d.v. = least duration of the tone, and smallest number of d.v. received, consistent with recognition of the tone.

E	Weak			Medium		
N	128	384	512	256	384	512
t	0.0946	0.0627	0.0579	0.0691	0.0445	0.0427
d.v.	12.1	24.1	29.6	17.6	17.1	21.8

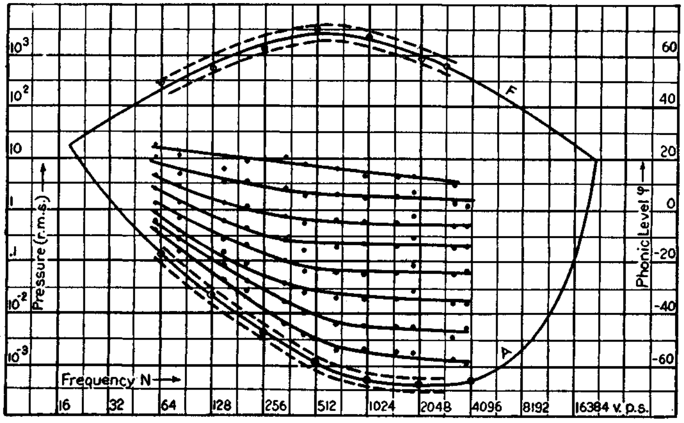

FIG. 1.—Phonic levels (φ) for equality of loudness of pure tones. Threshold values of audibility are shown by curve A (weighted mean (7, 9, 13), pitch limits range (6) from $N = 8$ to 40 and from $N = 12\,000$ to 35 000), of feeling, by curve F (18); half of observations lie between the dotted curves. Interior curves are contour lines of equal loudness, reference tone being $N = 700$ v.p.s.; each point is average of 3 observations by each of 22 observers; distance from curve A measures the sensation level. φ = phonic level, datum = 1 dyne/cm², unit = 1 sen; unit of pressure = 1 dyne/cm².

Loudness (8, 11, 16).—Until recently it was thought that the loudness of a tone is measured by its sensation level, but there is not a strict proportionality between these two quantities. Contour lines of equal loudness for pure tones show that tones below 1000 v.p.s. increase in loudness more rapidly than do tones of higher frequency. (*See* Fig. 1.)

Localization of Pure Tones (17).—If 100 v.p.s. $\lesssim N \lesssim$ 1000 v.p.s., then, approximately, $\theta = \psi/(0.8 + 0.0034N)$, if unit of N = 1 v.p.s.; θ = angle the apparent direction of the source makes with median plane of the observer; ψ = angular phase difference of the tone at the two ears. θ and ψ must be expressed in the same unit; positive direction of θ is from the front towards the ear of the leading phase.

Miscellaneous Aural Data.—Minimum audible power = $4(10)^{-}$ microwatt/cm² (9, 13, 20). Ear canal: Length = 2.1 to 2.6 cm, volume = 1 cm³, area of open end = 0.33 to 0.50 cm². Drum. Diameter = 0.85 cm vertical, 1.00 cm horizontal; area = 0.65 cm². Hammer: Length = 0.8 to 0.9 cm; weight = 23 mg. Anvil weighs 25 mg. Stirrup weighs 3 mg (10, 21). Mechanical impedance of drum (7) for N = 200 to 4000 v.p.s. = 20 to 30 dyne/(cm per sec); that is, a value of P corresponding to an r.m.s. periodic force of 20 or 30 dyne is required to impart to the drum an effective r.m.s. velocity of 1 cm/sec, the effective

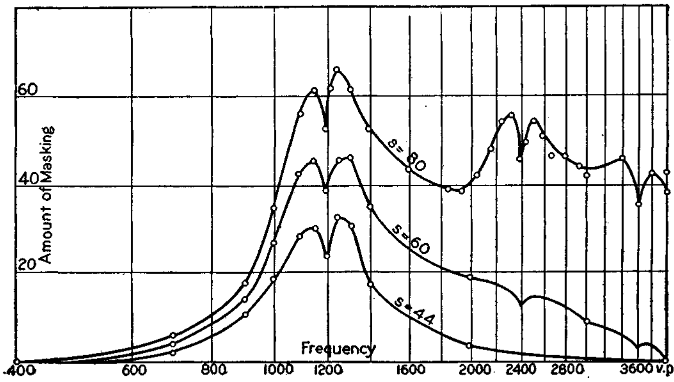

FIG. 3.—Masking of tones of various frequencies by one of N = 1200 v.p.s. and of sensation level = 44, 60 or 80 sen: Both tones sounded in same ear (19).

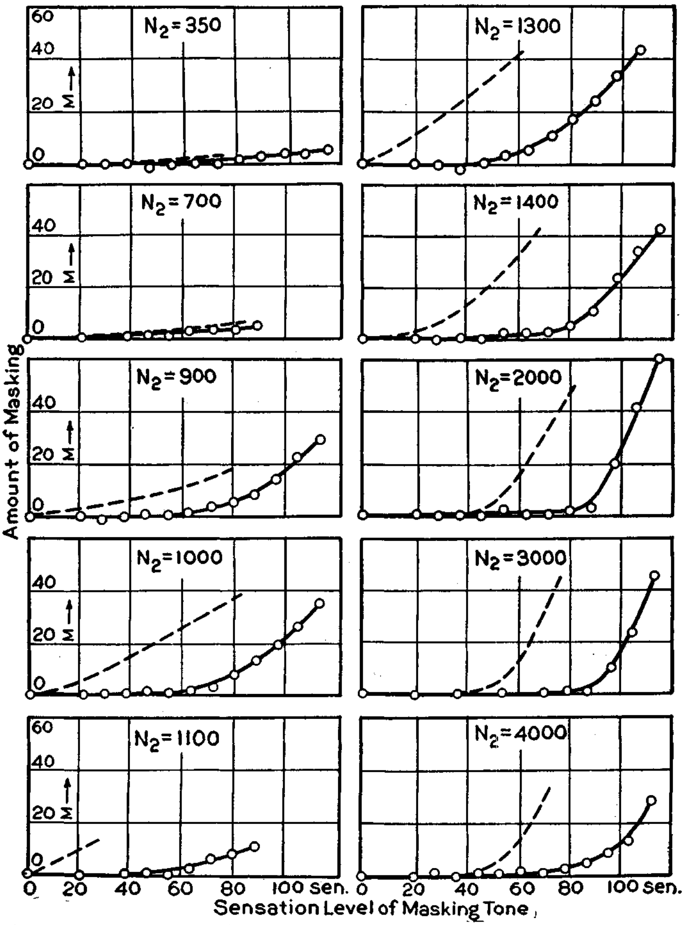

FIG. 4.—Masking of tones N_2 by tones of N = 1200 v.p.s. of various intensities: Tones sounded in opposite ears (19).

Tones introduced by telephone receivers. Dotted lines are from Fig. 2. Attenuation introduced by the skull from ear to ear is such that in monaural reception the phonic levels at the two ears differ by 40 or 50 sen. M = amount of masking. Unit of N_2 = 1 v.p.s.; of M and of sensation level = 1 sen.

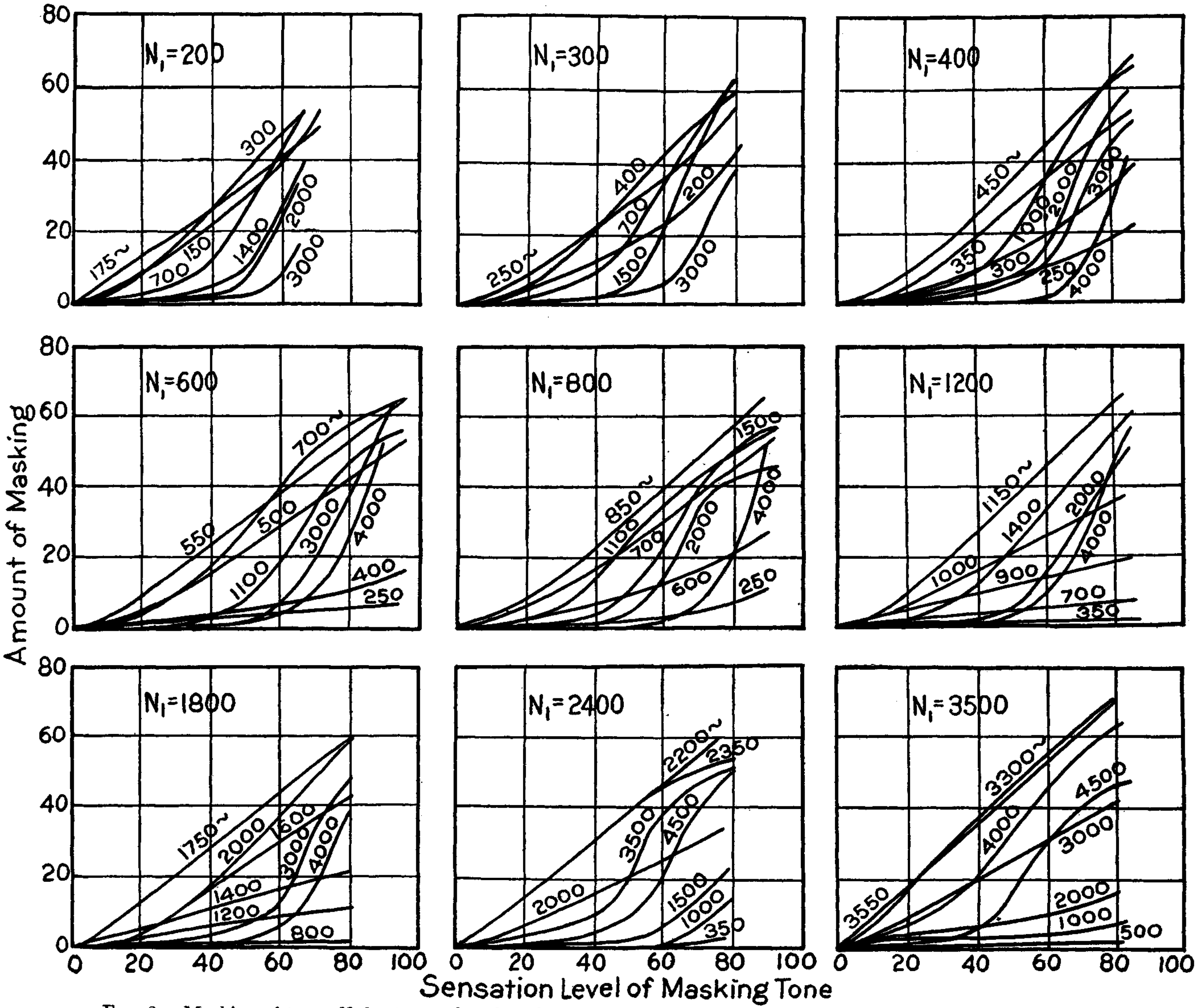

FIG. 2.—Masking of tones N_1 by tones of various frequencies and intensities: Both tones sounded in same ear (19). Frequency (N) of masking tone is marked on curve; unit of N and N_1 = 1 v.p.s.; of masking and sensation level = 1 sen.

velocity ($\bar{v}$) being defined as $\bar{v} = \frac{1}{A}\int_0^A v da$, A being the area of the drum and da being an element of area at which the velocity is v.

Recognition of English Speech (4).—In order that at least 50 % of the spoken syllables shall be recognized: (1) S must be $\gtrsim$ 25 sen if the sound is undistorted. (2) If S = 60 to 80 sen and the sound is distorted either by the removal of all frequencies above $N = N_1$, or of all below $N = N_2$, then N_1 must be >1200 v.p.s. and N_2 <1800 v.p.s. (*See* Fig. 5.)

Speech Power (7).—Mechanical speech power delivered by average speaker = 10 microwatt; if exclude silent intervals, it is 14 microwatt. Peak power frequently rises to 1000 microwatt. For unaccented vowels, average power in the particular cycle carrying the maximum energy is 35 microwatt; for accented vowels, it is 105 microwatt; instantaneous peak powers are 16 times average power (15). Telephonic speech power = electrical power output of a commercial telephone subset during a normal telephone conversation. For individual variations, *see* Fig. 6; for distribution of power among the tones, *see* Fig. 7.

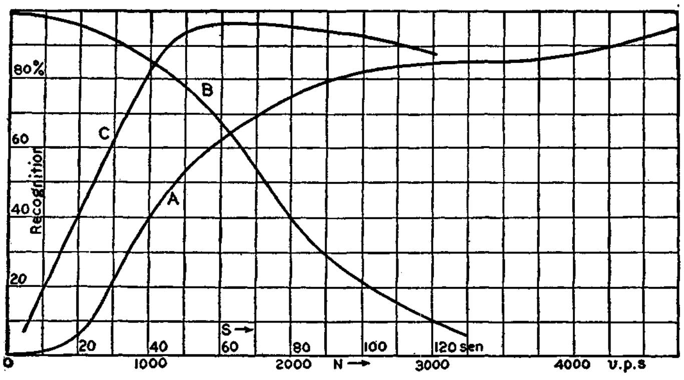

FIG. 5.—Recognition of English speech (4).
Recognition = relative number of syllables recognized. For curve A, all frequencies above N are eliminated; for B, all those below N; C shows effect of sensation level (S) upon recognition of the undistorted sounds. For A and B, S = 60 to 80 sen.

Table 2.—Relative Frequency (F) of Occurrence of Sound Elements of English Speech (3)

Sound = sound element; Key = English word containing the sound; unit of F = 1% of total

Sound	Key	F	Sound	Key	F
a	top	3.3	h		1.81
ā	tape	1.84	j		0.44
á	tap	3.95	k		2.71
e	ten	3.44	l		3.74
ē	eat	3.12	m		2.78
er	term	0.63	n		7.24
i	tip	8.53	ng	hang	0.96
ī	dike	1.59	p		2.04
o	ton	6.33	r		6.88
ō	tone	1.63	s		4.55
ó	talk	1.35	sh	shell	0.87
u	took	0.71	th	tooth	0.37
ū	tool	1.89	th	then	3.43
ou	our	0.59	t		7.13
b		1.81	v		2.28
ch	chalk	0.52	w		2.08
d		4.31	y		0.60
f		1.84	z		2.97
g		0.74	Total		100.00

LITERATURE

(For a key to the periodicals see end of volume)

(1) Bode, *Psychologische Studien*, (*Wundt*), **2**: 293; 07. (2) Crandall and MacKenzie, *2*, **19**: 221; 22. (3) Dewey, *The relative frequency of English speech sounds*, Cambridge, Harvard Univ. Press, 1923. (4) Fletcher, *143*, **193**: 729; 22. (5) Fletcher, *143*, **194**: 289; 23. (6) Fletcher, *143*, **194**: 323; 23. (7) Fletcher, *Bell System Tech. J.*, **4**: 375; 25. (8) Fletcher and Steinberg, *2*, **24**: 306; 24. (9) Fletcher and Wegel, *2*, **19**: 553; 22.

(10) Howell, *Text-book of physiology*. Philadelphia, Saunders, 1924. (11) Kingsbury, *2*, **29**: 588; 27. (12) Knudsen, *2*, **21**: 84; 23. (13) Kranz, *2*, **21**: 573; 23. (14) Riesz, Bell Telephone Laboratories, N. Y., *0*. (15) Sacia, Bell Telephone Laboratories, N. Y., *0*. (16) Steinberg, *2*, **26**: 507; 25. (17) Stewart, *2*, **15**: 425, 432; 20. (18) Wegel, *Bell System Tech. J.*, **1**: 56; 22. (19) Wegel and Lane, *2*, **23**: 266; 24.

(20) Wien, *278*, **97**: 1; 03. (21) Wrightson, *Enquiry into the mechanism of the internal ear*. New York, Macmillan, 1918.

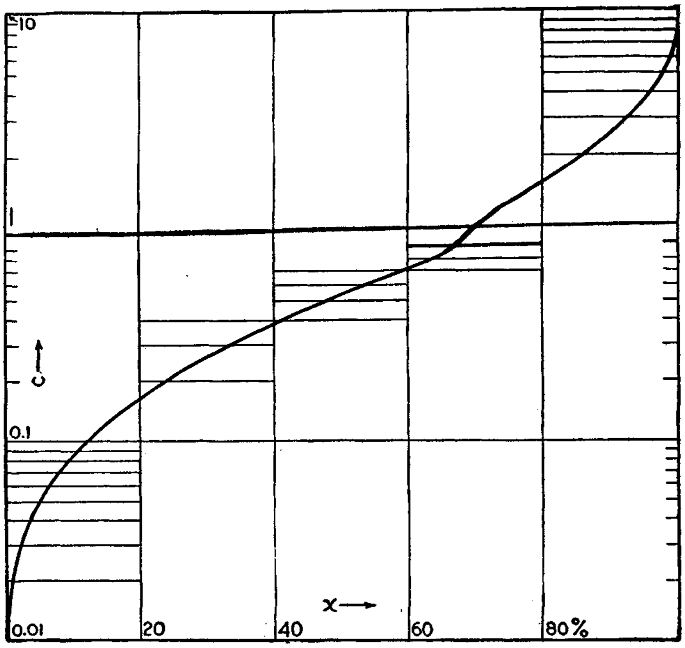

Fig. 6.—Variation in telephonic speech power of individuals (7). x = percentage of speakers having telephonic speech power $\lessgtr CA$, where A = average power of all speakers.

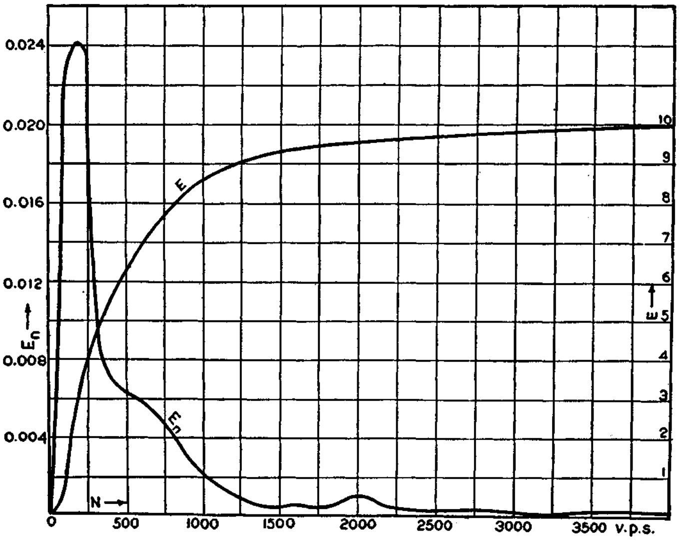

Fig. 7.—Distribution of power in average spoken English (2).

Total power carried by all the tones from $N = 0$ to $N = n'$ is $E = \int_0^{n'} E_n dn$, where $E_n dn$ = power carried by the tonal region $N = n - \frac{1}{2}dn$ to $N = n + \frac{1}{2}dn$. Unit of E_n = 1 microwatt per v.p.s.; of E = 1 microwatt; of n, n', N = 1 v.p.s.

SOUND-GENERATORS

F. R. Watson

CONTENTS

DEFINITIONS AND SYMBOLS

Amplitude.—The amplitude of the oscillation of a point is its extreme departure from that condition of rest about which the oscillations occur. If the departure (y) at the time τ satisfies the equation $y = A \sin (n\tau + \epsilon)$, A is the amplitude.

Frequency.—The frequency of an oscillation is the number of vibrations per unit of time.

Period.—The period of an oscillation is the time required for one vibration; it is the reciprocal of the frequency.

Vibration.—In each interval between successive returns of the body to exactly the same phase of its motion, it executes a single vibration. For example, from the instant a pendulum bob passes from left to right through the lowest point of its arc to the next instant in which it passes in the *same* direction (left to right) through the same point is the interval occupied by a single vibration of the pendulum.

a	Thickness in the plane of vibration.
E	Young's modulus of elasticity.
F	Tensile force.
l	Length.
N	Frequency.
N_i, N_o, N_t	Frequency for ideal case, at 0°C, at t, °C.
p	Pressure.
r, r_o	Radius, value of r at 0°C.
t	Temperature, °C.
v.p.s.	Vibrations per second.
ρ, ρ_0	Density, value of ρ at 0°C.
σ	Mass per unit of length.

Other symbols will be defined where used.

SOUND-GENERATORS

Of the sound-generators, exclusive of musical instruments, only those that are most commonly used or that appear to be useful are considered here. They may be classified as follows:

I. Strings and strips: (*A*) Transverse vibrations: (1) Plucked string. (2) Ribbon loud-speaker. (*B*) Longitudinal vibrations: (3) Stretched wires. (4) Berger's hydrophone.

II. Rods and forks: (5) Tuning fork.

III. Plates and diaphragms: (*A*) Electromagnetic drive: (6) Telephone receiver. (7) Hewlett's generator. (8) Loud-speaker. (9) Fessenden's hydrophone oscillator. (*B*) Electrostatic drive: (10) Electrostatic transmitter. (*C*) Mechanical drive. (11) Piston-phone. (*D*) Piezoelectric generator: (12) Quartz (SiO_2). (13) Rochelle salt ($KNaC_4H_4O_6.4H_2O$). (*E*) Free elastic vibrations: (14) Bell.

IV. Confined fluid: (15) Organ pipe. (16) Tonvariator. (17) Galton's pipe. (18) Singing tube. (19) Thermophone.

V. Free fluid: (20) Siren. (21) Diaphone. (22) Explosives.

Of the preceding generators, numbers 2 and 8 are especially suited for the intense emission of spoken sounds, and numbers 4, 9, 14, and 22 are suitable for the emission of sound under water.

Descriptions of other generators may be found in (**3, 4, 5, 9, 10, 18, 47, 49, 54, 59**).

1. *Plucked String* (**3, 39**).—If the string is perfectly flexible, $N_i = n/2l\,\sqrt{F/\sigma} = n/2l\,\sqrt{F(1+\alpha t)/\pi r_0^2\rho_0}$, if l, the distance between the bridges, is independent of t. Here n is the number of loops in the length l, n may have any integral value, and α is the coefficient of linear expansion of the string. Actual strings are not perfectly flexible; for them $N = N_i(1 + c)$, where c, the stiffness correction, increases as l is reduced. For a steel wire with r = 0.205 mm, F constant and such that N = 76 v.p.s. if l = 90 cm, Melde (**39**) found c varied thus:

l..............	90	45	30	22.5	18 cm
c..............	0	1.3	1.8	3.9	5.3%

2. *Ribbon Loud Speaker* (**51**).—When a variable electric current flows through a thin, corrugated, metallic ribbon mounted in a magnetic field, the ribbon vibrates, thus generating sound. For such loud speakers, an aluminum ribbon 10 cm long, 1 cm wide, 0.001 cm thick, weight = 30 mg, resistance = 0.05 ohm, is used; its maximum current, voltage, power, and amplitude are 10 ampere, 0.5 volt, 5 watt, and 0.5 cm. When fitted with a horn, the emitted speech was intelligible at a distance of 1 km (**26**).

3. *Longitudinal Vibration of a Stretched Wire* (**12**).—$N_i = 1/2l\sqrt{E/\rho}$ and is independent of F. For a steel wire of l = 676 cm and r = *ca.* 0.2 mm, N was found to be 762 v.p.s.

4. *Berger's Hydrophone* (**50**) consists of 3 steel strips, each 3.84 cm (1.5 in.) wide, 0.16 cm (1⁄16 in.) thick, and about 180 cm (6 ft.) long, attached, below the water-line, to the side of a ship, and set into longitudinal vibration by means of a friction drum driven by a 2.2 kw (3 h.p.) motor. The sound was heard under water to a distance of 6.4 km (4 miles).

5. *Tuning Forks* (**3, 40**).—$N = C\dfrac{a+\delta_a}{(l+\delta_l)^2}\sqrt{\dfrac{E}{\rho}}$, where C is a numerical constant, and δ_a, δ_l are corrections which are independent of a and l. For steel forks, $C\sqrt{E/\rho}$ = 81 800, δ_a = 0.05 cm, δ_l = 0.38 cm; l is the projection of the prong on the axis of the fork; N is independent of width perpendicular to plane of vibration. If $-26°C < t < +56°C$, $N_t = N_0/(1 + 0.000134t)$ (**11**); for higher temperatures, *see* Fig. 1. For variation of N with amplitude, *see* Fig. 2. By controlling the temperature and amplitude, and using a specially designed spark-gap, a fork of 25 v.p.s. has been vibrated several hours daily for several weeks without a change exceeding 1 in 10 000 in N (**60**). By means of a circuit containing an oscillating electron tube, forks of N = 50 to 2000 v.p.s. may be kept in vibration without the use of a mechanical contact circuit breaker (**16**).

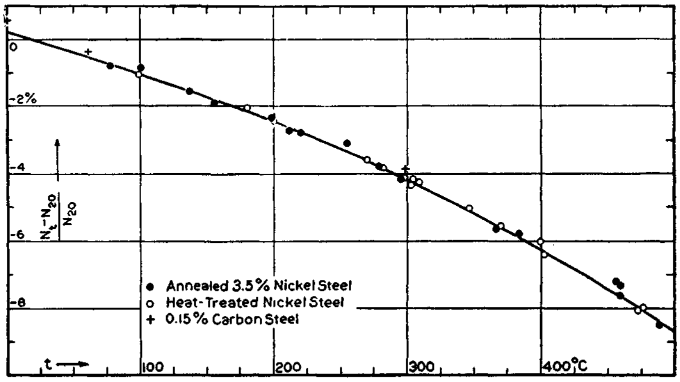

FIG. 1.—Tuning forks: Variation of frequency (N) with temperature (**31**).

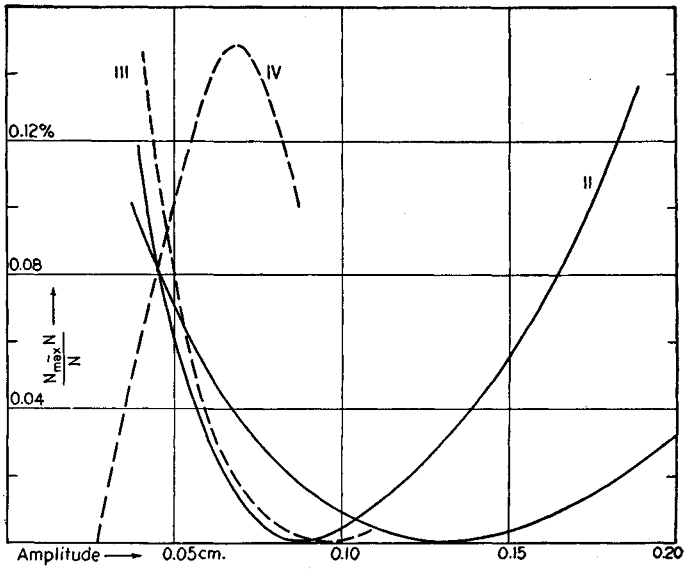

FIG. 2.—Tuning forks: Variation of frequency (N) with amplitude (**11**). The driving current was interrupted by break between spring and point. Curves I and II refer to same fork; for I the amplitude was varied by varying the current, for II it was varied by changing the positions of the pole-pieces of the magnet. Curves III and IV refer to two other forks; the contacts of fork IV were mounted quite differently from those of the others.

6. *Telephone receivers* consist of a circular metallic diaphragm, either of magnetic material or with a plate of such material attached to its center, which is clamped along its circumference and is vibrated by a varying magnetic field. For variation of the amplitude with the frequency of the field, *see* Fig. 3. The over-all efficiency (Eff.) is defined as the ratio of the acoustic energy emitted to the electric energy supplied. For a bipole, 87 ohm, Bell telephone receiver, $N = 992$ v.p.s., no cap over diaphragm, Eff. = (0.375 ± 0.025) % (33). For variation of Eff. with N *see*, Fig. 4. Minimum electrical power required to give a sound audible to a normal ear is of the order of 3.3×10^{-13} watt for a representative type of receiver (55). For acoustic characteristics, *see* (33).

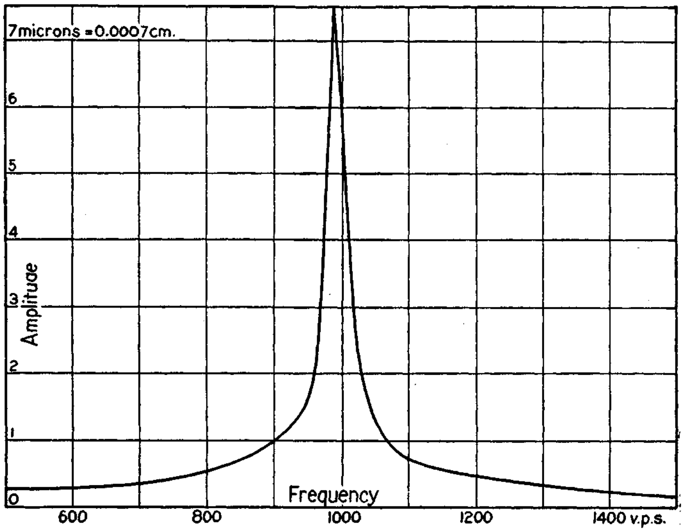

FIG. 3.—Telephone receiver: Variation of amplitude with frequency of current (30).

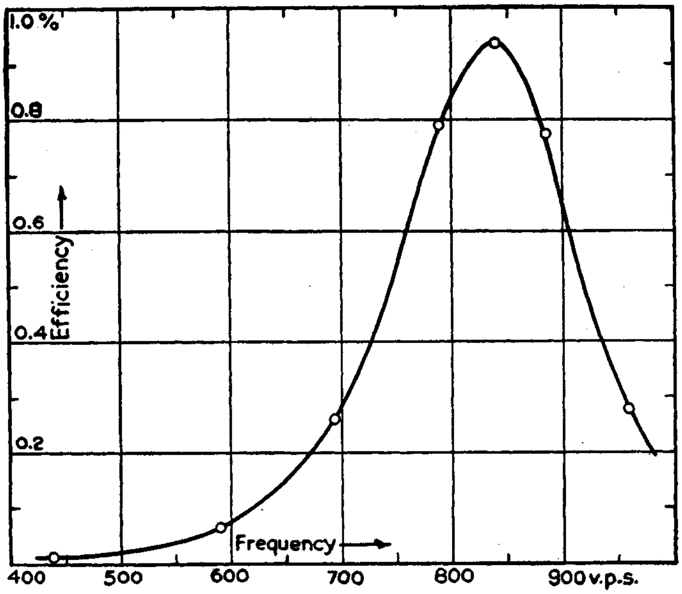

FIG. 4.—Telephone receiver: Variation of acoustic efficiency with frequency of the current (38).

Ordinates are the over-all efficiencies.

7. *Hewlett's tone generator* (27) consists of a thin, circular, metallic diaphragm clamped along its circumference, and placed between two flat circular coils, each wound in its own plane. By a suitable bridge connection, a constant direct current is passed through the coils in such a way as to produce in the diaphragm a radial magnetic field, and at the same time, an alternating current is so passed through them as to produce an axial field. As a result, the diaphragm vibrates with the period of the alternating current. If the diaphragm is nonmagnetic and the current is simply harmonic, the tone is pure. When a certain instrument was excited by a direct current of 1.5 ampere and a voice current of 0.1 ampere, the reproduced speech was comfortably audible at all points in a room 20 ft. square (28). The amplitude (A) varied thus with the frequency of the alternating current, the strength of the current remaining constant:

N........	1440	1600	2200	3700	v.p.s.
A........	4.6	4.16	4.04	1.72	$\times 10^{-5}$ cm

8. *Loud-speaker*.—For general discussion, *see* (13, 44); for "ribbon" loud-speaker, *see* 2, above. The over-all efficiency varies from 0.1 % to 1 % (13, 44). A balanced electromagnetic loud-speaker, diaphragm 7.62 cm (3 in.) in diameter, equipped with a horn, and radiating approximately 1 watt of acoustic energy, was heard loudly at a distance of 0.8 km (0.5 mile) (21). A loud-speaker equipped with a paper cone of 45°, maximum diameter = 15.25 cm (6 in.), paper 0.18 to 0.25 mm (0.007 to 0.010 in.) thick, had a general sensitivity equal to that of a good horn-type speaker, and responded to both low and high frequencies (48). Data for loud-speaker horns (19, 22).

9. *The Fessenden hydrophone oscillator* is a diaphragm operated by either an electrodynamic or electromagnetic drive. With the electrodynamic arrangement, a 5 kw. oscillator of 545 kg. wt. (1 200 lb. wt.) has a tuned diaphragm, about 60 cm (2 ft.) in diameter, clamped at the rim, and attached at the center to a light, hollow copper cylinder. This cylinder is mounted in a powerful magnetic field (about 15 000 line/cm^2) so that alternating currents about the core inside the cylinder induce in the copper alternating currents of about 10 000 ampere. The cylinder is thus pushed and pulled with magnetic forces of about 1 800 kg. wt. (4 000 lb. wt.). When suspended 366 cm. (12 ft.) below the surface of open water the sound ($N = 500$ v.p.s.) was detected under water at a distance of 57.4 km (1, 50).

10. *Electrostatic, or condenser, transmitter* (58) consists of an electric condenser composed of a thin (0.051 mm) metal diaphragm and a heavy plate separated by an air layer 0.025 mm thick. The diaphragm is under such radial tension that its natural frequency in air is 7000 v.p.s. An alternating voltage applied to the condenser causes the diaphragm to vibrate with twice the frequency of the voltage. The intensity of the emitted sound is of the same order as that from a telephone receiver. Such a transmitter may be used as a standard source of sound.

11. *Piston-phone* (56, 57).—A rotating cam imparts a simple harmonic motion to a piston which is attached to a diaphragm; $N = 10$ to 200 v.p.s.

12, 13. *Piezoelectric Generator*.—A suitably cut, thin parallelopipedon of a piezoelectric crystal (*see* p. 207) will execute dilatational-rarefactional vibrations when subjected to a transverse alternating electric field. The amplitude of the vibrations is exceedingly small unless the frequency of the field is near that of one of the natural periods of the parallelopipedon. Such plates are useful for generating waves of high pitch.

If the plate is of quartz (SiO_2) and is cut so that its broad faces are perpendicular to an electrical axis and its breadth is parallel to the optic axis, then its length (l) will be perpendicular to each of these axes, and a varying field perpendicular to its broad faces will generate vibrations in the directions of l and of e, the thickness; the natural frequencies, N_l and N_e are given by the equations $lN_l = eN_e = 275\ 000$ cm v.p.s.

Plates of rochelle salt ($KNaC_4H_4O_6.4H_2O$) may be used likewise, and in some respects are superior to those of quartz (7).

14. *Bells* rung under water may be heard under water at a distance of 3 to 5 km (2 to 3 miles) (1, 41).

15. *Organ Pipes.*—The natural pitch of an open organ pipe is $N = \frac{v}{2(l + c + c')}$, and of a closed one is $N = \frac{v}{4(l + c)}$, where c = correction for mouth-end of pipe = $2.7r$ (45), c' = correction for open end (if pipe has a flange $c' = 0.82r$ (36), if no flange $c' = 0.6r$ (45), observed value for thin brass tube of $r = 5.3$ cm is $c' = 0.576r$ (6)), v = velocity of sound in fluid filling the pipe = $\sqrt{\gamma p/\rho} = v_0\sqrt{1 + \alpha t + \beta t^2}$, γ = ratio of specific heats; for air, $v_0 = 330.6$ m/sec, $\alpha = 0.00371$, $\beta = -0.126 \times 10^{-6}$, for other fluids, *see* p. 461. The pitch of the sound actually emitted increases with the blowing pressure; for a pipe of natural pitch 255 v.p.s., the observed pitch was 255 + δ, where δ varied as follows (46):

p	1.9	2.08	2.2	2.69	3.35
δ	−0.5	+0.1	+1.5	+2.1	+4.2

p	3.88	4.72	5.74	6.92	10.7 cm H_2O
δ	+5.6	+7.1	+8.4	+9.3	+11 v.p.s.

The intensity (I) also increases with the blowing pressure (37):

p	20	24.8	30.8	35.8	39.0	cm H_2O
I	4	9	18	26	35	Arbitrary units

16. *Tonvariator* (53) is a Helmholtz resonator blown by air-blast. Its pitch can be varied continuously over about an octave; its tone is practically pure, the overtones being very high and weak (25, 47). The intensity (I) increases linearly with the blowing pressure (p cm of H_2O), at least within the range $10 < p < 39.5$, being given by $I = 0.67p - 4.7$, unit of I being arbitrary (37).

17. *Galton's pipe* gives tones varying from about 3 500 to 50 000 v.p.s., depending upon its length (l) and the width (w) of its mouth (17):

l	22.4	7.18	4.21	2.7	1.8
w	2.3	1.6	0.9	0.9	0.9
N/1000	3.48	10.0	15.0	20.0	25.0

l	1.26	0.82	0.47	0.27 mm
w	0.9	0.9	0.9	0.9 mm
N/1000	30.0	35.0	40.0	45.0 v.p.s.

18. *Singing tube* (35) consists of an outer glass (pyrex) tube closed at one end, and a shorter inner tube open at both ends and at one end sealed to the outer tube at such a place that its other end is near the closed end of the outer tube. When the relative dimensions of the tubes are suitably adjusted, a strong, pure tone is emitted when the closed end of the tube is heated. The pitch depends upon the difference in temperature of the two ends of the tube. For a certain tube the following data were obtained (34):

t_c	1	204	355	448	524	°C
t_o	−181	−88	−16	+26	+57	°C
$t_c - t_o$	182	292	371	422	+467	°C
N	213	300	378	425	450	v.p.s.

19. *Thermophone* (2, 57).—When a very thin metallic strip immersed in a fluid is heated by an alternating electric current, the periodic expansion and contraction of the adjacent film of fluid give rise to vibrations in the fluid. The intensity of the sound is low, and is indefinite unless the fluid is confined in an enclosure of which the dimensions are all small as compared with the wave-length of the vibrations. If the heating current has a pure sine-wave form, the emitted sound is a pure tone of twice the frequency of the current. (*See* Fig. 5.)

20. *Siren.*—In a "pure tone" siren, the overtones are weak (42). (*See* Fig. 6.)

21. *Diaphone* (32) is a modified siren. It consists of a cylinder fitted with a piston which is oscillated through a small amplitude by compressed air, and which intermittently interrupts an air-blast. It emits a powerful tone. It may emit 1.76 kw (2.36 h.p.) of acoustic energy with an over-all efficiency of 6 to 8% and be heard for miles.

22. *Explosives* (23, 24, 52).—The detonation of bombs containing from 225 to 900 g (0.5 to 2 lb.) of T.N.T. (2, 4, 6-trinitrotoluene, $C_7H_5N_3O_6$) has been used as an under-water source of sound. The sound from a 500 g bomb detonated at 8 to 10 m below the surface has been detected under water at distances of 15 to 18 km (52).

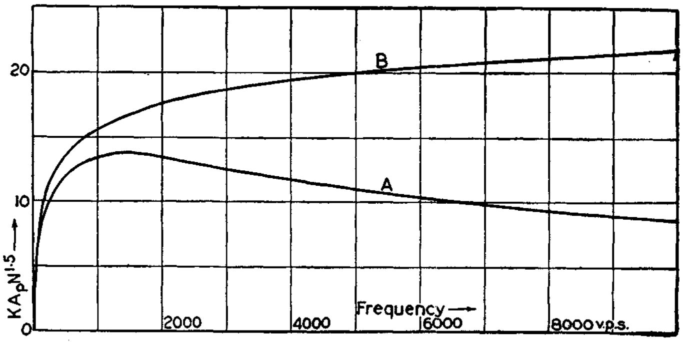

Fig. 5.—Thermophone: Relation between frequency (N) and amplitude (A_p) of oscillation of pressure (57).

In each case mean temperature of strip = 335°K, of air in enclosure = 300°K. For A, strip was a Wollaston wire 1 cm long, $2r = 0.003$ mm; volume of enclosure = 1 cm³; for B, strip was gold foil, area = 5.5 cm², thickness = 0.079μ = 0.79×10^{-5} cm; volume of enclosure = 14 cm³. K is a constant.

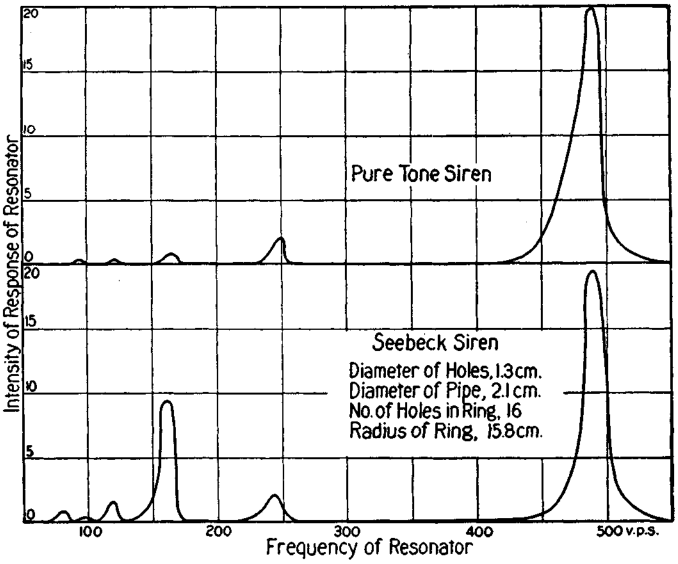

Fig. 6.—Sirens: Comparison of "Pure tone" and Seebeck sirens (42).

Notes analyzed by means of resonators. Arbitrary unit of intensity.

DEVICES FOR STABILIZING THE FREQUENCY OF OSCILLATION OF CIRCUITS CONTAINING ELECTRON TUBES

The frequency of an oscillating electron tube and circuit may be stabilized by the use of a piezoelectric resonator (*see* No. 12 above). Variations with resonator are only about 3% of those without (8).

By the use of 2 electron tubes and coupling by tuned impedances, the frequency of oscillation of the circuit may be made quite independent of changes in plate voltage and in filament current.

In one case a change of 50 % in plate voltage produced but 0.1 %, and of 43 % in filament current produced but 0.3 %, change in the frequency (20).

By the use of a tuning fork (14, 29), the frequency can be maintained constant and equal to that defined by the fork to within 1 part in 100 000. Changing tubes produced a maximum effect of 1 in 100 000; there was no change as the tubes aged and no change as the filament current was reduced, provided the current was not less than 80 % of its normal value. As the plate voltage was increased the frequency increased by 0.0002 % per volt of change.

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DETECTION AND MEASUREMENT OF SOUND

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This bibliography covers all devices now available for quantitative measurements. For a recent discussion of such devices, *see* (39.1). Apparatus covering the range within which the human ear is sensitive (*see* p. 450) is very elaborate and compromises are generally required to meet a given situation.

1. Interferometric measurement of amplitude of changes in density (29, 35, 39).
2. Rayleigh disc: In free air (52); in simple resonator (12, 30); in double resonator (4, 38, 41).
3. Webster's phonometer (21, 42, 43).
4. Wien's vibration manometer (47, 51).
5. Torsion balance for measuring pondermotive force (2, 31, 51), theory (31).
6. Miller's phonodeik (23).
7. Ballistic phonometer (3).
8. Acoustic valves (28).
9. Magnetophones (20, 27, 34).
10. Contact microphones (10, 27).
11. Thermo-microphones (8, 9, 15, 16, 17, 24, 25, 33, 40).
12. Condenser microphones (5, 45, 46).
13. Resonators (13, 25, 26, 32, 40).
14. Horns (7, 11, 14, 18, 26, 36, 37, 43, 44).
15. Geophones (1, 22).
16. Hydrophones (6, 19, 48, 49, 50).

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TRANSMISSION, REFLECTION, REVERBERATION AND ABSORPTION OF SOUND

P. E. Sabine

SYMBOLS AND DEFINITIONS

A	Amplitude of displacement of element of the medium.
a	Absorbing power.
E	Bulk modulus, modulus of volume elasticity.
I	Intensity of the sound.
l	Length of a tube, or thickness of a septum.
N	Frequency, pitch, number of complete vibrations per unit of time.
P	Acoustic power.
R	Radius.
s	Area.
T	Duration of audible reverberation.
t	Time.
V	Volume of room or other enclosure.
v	Velocity of sound in medium considered.
v.p.s.	Vibrations per second.
α	Coefficient of absorption.
δ	Damping coefficient, coefficient of attenuation.
λ	Wave-length.
μ	Acoustic resistivity.
ρ	Density.
σ	Mass of septum per unit of area.

Absorbing Power.—As the result of the absorption of sound by a surface of area s, the intensity of the sound in an enclosure dies away exponentially after its emission ceases; $I_t = I_0e^{-\alpha svt/4V}$, where t is the time that has elapsed since I had the value I_0, the source having ceased to emit sound prior to the beginning of the interval t, and v is the velocity of sound in the medium which fills the volume V. The absorbing power of the surface is αs, and α is the coefficient of absorption. If the boundaries (walls, fittings, and occupants) consist of several types of surfaces, the total absorbing power is $a = \alpha_1s_1 + \alpha_2s_2 + \cdot\cdot\cdot$; it is of the dimensions of an area.

Acoustic power is the amount of acoustic energy that is emitted per unit of time.

Acoustic resistivity of a medium is $\mu = \sqrt{E\rho}$. It is the amount by which the r.m.s.[1] pressure in a plane wave must exceed the static pressure if the r.m.s.[1] velocity of the medium is to be unity.

Coefficient of Absorption.—*See* Absorbing power.

Coefficient of Attenuation.—As a sound travels along a tube, the intensity decreases exponentially; $I_x = I_0e^{-\delta x}$; δ is coefficient of attenuation.

Intensity (I) of a sound is used in this section to denote the amount of acoustic energy per unit volume of the medium. For a single beam of advancing sound, Iv is the acoustic energy transmitted per unit of time through a unit of area perpendicular to the direction of propagation.

Transmittivity of an interface or septum = (transmitted energy) ÷ (incident energy).

Reflectivity of a surface = (reflected energy) ÷ (incident energy).

TABLE 1.—TRANSMISSION OF SOUND THROUGH TUBES, HORNS AND WAVE-FILTERS

Amplification by horns: theoretical (1, 2, 7, 8, 14, 17, 23, 37); experimental (3, 4, 12, 14, 15, 16, 18, 20, 21, 22, 31, 38, 39).

Wave-filters are conduits with side openings and, in certain types, associated branches and air-chambers; sounds in predetermined ranges of frequencies cannot pass through them. Theory and experiments (32).

For cylindrical tubes, radii R_1 and R_2 ($R_2 = r_2R_1$), connected by a cone of length l, sound proceeding from tube 1 to tube 2,

$$\frac{A_2R_2^2}{A_1R_1^2} = \frac{1}{\left[1 + \frac{(r_2-1)^2}{r_2}\cdot\frac{(1-\cos\eta)}{\eta^2}\right]^2 + \left[\frac{(r_2-1)^2}{r_2}\cdot\frac{(\eta-\sin\eta)}{\eta^2}\right]^2},$$

where $\eta = \frac{4\pi l}{\lambda}$ (5).

For tube of constant R, $I_x = I_0e^{-\delta x}$; tabular values are δ (11). Unit of R = 1 cm = 0.394 in.; of l = 1 m = 3.28 ft.; of N = 1 v.p.s.; of $\delta = 0.01\ \text{m}^{-1} = 0.00305\ \text{ft.}^{-1}$.

$2R$	N	254	1040	2285	3280	254	1040	2285	3250
	Material	Straight tube				l = 3.04; 90° bend			
2.70	Brass	9.8		16.7	15.7				
2.70	Iron	12.1	13.4	18.7	20.0				
2.54	Fiber	14.8	15.1	25.2	30.2				
4.92	Brass	6.9	8.2	12.1	11.8	6.9	8.9	8.9	14.4
4.92	Fiber	8.9	13.5	14.1	15.1				
7.30	Brass	5.6	6.2	8.9	8.2	6.2	8.2	9.8	10.2
9.84	Brass		4.9	6.6	5.6	4.1	3.1	10.3	7.2

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[1] r.m.s. = square root of the mean square.

TABLE 2.—ACOUSTIC RESISTIVITY AND TRANSMISSION OF PLANE WAVES FROM MEDIUM TO MEDIUM (5)

The external media are assumed to have a thickness that is great as compared with λ; the media are indicated by subscripts, 1, 2, 3, . . . , in the order in which they are entered by the wave, A_1, A_1r = displacement amplitude of incident, of reflected, wave in medium 1.

Two media, plane boundary, normal incidence. $A_1 - A_1r = A_2$; $(A_1 + A_1r)\mu_1 = A_2\mu_2$; $(A_1 + A_1r)/(A_1 - A_1r) = \mu_2/\mu_1$. Write m_2 for μ_2/μ_1; *i.e.*, $\mu_2 = m_2\mu_1$. Then for the interface, the transmittivity is $A_2^2\mu_2/A_1^2\mu_1 = 4m_2/(m_2+1)^2$; the reflectivity is $(m_2 - 1)^2/(m_2+1)^2$.

Three media, plane parallel boundaries, normal incidence. Let $m_2 = \mu_2/\mu_1$, $m_3 = \mu_3/\mu_2$, and l_2 and λ_2 = thickness of medium 2 and wave-length in it; then the transmittivity of the septum is

$$\frac{4m_2m_3}{(m_2m_3+1)^2}\left\{\frac{1}{1-\left[\frac{(m_2^2-1)(m_3^2-1)}{(m_2m_3+1)^2}\sin^2\frac{2\pi l_2}{\lambda_2}\right]}\right\}$$

Acoustic resistivity $(\mu) = \sqrt{E\rho}$; velocity $(v) = \sqrt{E/\rho}$. Unit of E = 1 kg wt./mm² = 1422 lb. wt./in.²; of ρ = 1 g/cm³ = 62.4 lb./ft.³; of v = 1 m/sec = 3.28 ft./sec; of $\mu = 10^4$g cm^{-2} sec^{-1} = 2.05 × 10⁴ lb. ft.$^{-2}$ sec.$^{-1}$.

Medium	E	ρ	v*	μ*
Steel	20 000	7.8	5 010	391
Cast iron	9 500	7.0	3 650	255
Brass	6 500	8.4	2 750	232
Bronze	3 200	8.8	1 890	166
Lead	600	11.4	718	81.9
Wood: Teak	1 600	0.86	4 270	37
Fir	900	0.45	4 430	20
Beech	600	0.80	2 710	22
Water	200	1.0	1 400	14
Rubber	<1	*ca.* 1	<100	<1
Air	0.014	0.0013	325	0.004

* The numbers in this column have been slightly changed in order to make them accord with the tabulated values of E and ρ.

TABLE 3.—TRANSMISSION OF SOUND THROUGH SEPTA BOUNDED BY AIR

Quilts.—Soft, flexible, porous, highly absorbent septa (25). $\text{Log}_{10}(I_1/I_3) = \beta + \gamma l_2$, where l_2 = thickness of the septum and I_3 is intensity after passage through the septum. Unit of ρ = 1 g/cm³ = 62.4 lb./ft.³; of N = 1 v.p.s.; of β = 0.01; of γ = 0.01 cm⁻¹ = 0.305 ft.⁻¹.

Material of septum	ρ	N	128		256		512		1024		2048		4096	
		Covering	β	γ	β	γ	β	γ	β	γ	β	γ	β	γ
Hair, loosely felted	0.14	None	38	5	25	8	35	10	35	15	26	17	48	17
Plant fiber board, coarse	0.24	None	77	25	77	20	68	29	105	41	10	70	22	80
Seaweed, quilted	0.11	Light paper	85	14	67	14	58	22	33	34	35	35	30	52
Plant fiber, soft, quilted	0.14	Heavy paper	71	17	56	14	45	23	45	55	50	108	100	123
Hair and asbestos fiber	0.40	Heavy paper	122	22	130	24	122	43	110	65				
Hair and asbestos fiber	0.55	Paper + burlap	60	36	96	34	87	63	56	100				

Wood, Glass, Steel (24).—Sound transmitted by forced vibrations of the septum: resonance may cause a large variation in transmission for a small variation in pitch. Tabulated values are averages for the 6 values of N of the preceding section. Each complete septum was 2.1 m by 0.79 m (= 6.9 ft. by 2.59 ft.); l = thickness of septum. Unit of l = 1 cm = 0.394 in.

Material	Remarks	l	I_1/I_3
Plate glass	1 pane	0.63	200
Plate glass	4 panes each, 38 by 99 cm	0.63	282
Plate glass	4 panes each, 38 by 99 cm	0.47	190
Plate glass	Small, leaded panes	0.47	302
Window glass	12 panes, each 25.4 by 48 cm	0.32	140
Steel door		0.63	1020
Wooden door	Panelled, birch veneer		74
Oak door	Solid, well seasoned	4.45	140
Oak door	Solid, damp	4.45	231

Masonry (27).—Tabulated values are averages for 20 tones covering the range N = 128 to 4096 v.p.s.; each septum was 1.88 m by 2.34 m (= 6.17 ft. by 7.68 ft.); $I_1/I_3 = K\sigma^{2.5}$, approximately, where $K = 0.0112$ m⁵kg$^{-2.5}$ = 0.590 ft.⁵ lb.$^{-2.5}$; l_t, l_p, l = thickness of tile, of plaster, of complete septum. Unit of l_t, l_p, l = 1 cm = 0.394 in.; of σ = 1 kg/m² = 0.205 lb. ft.²

Material	Remarks	l_t	l_p	l	σ	I_1/I_3	$K\sigma^{2.5}$
Gypsum tile	Solid	5.08		5.08	50.8	230	206
Gypsum tile	Hollow	7.62		7.62	54.3	260	243
Plaster	Solid, metal lath		3.81	3.81	68.0	340	427
Gypsum tile	Solid	7.62		7.62	69.5	468	451
Clay tile	Hollow	10.16		10.16	83.2	677	708
Gypsum tile	Solid, plastered	5.08	3.16	8.24	104.8	1180	1375
Gypsum tile	Solid, plastered	7.62	3.16	10.78	124.2	1910	1923
Clay tile	Hollow, plastered	10.16	3.16	13.32	141.0	2500	2640
Plaster	Solid, metal lath		8.9	8.9	159.0	4000	3570
Plaster	Solid, metal lath		11.75	11.75	204.0	6600	6660

TABLE 4.—COEFFICIENT OF ACOUSTIC ABSORPTION BY BOUNDARIES

If I_0 is the intensity of sound in an enclosure, of volume V, at some instant after the production of the sound has ceased, the intensity at a later time is $I_t = I_0e^{-avt/4V}$, where $a = \alpha_1s_1 + \alpha_2s_2 + \cdot\cdot\cdot$; s_1 = area of the boundary for which the coefficient of absorption is α_1; α_{512} = value of α for N = 512 v.p.s.; α_{av} = average value of α for range N = 128 to 4096 v.p.s. For data for special commercial sound-absorbent materials, *see* (36).

Masonry.—l_m, l_c = thickness of material, of coating. Unit of l_m, l_c = 1 cm = 0.394 in.; of α_{512}, α_{av} = 0.01.

Finish	Material	l_m	l_c	α_{512}	α_{av}	Lit.
Unpainted	Brick	45		3.1	4.0	(26)
Painted	Brick	45		1.7	1.9	(26)
Smooth	Brick + gypsum plaster	45	1.5	1.2	1.5	(29)
Smooth	Clay tile + gypsum plaster	10		2.2	3.4	(29)
Smooth	Gypsum block + gypsum plaster	7.6		4.4	3.6	(29)
Smooth	Lime plaster, wood lath and studding			1.8	2.9	(26)
Smooth	Clay tile + gypsum plaster	10		2.0	2.8	(26)
Rough	Clay tile + gypsum plaster	10		4.9	4.4	(29)
Rough	Gypsum plaster, metal lath	6.3		4.7	3.6	(29)
Rough	Gypsum plaster, metal lath *	11.4		4.7	3.0	(29)
Rough	Lime plaster, wood lath and studding	11.4		3.4	3.0	(26)

* Wood studding.

Furnishings and Wall Coverings.—α determined by method of reverberation, unless another is indicated; "draped" = draped back one-fourth; l = thickness of covering, σ = mass of covering per unit area. 1 cm = 0.394 in.; 1 g/m² = 0.00184 lb./yd.² = 0.000205 lb./ft.²; unit of α = 0.01.

Material	Remarks	α_{512}	Lit.
Audience	Closely seated	96	(26)
Cork	l = 2.54 cm	12	(26)
Cork	l = 3.8 cm	32*	(34)

Table 4.—(*Continued*)

Material	Remarks	α_{512}	Lit.
Carpet	$l = 0.8$ cm	20	(26)
Carpet	Brussels	23*	(34)
Cheesecloth	$\sigma = 48$ g/m^2	1.9	(26)
Chenille		23	(26)
Coco matting		17	(30)
Cotton draperies	Straight, $\sigma = 330$ g/m^2	9	(29)
Cotton draperies	Draped, $\sigma = 330$ g/m^2	29	(29)
Velour draperies	Straight, $\sigma = 580$ g/m^2	10	(29)
Velour draperies	Draped, $\sigma = 580$ g/m^2	37	(29)
Rugs	Oriental	29	(26)
Rugs	Oriental	26*	(34)
Linoleum		12	(26)
Felt	Asbestos, $l = 1.0$ cm	35	(26)
Felt	Asbestos, $l = 1.9$ cm	26*	(34)
Felt	Asbestos and hair	38	(26)
Felt, loose	Hair, $l = 2.54$ cm	52	(26)
Felt, loose	Hair, $l = 2.54$ cm	49	(29)
Felt, loose	Hair, $l = 2.54$ cm	51*	(34)
Felt, wood fiber	$l = 2.54$ cm, $\sigma = 1400$ g/m^2	57	(29)
Fiber board	Sugar cane, $l = 1.1$ cm	20	(29)
Fiber board	Flax, $l = 1.43$ cm	28	(29)
Fiber board	Sugar cane, $l = 1.27$ cm	31	(35)
Fiber board	Wood, $l = 1.27$ cm	31	(35)
Glass		3	(26)
Wood sheathing	Pine, $l = 2$ cm	10	(26)
Cushions	α_{512} varies from 54 to 76	60	(26)

* Flue method.

Table 5.—Absorbing Power of Objects

Absorbing power (a) of an object = αs (*cf.* Table 4). Unit of a = 0.01 m^2 = 0.108 ft.^{2}

Object	Remarks	a	Lit.
Audience	Per person	44	(26)
Chairs	Ash	1	(26)
Chairs	Wood, veneered	3	(29)
Church pews	Wood, per sitting	2	(35)
Pew cushions	Per sitting	13.5 to 19	(26)
Opera chairs	Seats upholstered	9 to 23	(35)
Opera chairs	Seats and backs upholstered	14 to 19	(29)

Table 6.—Reverberation in Rooms

Duration (T) of audible reverberation in a room of volume V and absorbing power a is $T = \frac{4V}{av} \log_e \frac{I_0}{i} = \frac{9.2V}{av} \log_{10} \frac{I_0}{i}$, where I_0 = average intensity of the sound at the instant its production ceased $= \frac{4P}{av}(1 - e^{-avt/4V})$, where t = the time the sound has been continuously produced; i = minimum audible intensity. Assume $v = 342$ m sec^{-1} (= 1122 ft. sec^{-1}) and t is so great that $I_0 = 4P/av$, and put T_0 = value of T when $I_0/i = 10^6$; T_{10} = value of T when $P/i = 10^{10}$ m^3 sec^{-1} (= 35.3×10^{10} ft.^{3} sec^{-1}). Then if units are 1 m and 1 sec, $T_0 = 0.161V/a$, $T_{10} = 0.0269 \frac{V}{a}(8.07 - \log_{10} a)$, and if units are 1 ft. and 1 sec, $T_0 = 0.049 \frac{V}{a}$, and $T_{10} = 0.0082 \frac{V}{a}(9.10 - \log_{10} a)$.

For each of the 11 rooms considered below, T is considered satisfactory for the purpose indicated. Values of T_0 and T_{10} are computed from V and the known values of α for the surfaces and furnishings, assuming $N = 512$ v.p.s. and that the audience fills the room to its capacity. Key = key number of room. Unit of V = 1 m^3 = 35.3 ft.^{3}; of T_0 and T_{10} = 1 sec.

Key	Purpose	V	Seats	T_0	T_{10}	Lit.
1	Piano	74 to 210		0.95 to 1.10	1.07 to 1.19	(26)
2	Intimate drama	1 700	300	1.20	1.14	(26)
3	Drama	5 900	1 670	1.51	1.23	(35)
4	Orchestra	11 500	1 600	2.35	2.02	(26)
5	Music, speech	12 200		1.70	1.41	(33)
6	Orchestra	18 400	2 600	2.33	1.92	(26)
7	Opera	14 200	2 350	1.51	1.23	(29)
8	Orchestra	20 600	2 300	2.40	1.96	(29)
9	Orchestra	22 400	3 340	2.08	1.66	(35)
10	Orchestra, speech	22 600	5 000	1.70	1.33	(33)
11	Music, speech	26 200	3 640	1.90	1.48	(29)

Key Numbers and Locations of Rooms Studied

Key	Name and location
1	New England Conservatory, Boston (5 small rooms)
2	Little Theater, New York, N. Y.
3	Apollo Theater, Chicago, Ill.
4	Gewandthaus, Leipzig, Germany
5	Academy of Music Opera House, Brooklyn, N. Y.
6	Symphony Hall, Boston, Mass.
7	Opera House, Boston, Mass.
8	Masonic Auditorium, Cleveland, Ohio
9	Eastman Theater, Rochester, N. Y.
10	Hill Memorial, Ann Arbor, Mich.
11	Auditorium Theater, Chicago, Ill.

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VELOCITY OF SOUND

ARTHUR L. FOLEY

As the determination of the velocity of sound is beset by many difficulties, the values obtained by different observers under nominally identical conditions are frequently quite different. Hence, it has seemed best to give either the individual observations, if few, or the simple average of all, if many (occasionally excluding a few that are markedly discordant); and, when data corresponding to each of a series of values of a single variable are available, to give, if possible, the coefficients of a simple empirical equation that represents the series within the estimated experimental error. Such an equation should not be used beyond the indicated limits. The averages and coefficients have been determined for these tables; the literature references indicate merely the sources of the data upon which they rest. Wherever given, the deviations from the equations refer to the deviations of the values derived by the authors, not necessarily of the individual determinations.

SYMBOLS

t Temperature, °C.

T, T_0 Absolute temperature, absolute temperature of 0°C.

V Velocity of sound in an unlimited volume of the medium, except in Table 7 where it is the observed velocity in the confined gas. Subscripts (*e.g.*, V_t) indicate the temperature, or the temperature and pressure, to which V refers.

RELATION OF VELOCITY OF SOUND TO VARIOUS FACTORS

Pitch.—For frequencies up to 800 000 per sec, the velocity in free air and in free illuminating gas has been found to be independent of the pitch (22, 58). For air and CO_2, *see* (71). When a gas is confined in a tube, the velocity is less than in the free gas, but approaches that as the frequency is increased; *see* Table 7. In liquids also, the velocity is independent of the pitch unless the viscosity is very great and the frequency is very high; in going from 43 000 to 600 000 per sec, the velocity in water decreases only 5 % (8). In glass rods, the velocity of transverse waves increases with the frequency and with the diameter; an increase from 400 m/sec to 2 400 m/sec has been observed when the frequency was increased from 285 000 to 455 000 per sec (111).

Intensity.—Even at ordinary intensities, the velocity is only approximately independent of the intensity, and at great intensities it is far from such independence, the velocity increasing with the intensity (9, 28, 32, 50, 61, 62, 72, 73, 83, 96, 97, 100, 102, 109). The effect of the motion of the medium (*q.v.*) must be considered. Velocities ranging from 331 to 1270 m/sec in air (32, 72, 100), and from 1400 to 2013 m/sec in water (96) have been observed.

Medium.—Unless the intensity is great, the velocity of sound with reference to the medium is quite approximately given by the equation $V^2 = E/d$, where E is the adiabatic volume elasticity, and d is the density of the medium. In general, both E and d vary with the temperature, pressure, and composition of the medium. For an ideal gas, $E = \gamma p$, and $V_t = V_0 T/T_0$ is independent of the pressure; γ = ratio of the specific heats. For many actual gases an equation of the form $V^2_{t,p} = V^2_{0,p}(1 + at + bt^2)$ represents the observations within their experimental error; a will usually differ from $1/T_0$. Irons (47) concludes that the best general equation is $V = a + bT^n$, where n is near 0.5 and varies with the complexity of the molecule.

Velocity of Medium.—When the medium is streaming with reference to the observer, the apparent velocity of the sound is the sum of the normal velocity and that component of the mass velocity of the medium which is in the direction of the line joining the source and the observer. The wave-front of the sound wave from a gun is a circle with a moving center (67); if the distance measured along the axis of the gun from the muzzle to the wave-front is x, then $x = V\tau + a(1 - e^{-b\tau})$, where V is the normal velocity, and τ is the time since the initiation of the wave. The apparent velocity is $dx/d\tau = V + abe^{-b\tau}$. For a 10-inch gun firing a service charge, $a = 22$ m, and $b = 27$ sec^{-1} (67); *see also* (48).

Velocity of Source.—Giving the source a velocity of 85.5 m/sec with reference to the medium and observer, relatively at rest, produces no change in the velocity of the sound (1).

Radiation.—Under the action of X-rays an increase of 5 % in the velocity in O_2 and N_2, and a greater increase in H_2 have been observed (55). The action of ultra-violet light on O_2 forms ozone and decreases the velocity. Radiation from Ra produces no change. Velocity in argon is unaffected by radiation (92). It has been suggested that the effect upon the velocity arises, in general, from a change in the ratio of the specific heats (20).

Topography.—The apparent velocity in free air is affected by the local topography and altitude (10, 59, 85).

TABLE 1.—VELOCITY OF SOUND IN FREE AIR

The following data refer to dry air. The presence of water vapor increases the velocity. If e = pressure of water vapor present in air at barometric pressure p, then

$$V_d = V_h\sqrt{1 - \frac{e}{p}\left(\frac{\gamma_w}{\gamma_a} - \frac{5}{8}\right)},$$

where V_d and V_h = velocity in dry and in humid air of the same temperature, and γ_a and γ_w = ratio of specific heats of air and of water (88). Observed values (59) of V_h at 75% of saturation and over range −14 to +27°C are significantly greater than those computed by means of this equation, the value at 21.85° being 353.0 m/sec while the values computed for 50% and 100% are only 345.5 and 346.2, V_d being taken as 344.7, which corresponds to V_0 = 331.7. Unit of V = 1 m/sec; of p = 1 atm.; temperature = t, °C.

Velocity (V_0) at 0°C, and 1 Atm.

It has been noticed (33) that, from 1738 to 1919, there seems to be a progressive decrease, totaling about 0.3%, in the recorded values of V_0, suggesting a slight change in the constitution of the atmosphere. This decrease has not been considered in taking the following averages. In the table are given (*a*) the unweighted averages of the recorded values grouped roughly according to method used; (*b*) the weighted average of all values obtained prior to 1902 (74); and (*c*) the average of the 1902 average and the best values obtained since then (33).

Method	Range	V_0	Lit.
Gun fire	330.7–332.4	331.4	(2, 3, 10, 12, 30, 34, 67, 68, 72, 90)
Pipes and tubes	330.0–331.9*	331.1	(6, 22, 23, 26, 57, 72, 80, 88, 101, 102, 105)
Other methods	331.3–332.1	331.6	(39, 40, 59, 94, 95)
Weighted mean prior to 1902		331.78	(74)
Weighted mean to 1927		331.45	(33)

* Omitting 328.6 (23).

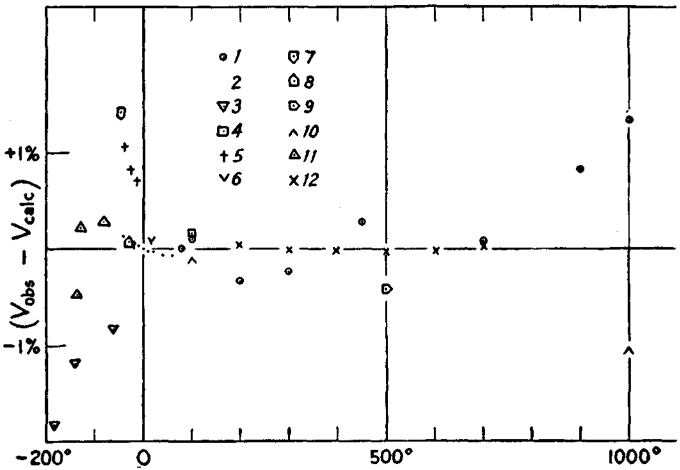

FIG. 1.—Excess of observed velocity in air above that calculated by means of the equation

$$V_t = 330.6\sqrt{1 + 0.003707t - 1.256t^2 10^{-7}}$$

1. Average of several observers.
2. Ciccone and Campanile (17).
3. Cook, and Witkowski and Cook (19, 107), values at −136° and −104°, 3.55% and 3.42% low, lie below the bottom of the figures.
4. Dixon, Campbell, and Parker (23).
5. Dulong (26).
6. Esclangon (30).
7. Greeley (38).
8. Grüneisen and Merkel (39).
9. Low (58).
10. Stevens (88).
11. Strecker (91).
12. Zoch (113).

Variation of V_t with Temperature

The recorded values between −181 and +1000° are represented by the equation $V_t = 330.6\sqrt{1 + 0.003707t - 1.256t^2 \times 10^{-7}} \times (1 + \delta)$, where δ has the values shown in Fig. 1; with two exceptions, the extreme range of δ is from −1.83% at −181° to +1.42% at −45.6°, and between 0 and 700° the range is from −0.43 to +0.29%.

Variation of V_t with Pressure (52, 107); *cf.* (53, 89)

$\Delta \equiv (V_p - V_1) \div V_1$, temperature constant. Unit of p = 1 atm.; of Δ = 0.01

t	−140°	−103.5°	−79.3°	−78.5°	−35°	0°C	Lit.
p	Δ						
20	−16.8	− 3.1		−1.8	−0.3	− 0.1	(107)
25			−1.7			+ 0.8	(52)
40		− 5.8		−3.2	−0.3	+ 0.5	(107)
50			−1.8			+ 2.2	(52)
60				−2.5	0	+ 1.8	(107)
75			−0.2			+ 4.1	(52)
80					+1.3	+ 3.5	(107)
100						+ 6.0	(107)
100		+12.8				+ 6.4	(52)
125		+22.7				+ 9.5	(52)
150		+33.4				+13.2	(52)
175		+45.4				+17.3	(52)
200		+56.4				+19.0	(52)

TABLE 2.—VELOCITY OF SOUND IN GASES AND VAPORS: ONE TEMPERATURE

(For variation with temperature, *see* Table 3.) Temperature = t, °C; pressure = 1 atm.; Δ_a = average departure of observed velocities from the value tabulated; if no value given for Δ_a, there is but one acceptable determination. The symbols serve merely to identify the gases, and give no indication of their molecular states. Unit of V = 1 m/sec; of Δ_a = 1% of V.

Gas	t	V_t	Δ_a	Lit.
Air	*See* Table 1			
A	0	307.8	0.2	(23, 45)
Br	0	135.0		(91)
Ca	850	652		(104)
Cl	0	205.8	0.2	(64, 91)
H	0	1261.7*	0.3	(21, 26, 39, 72, 75, 93)
He	0	971		(75)
Hg	330	187.0†		(54)
I	0	107.7†		(91)
K	850	652		(104)
N	0	337.7	0.1	(11, 23, 75, 79, 80)
O	0	316.2	0.3	(26, 75)
H_2O	0	401		(65)
HCl	0	295.2	0.4	(65, 80, 91)
HBr	0	199.8		(91)
HI	0	157.1		(91)
ICl	0	135.4		(91)
IBr	0	120.4		(91)
SO_2	0	209.2	0.1	(65, 80)
H_2S	0	289.3		(65)
NO	0	325		(65)
N_2O	0	260.5	1.3	(45, 64, 72, 80, 112)
NH_3	0	414.8	0.2	(65, 80, 112)
CO	0	337.4	0.1	(80, 112)
CO_2	0	259.3‡	0.6	(11, 23, 26, 45, 64, 65, 80, 112)
SiF_4	0	167.4		(65)

* Values 1238 (58), 1226 (80), and 1286.0 (113) have been ignored.
† At pressure of saturated vapor.
‡ Zoch (113) finds 281.9.

Formula	Name	t	V_t	Δ_a	Lit.
CCl_4	Carbon tetrachloride	77	150.2		(56)
CS_2	Carbon disulfide	0	195.0		(5)
$CHCl_3$	Chloroform	20	155		(5)
CH_2Cl_2	Methylene chloride	43	175.9		(36)

TABLE 2.—(*Continued*)

Formula	Name	t	V_t	Δ_a	Lit.
CH_4	Methane	0	430.5	0.3	(23, 65)
CH_4O	Methyl alcohol	67	341.2		(56)
C_2N_2	Cyanogen	0	229.5		(65)
C_2H_2	Acetylene	0	327.5	0.2	(45, 80)
C_2H_4	Ethylene	0	317.0	0.5	(26, 45, 65, 80, 112)
$C_2H_4O_2$	Acetic acid	136	209		(88)
C_2H_6	Ethane	0	303.0*		
C_2H_6O	Ethyl alcohol	0	230.6		(65)
C_3H_6O	Allyl alcohol	95	218.5		(36)
C_3H_6O	Propionaldehyde	50	258.3		(36)
C_3H_6O	Acetone	58	208.4		(36)
$C_3H_6O_2$	Propionic acid	146	232		(56)
$C_4H_8O_2$	Butyric acid	158	222.2		(56)
$C_4H_8O_2$	Isobutyric acid	150	208.4		(56)
$C_4H_8O_2$	Ethyl acetate	76	208.1		(56)
$C_4H_{10}O$	Ethyl ether	0	180.6	0.8	(5, 65)
$C_4H_{10}O$	Butyl alcohol	82	225.6		(56)
$C_5H_{10}O_2$	Valeric acid	169	218.4		(56)

TABLE 2.—(*Continued*)

Formula	Name	t	V_t	Δ_a	Lit.
C_5H_{12}	Pentane	43	191.5		(24)
$C_5H_{12}O$	Amyl alcohol	136	218.8		(56)
C_6H_6	Benzene	15	193		(5)
C_6H_{14}	Hexane	80	184.2		(24)
$C_8H_{16}O_2$	Isobutyl butyrate	157	184.3		(56)
$C_{10}H_{20}O_2$	Isoamyl valerate	166	157.2		(56)
	Benzine	90	200		(24)
	Coal gas	0	500†		(58, 113)
	Coal gas	13.6	453		(22)
	Gasoline	50	171.3		(36)

Mixed Gases (24), 20°C; volume %.

% H_2	% O_2	V	% H_2	% CO_2	% Air	V	% N_2	% CO	V
56.4	43.6	474.2	61.2	38.8		424.8	83.8	16.2	351.8
51.6	48.4	453.5	34.1	65.9		328.5	39.4	60.6	351.6
21.0	79.0	364.7	51.2	43.5	5.3	389.2			

* Deduced from observations at various temperatures; *cf.* Table 3. Heuse (48) gives V_0 = 378. † Low (58) finds 490 to 515; Zoch (113) gives 490.4.

TABLE 3.—VELOCITY OF SOUND IN GASES AND VAPORS: VARIATION WITH TEMPERATURE

The empirical equation $V = V'\sqrt{1 + \alpha t 10^{-3} + \beta t^2 10^{-6}}$ should not be used beyond the "range" indicated; when β is not zero, its value is given in a foot-note. Δ_a = average departure of the submitted data from the value given by the empirical formula. The pressure is not always explicitly stated by the observer; it is assumed to be 1 atm. unless another value is indicated. Unit of V' = 1 m/sec; of Δ_a = 1 % V'. Temperature = t, °C.

Symbol	Substance	V'	α	Range	Δ_a	Lit.
	Air, *v.* Table 1					
A	Argon	307.8	3.67_7	0° to 1000°	0.1	(23, 45)
Hg	Mercury*	$V_{330} = 187.0$; $V_{360} = 208.1$				(54, 56)
I	Iodine*	107.7	3.93_7	0° to 290°	0.9	(56, 88, 91)
N	Nitrogen	337.7	3.58_6	0° to 1000°	0.1	(11, 23, 75, 79, 80)
O	Oxygen	316.2	3.78_1	−184.7° to 21°	†	(19, 26, 75)
	Oxygen	300.8	3.65_2	−184.7° to −28.4°	1.0	(19)
H_2O	Water	$V_0 = 401$; $V_{93} = 402$; $V_{96} = 410$				(49, 65)
	Water	$V_{110} = 413$;* $V_{120} = 417.5$;* $V_{130} = 424.4$*				(98)
	Water	$V_{100} = 471.5$; $V_{1000} = 853.9$				(82)
NH_3	Ammonia	414.8	3.71_6	0° to 86°	0.1‡	(24, 65, 80, 112)
N_2O	Nitrous oxide	$V_{14.5} = 264.6$; $V_{600} = 446.9$				(82)
CO_2	Carbon dioxide	258.0	3.63_0	0° to 1080°	0.0‡	(11)
	Carbon dioxide	258.4	3.53_4§	0° to 600°	0.0	(23)
	Carbon dioxide	$V_{15} = 264.7$; $V_{1000} = 523.4$				(82)
CS_2	Carbon disulfide	195.0‖	2.12_6	0° to 70°	0‡	(5, 56)
$CHCl_3$	Chloroform	$V_{20} = 155$; $V_{63} = 144.5$; $V_{80} = 163$; $V_{99.8} = 171.4$				(5, 36, 88)
CH_4	Methane	430.5	2.85_7	0° to 600°	0.2	(23, 65)
CH_4O	Methyl alcohol	$V_{67} = 341.2$; $V_{77} = 325.7$; $V_{99.7} = 350.3$*				(24, 56, 88)
C_2H_4	Ethylene	317.0	3.14_2§	0° to 89°	0.1	(24, 26, 45, 65, 80, 112)
C_2H_6	Ethane	303.0	3.30_4	10° to 100°	0.1‡	(23)
C_2H_6O	Ethyl alcohol	230.6	4.10	0° to 99.8	1.1‡	(24, 56, 65, 70, 88)
$C_4H_{10}O$	Ethyl ether	180.6	1.25_0§	0° to 100	0.4‡	(5, 24, 49, 65, 93)
$C_4H_{10}O$	Butyl alcohol	$V_{82} = 225.6$; $V_{116} = 235.4$				(56)
C_5H_{12}	Pentane	163.9	10.16§	43° to 86°	0.1	(24)
C_6H_6	Benzene	$V_{15} = 193$; $V_{90} = 200$; $V_{100} = 205$				(5, 24, 88)

* At pressure of saturated vapor.

† For 0°, 21°, and −184.7°, Δ_a = 0.2; at −28.4°, −66.5°, and −137.3° computed V too great by 5.5 %, 3.4 %, and 4.1 %, respectively.

‡ The following values have been omitted: NH_3, V_0 = 407.4 (72), low 1.8 %. CO_2, V_{20} = 257.3 (58), = 259.8 (93), low 3.7 % and 2.7 %. CS_2, V_0 = 189 (65), V_{48} = 187.7 (36), low 3.1 % and 8.3 %. C_2H_6, V_0 = 378 (45), high 25 %. C_2H_6O, V_{48} = 235.7 (49), low 6.6 %. $C_4H_{10}O$ (ether), V_{17} = 175.9 (58) and V_{35} = 180.0 (36), low 4.0 % and 3.8 %; V_{36} = 192.8 (58) and V_{37} = 194.4 (70), high 2.8 % and 3.5 %.

§ Values of β: CO_2, −0.210; C_2H_4, 24.6; $C_4H_{10}O$ (ether), 25.0; C_5H_{12}, −37.6.

‖ $V_{99.7}$ = 223.2 (88), high 4.4 %; at pressure of saturated vapor.

TABLE 4.—VELOCITY (V) OF SOUND IN LIQUIDS

Pure liquids; aqueous solutions; ill-defined liquids. In column C is given either the density (g/cm³) or the wt. % of the solute; temperature = t, °C. Unit of V = 1 m/sec.

Pure Liquids

Symbol	Substance	t	V_t	Lit.
Hg	Mercury	20	1407	(13)
H_2O	Water, distilled, air-free	15	1447*	(25)
		4	1419.2	(13)
		21.5	1483.6	(13)
	Water, pure	15	1433†	(64)
	Natural waters, *v.* Table 5			
HNO_3	Nitric acid	15.5	1518	(25)
		16	1425	(76)
CS_2	Carbon disulfide	15	1161	(25)
		20	1160	(76)
$CHCl_3$	Chloroform	15	983	(25)
CH_3NO_2	Nitromethane	21.0	1360.5	(14)
CH_4O	Methyl alcohol	19.0	1143.2	(14)
C_2H_6O	Ethyl alcohol	8.4	1264	(64)
		15	1275	(76)
		23	1160	(105)
C_3H_6O	Acetone	20.5	1189.4	(14)
$C_4H_{10}O$	Ethyl ether	0	1152	(64, 105)
		15	1024	(25, 76)
$C_5H_{12}O$	Amyl alcohol	20.0	1269.8	(14)
C_6H_5Cl	Chlorobenzene	17.0	1315.4	(14)
$C_6H_5NO_2$	Nitrobenzene	17.5	1506.1	(14)
C_6H_6	Benzene	16.3	1170	(76)
		17	1166‡	(25)
C_6H_7N	Aniline	20.8	1675.7	(14)
$C_6H_{12}O_3$	Paraldehyde	21.5	1202.4	(14)
C_6H_{14}	*n*-Hexane	21.0	1111.7	(14)
$C_7H_7NO_2$	*o*-Nitrotoluene	20.5	1482.0	(14)
C_7H_8	Toluene	20.5	1327.2	(14)
C_7H_8O	*m*-Cresol	21.5	1492.5	(14)
C_7H_9N	*o*-Toluidine	21.0	1644.8	(14)
	m-Toluidine	21.6	1602.4	(14)
C_8H_{10}	Ethylbenzene	20.0	1351.0	(14)

Aqueous Solutions

Solute	C	t	V_t	Lit.
HCl	1.207	15.5	1518	(25)
		16	1455	(76)
H_2SO_4	7%	18.5	1455	(76)
	31%	19.7	1475	(76)
	63%	19.6	1380	(76)
	92%	20.6	1280	(76)
NH_3	2.8%	15	1440	(76)
	7.3%	15	1470	(76)
	17.5%	15	1540	(76)
	23%	15	1635	(76)
	0.880	16	1663	(25)
C_2H_5OH	11%	4.4	1496	(64)
	95%	12.5	1241	(25)
	95%	20.5	1213	(25)
$ZnSO_4$	8%	16	1445	(76)
	30%	13	1465	(76)
	41%	17.5	1510	(76)
$CuSO_4$	1.0663	21.5	1513.0	(13)
	1.1238	21.5	1538.5	(13)
	1.1615	21.5	1562.3	(13)
$FeSO_4$	1.104	16.5	1485	(76)
$CaCl_2$	1.0661	21.5	1546.9	(13)
	1.1271	21.5	1601.3	(13)
$CaCl_2$.—(*Continued*)	1.1942	21.5	1672.0	(13)
	43%	22.5	1980	(105)
$BaCl_2$	1.0662	21.5	1503.6	(13)
	1.1256	21.5	1524.4	(13)
	1.1970	21.5	1547.6	(13)
NaCl	10%	15	1470	(25)
	15%	15	1530	(25)
	20%	15	1650	(25)
	Conc.‖	14.7	1661	(64)
	Conc.‖	18.1	1561	(105)
	1.0662	21.5	1586.1	(13)
	1.1259	21.5	1676.1	(13)
	1.1971	21.5	1784.6	(13)
Na_2SO_4	5.3%	18.6	1491	(76)
	6%	19.4	1474	(76)
	11.7%	17.3	1508	(76)
	11.8%	20	1525	(105)
	Conc.‖	19	1584	(105)
	Conc.‖	14.7	1528	(64)
$NaNO_3$	Conc.‖	15.3	1650	(64)
	Conc.‖	20.9	1670	(105)
Na_2CO_3	Conc.‖	22.2	1594.4	(105)
KOH	12%	15.7	1430	(76)
	19%	19.1	1580	(76)
	29%	19.7	1620	(76)
KNO_3	Sat.¶	14.4	1515	(64)

Ill-defined Liquids

Liquid	t	V_t	Lit.
Gasoline	7.4	1395	(64)
Petroleum	7.4	1395	(64)
	15	1326	(64)
Turpentine	3.5	1371	(64)
	15	1326	(25)
	24	1212	(105)

* $V_t = 1398 + 3.28t$ from 13° to 31° (25).

† $V_t = 1383 + 3.33t$ from 3.9° to 25.2° (64).

‡ Author calls it "Benzin," does not give formula.

‖ Described as "concentrated;" perhaps saturated was meant.

¶ Saturated solution.

TABLE 5.—VELOCITY (V) OF SOUND IN NATURAL WATERS

In all oceans, the average vertical velocity for depths of 3.5 to 8.0 km is 1528 to 1529 m/sec; for lesser depths, it is less; values computed from density and adiabatic compressibility by method of Heck and Service (41) may differ by 20 m/sec from the actual value (41). Unit of V = 1 m/sec; of depth = 1 m; temperature = t, °C.

Water	Depth	Salt	t	V	Lit.
Lake Geneva			8.1	1435	(18)
Seine River			15	1437	(105)
			30	1528	(105)
			50	1652.2	(105)
			60	1724.7	(105)
Ocean: Horizontal Velocity					
Open ocean	13	3%*	14.5	1503.5	(63)
Block Island Sound, N. Y.	30	3.35%	3.0	1453.3	(87)
Long Island Sound, N. Y.	30		13	1492.3	(29)
Isle of Wight		3.51%	6	1474	(110)
		3.52%	7	1478	(110)
		3.5%	16.95	1511	(110)

TABLE 5.—(*Continued*)

Water	Depth	Salt	t	V	Lit.
Ocean: Vertical Velocity					
North Atlantic	1288			1520	(41)
Caribbean Sea	338			1478	(41)
	1771			1486	(41)
Pacific	1185			1505	(41)
	2962			1493	(41)
All oceans	3500 to 8000			1528	(41)

* Density at 14.9° = 1.0245 g/cm³.

TABLE 6.—VELOCITY (V) OF SOUND IN SOLIDS

Pure metals; alloys; papers, fabrics, and skins; woods; miscellaneous. Either room temperature or t, °C. Unit of V = 1 m/sec.

Metals	t	V	Lit.
Pure Metals			
Ag		2645	(65)
	18	2608*	(105)
	10	2678†	(105)
	20	2678†	(105)
	100	2640†	(105)
	200	2480†	(105)
Al		5105	(65)
Au	(?)	2082	(65)
	10	2112†	(105)
	20	1743*	(105)
	100	1720*	(105)
	200	1735*	(105)
Cd		2307	(65)
Co		4724	(65)
Cu	20	3560	(105)
	100	3290	(105)
	200	2950	(105)
	(?)	3825	(65)
		3984	(16)
Fe	20	5130	(105)
	100	5300	(105)
	200	4720	(105)
	(?)	5016	(65)
	15	4913	(105)
Steel	18	4982‡	(105)
	10	4940§	(65)
		5093§	(54)
	20	4990‖	(105)
	100	4920‖	(105)
	200	4790‖	(105)
Mg		4602	(66)
Ni		4973	(65)
Pb		1322	(65)
	18	1229*	(105)

Metals	t	V	Lit.
Pure Metals.—(Continued)			
Pd	10	3074	(105)
		3257	(65)
Pt	(?)	2792	(65)
	20	2690	(105)
	100	2570	(105)
	200	2460	(105)
	18	2688*	(105)
	10	2736†	(105)
Sn	13	2490	(35)
		2490	(16)
		2640	(65)
Zn	13	3681	(35)
		3699	(65)
Alloys			
Brass		3479	(65)
		3617	(54)
		3235¶	(105)
Steel		*See above,* Fe	

	x	V	Lit.
Zn-Sn (13°C, x atoms Sn to 5 atoms Zn)	0	3681	(35)
	1	3338	
	2	3195	
	3	3100	
	4	3032	
	5	2980	
	6	2940	
	7	2898	
	8	2850	
	9	2785	
	10	2710	
	∞	2490	

Papers, Fabrics, Skins (66)

The velocity in a given specimen depends upon the tension. All the membranous materials were cut in strips 15 mm wide ((66), p. 575), but neither their thicknesses nor the diameters of the cords are stated. The velocity was observed while the strip, or cord, carried a longitudinal load of w kg.

Material	w	V
Cord: Cotton	1	1425
Linen	1	1815
	2	1942
Oilcloth	1	559
Paper: Blotting	0.5	1627
Parchment	0.7	2198
Silvered	0.6	2575
Straw	0.5	1617
Tissue	0.1	1989
Tracing	0.7	2278
Writing	0.9	2107
Parchment: French	2	1860
German	1.5	1636
Satin ribbon	1	2015
Sheepskin	0.1	471

Woods

$V_\parallel$, V_r, V_c = velocity parallel to grain, radial velocity, circumferential velocity; unit = 1 m/sec. d = density; unit = 1 g/cm³.

Wood	d	V_c	V_r	$V_\parallel$	Lit.
Ash		1260	1390	4670	(105)
	0.542			4272	(46)
	0.562			3657	(46)
Beech		1415	1840	3340	(105)
				3412	(66)
Cedar	0.455			3975	(46)
	0.465			4926	(46)
Cherry				4410	(46)
Elm		1013	1420	4120	(105)
Fir				5256	(86)
				4179	(66)
Fir: Red				4274	(46)
White				4640	(46)
Mahogany				4135	(46)
Maple				4110	(105)
Oak				3381	(66)
Oak: Red				4180	(46)
White				4316	(46)
Pine				3320	(105)
Poplar				4280	(105)
Sycamore				4460	(105)
Walnut				4781	(46)

Miscellaneous Materials

$\left\{\begin{matrix}430\\530\end{matrix}\right.$ indicates that V ranges from 430 to 530 m/sec

Material	t	V	Lit.
Beeswax	15	880	(86)
	16	863	(103)
	28	450	(86)
Brick		3652	(16)
Caoutchouc, vulcanized: Black	0	54	(31)
	50	30.7	(31)
Red	0	69.3	(31)
	57	36.6	(31)
	70	33.9	(31)
Gray	0	43.2	(31)
	45	32.3	(31)
Tubing		27	(86)
Very hard		150	(86)
Cork		430	(86)
		530	
Ebonite	15	1573	(15)
Gelatin		1364	(44)
		1626	
Glass		5991	(86)
		5060	(54)
	16	5202	(103)

Miscellaneous Materials.—(*Continued*)

Material	t	V	Lit.
Glass: Soda		5000	**
		5300	
Flint		4000	**
Granite		3950	(37)
Ivory		3013	(17)
Marble		3810	(37)
Paraffin	6.1	1522	(84)
	16	1304	(103)
	17.3	1419	(84)
	21.6	1325	(84)
	25.2	1192	(84)
	27.8	1035	(84)
	29.3	851	(84)
	30.5	748	(84)
	32.9	470	(84)
	35.3	250	(84)
Rock (±700 m/sec)		2500	(4)
Sand (±600 m/sec)		2000	(4)
Sealing wax		1320	(86)
Shellac, white		1320	(86)
	8.7	1009	(84)
	26.3	869	(84)
	40	762	(84)
Slate		4510	(37)
	4.9	1517	(84)
Spermaceti	33.1	1091	(84)
Stearin	16	1378	(103)
	16.1	1354	(84)
	33.6	1181	(84)
	48.2	911	(84)
Suet	18	460	(86)
Tallow	16	390	(103)
Tuff		2850	(37)
Wax (*v.* Beeswax)			

* Soft.
† Hard.
‡ Mild steel.
§ Blue tempered steel.
‖ Cast steel.
¶ Unannealed.
** Various observers.

TABLE 7.—VELOCITY OF SOUNDS IN GASES CONFINED IN TUBES

The velocity of sound in a gas contained in a tube depends upon the heat conductivity of, and the velocity of sound in, the material of the tube, upon the viscosity and the heat conductivity of the gas, upon the character of the inner surface of the tube, upon the rate and the direction at which heat and vibrations are transferred between the tube and external objects, upon the pitch and intensity of the sound, and upon the thickness and diameter of the tube (27, 32, 42, 51, 69, 72, 77, 78, 81, 93). If the inner surface of the tube is smooth, and if the transfer of energy to external objects is negligible, the velocity is given by the expression $V = V_\infty(1 - K/D\sqrt{n})$, where D = diameter, n = pitch, K depends upon the properties of the tube and gas, and V_∞ = velocity in an unlimited volume of the gas. Under other conditions, this expression may be multiplied by a quantity depending upon the material and dimensions of the tube, and K may involve D and n. Some observers (77, 81) claim $V = V_\infty(1 - K/Dn^{2/3})$, another (108) concludes that the exponent of n is 0.53.

For air in iron and in porcelain (72, 93), $D \geq 4$ cm, $n = 500$, 600, and "explosion," V differs but little from its value in free air; *see also* (99). When other observations are represented by the following equations, δ has the values tabulated:

Air in glass, $D > 0.6$ cm (54, 58, 69, 81), $V = 331.0(1 - 0.501/D\sqrt{n})(1 + \delta)$.

Air in glass, $D < 0.4$ cm (78), $V = 331.0(1 - 0.441/D\sqrt{n}) \times (1 + \delta)$.

Air in brass, $D > 1$ cm (6), $V = 331.0(1 - 0.362/D\sqrt{n}) \times (1 + \delta)$.

Air in brass, $D < 0.2$ cm (78), $V = 331.0(1 - 0.834/D\sqrt{n}) \times (1 + \delta)$.

CO_2 in glass (93), $V = 260.0(1 - 0.452/D\sqrt{n})(1 + \delta)$.

H_2 in glass (93), $V = 1249.5(1 - 0.262/D\sqrt{n})(1 + \delta)$.

Unit of $\delta = 0.001$; of $D = 1$ cm; of $n = 1$ double vibration per sec.

Air in glass									Air in brass			
n	256	320	384	512	1023	1850	2482	5550	n	256	384	512
D	δ								D	δ		
0.101			+3	− 8					0.099		0	0
0.151			+2	+ 6					0.148		−25	+16
0.34		+32		+35					1.17	0		
0.68							−2		1.95	−1		
0.93	+2			+ 2	−0				3.25	+0		
1.3						+5		+5	5.41	+0		
1.71	+1			0	−1				8.82	0		
2.80	0			− 0	−2							
5.5								+7				

CO_2 in glass						H_2 in glass			
D	0.21	0.35	0.53	1.02	2.11	0.35	0.53	1.02	2.11
n	δ					δ			
705		−0	−1	−3	−1				
1943	+4	0	−2	−3	+4				
3755	+6	+4	−1	−3	+5	−0	+1	−0	+9

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(For a key to the periodicals see end of volume)

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LITERATURE REFERENCES

LITERATURE REFERENCES

In all literature references cited in International Critical Tables the name of the journal or publication is indicated by means of a *Key number* corresponding to the list given below. The numbers which follow this key number in a literature citation are, in the order named: (1) the volume, (2) the page, and (3) the last two figures of the year. Thus *64V*, **31**: 253; 22, indicates Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, page 253, 1922. Series numbers are not given. Key numbers referring to books and other non-serial publications are preceded by the letter *B*, and the volume number is given in roman numerals. Thus *B10*, **IV**: 191; 18, indicates Doelter, Handbuch der Mineralchemie, page 191 of Vol. 4 of the 1918 edition. The Key number *O* is used to indicate "private communication from."

DAS LITERATURVERZEICHNIS

In allen Literaturstellen, die in I. C. T. verzeichnet sind, ist der Name der Zeitschrift oder der Publikation mit Hilfe einer *Schlüsselnummer*, entsprechend der unten folgenden Liste, angegeben. Die Zahlen, welche diesen Schlüsselnummern bei einem Literaturzitat folgen, bedeuten der Reihe nach: (1) der Band, (2) die Seite und (3), die letzten zwei Zahlen des Jahrganges. So bedeutet z. B. *64V*, **31**: 253; 22, Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Band 31, Seite 253, 1922. Serien-Nummern werden nicht angegeben. Der Schlüsselzahl wird ein *B* vorausgesetzt, wenn sie Bücher, oder eine andre nicht periodische Veröffentlichung bezeichnet. Die Bandnummer wird durch römische Ziffern angegeben. Es bedeutet z. B. also *B10*, **IV**: 191; 18, Doelter, Handbuch der Mineralchemie, Seite 191, des 4 Bandes, der Auflage des Jahres 1918. Die Schlüsselzahl *O* wird gebraucht, um anzuzeigen, dass es eine "private Mitteilung" ist.

RÉFÉRENCES BIBLIOGRAPHIQUES

Le nom du journal ou de la publication de toutes les références bibliographiques citées dans les Tables Critiques Internationales est indiqué au moyen d'un *nombre-clé* correspondant à la liste donnée ci-dessous. Les nombres qui suivent ce nombre-clé dans un renvoi bibliographique indiquent dans l'ordre suivant: (1) le volume, (2) la page, et (3) les deux derniers chiffres de l'année. Ainsi *64V*, **31**: 253; 22, indique Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, page 253, 1922. Les numéros des séries ne sont pas donnés. Les nombres-clés se rapportant à des livres ou à des publications non périodiques sont précédés de la lettre *B* et le numéro du volume est donné en chiffres romains. Ainsi, *B10*, **IV**: 191; 18, indique Doelter, Handbuch der Mineralchemie, page 191 du volume 4 de l'édition de 1918. Le nombre-clé *O* est employé pour indiquer "communication privée de."

INDICAZIONI BIBLIOGRAFICHE

In tutte le indicazioni bibliografiche che si incontrano nelle "Tabelle Critiche Internazionali" il nome del giornale o della pubblicazione è espresso con un *numero chiave* riportato nell'elenco dato più oltre. I numeri che, nella citazione, vengono dopo il numero chiave sono disposti con l'ordine seguente: (1) il volume, (2) la pagina, e (3) le ultime due cifre del millesimo. Cosi *64V*, **31**: 253; 22, indica la Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, pagina 253, 1922. I numeri di serie non vengono dati. Quando un numero chiave è preceduto dalla lettera *B* si riferisce a libri o ad altre pubblicazioni non periodiche, e il numero del volume viene allora scritto in cifre romane. Cosi *B10*, **IV**: 191; 18, indica Doelter, Handbuch der Mineralchemie, pagina 191 del IV° volume dell'edizione 1918. Il numero chiave *O* indica "Comunicazione privata da . . . "

KEY TO THE PERIODICALS

Data regarding the libraries which receive many of these periodicals may be found through the following sources:

United States and Canada: "Periodicals Abstracted by Chemical Abstracts, 1926" (Chemical Abstracts, Ohio State Univ., Columbus, Ohio); "Union List of Serials in the Libraries of the United States and Canada, 1927" (H. W. Wilson & Co., New York City); "A Catalogue of Scientific Periodicals in Canadian Libraries, 1924" (McGill Univ., Montreal, Canada).

Great Britain: "A World List of Scientific Periodicals Published in the Years 1900–1921" (Oxford Univ. Press, London, 1925–).

Holland: "Chemisch Jaarboekje tevens Jaarboekje der Nederlandsche Chemische Vereeniging, Vol. 3." (Amsterdam, D. B. Centen, 1920).

1. Journal of the American Chemical Society.
2. Physical Review.
3. London, Edinburgh and Dublin Philosophical Magazine and Journal of Science.
4. Journal of the Chemical Society, London. (Memoirs of the Chemical Society; *continued as* Quarterly Journal; *later* Journal.)
5. Proceedings of the Royal Society (London). A. Mathematical and Physical Sciences.

5B. Proceedings of the Royal Society (London). B. Biological Sciences.

6. Annales de chimie et de physique. (*Divided into* Nos. 14 and 16 *in 1914*).
7. Zeitschrift für physikalische Chemie, Stöchiometrie und Verwandtschaftslehre.
8. Annalen der Physik. [Journal der Physik, 1790–1794. Neues Journal der Physik, 1795–1796. Annalen der Physik, 1799–1819; Annalen der Physik und der physikalischen Chemie, 1819–1824 (Gilbert). Annalen der Physik und Chemie, 1824–1899 (Poggendorff, Wiedemann). Annalen der Physik, 1900–   (Drude, Wien and Planck).]
9. Zeitschrift für Elektrochemie und angewandte physikalische Chemie.
10. Tables annuelles internationales de constantes et données numériques.
11. American Chemical Journal. (*Combined with* No. 1 *in 1914*.)
12. American Journal of Science. (American Journal of Science and Arts, 1820–79; *known also as* Silliman's Journal of Science.)
13. Annalen der Chemie, Justus Liebig's.
14. Annales de chimie.
16. Annales de physique.
17. Anzeiger der Akademie der Wissenschaften in Wien. Mathematisch-naturwissenschaftliche Klasse.
18. Archives néerlandaises des sciences exactes et naturelles. Séries IIIA (Sciences exactes).
19. Arkiv för Kemi, Mineralogi och Geologi.
20. Arkiv för Matematik, Astronomi och Fysik.

21. Astrophysical Journal.
22. Atti della reale accademia nazionale dei Lincei. (Rendiconti classe di scienze fisiche, matematiche e naturali.)
23. Atti della reale accademia delle scienze di Torino.
24. Atti del reale istituto Veneto di scienze, lettere ed arti.
25. Berichte der deutschen chemischen Gesellschaft.
26. Berichte der deutschen physikalischen Gesellschaft. *See also* No. 96.
27. Bulletin de la société chimique de France. (*Before 1908 was* Bulletin de la société chimique de Paris.)
28. Bulletin de la société chimique de Belgique. (*Before 1904 was* Bulletin de l'association belge des chimistes.)
30. Bureau of Mines, Technical Papers.
31. Bureau of Standards, Scientific Papers. (*Continued as* No. 546.)

31A. Bureau of Standards, Bulletin. (*Continued as* No. 546.)

32. Bureau of Standards, Technologic Papers. (*Continued as* No. 546.)
33. Chemical and Metallurgical Engineering. (*Name changed July, 1918 from* Metallurgical and Chemical Engineering.)
34. Comptes rendus hebdomadaires des séances de l'académie des sciences, de l'institut de France.
36. Gazzetta chimica italiana.
37. Helvetica Chimica Acta.
38. Journal of the American Ceramic Society.

38B. Bulletin of the American Ceramic Society.

39. Journal of the American Institute of Electrical Engineers.
40. Journal of the American Institute of Metals. *See* No. 329.
41. Journal of the Chemical Society of Japan (Nippon Kwagaku Kwai Shi). (*Name changed in Jan., 1921 from* Journal of the Tokyo Chemical Society.)

41B. Bulletin of the Chemical Society of Japan.

42. Journal de chimie physique.
44. Journal of the Faculty of Science, Tokyo Imperial University.
45. Industrial and Engineering Chemistry. (*Name changed Jan., 1923 from* Journal of Industrial and Engineering Chemistry.)
46. Journal of the Institution of Electrical Engineers (London).
47. Journal of the Institute of Metals (London).
48. Journal of the Optical Society of America and Review of Scientific Instruments.
50. Journal of Physical Chemistry.
51. Journal de physique et le radium. (*Formed from* Le radium *and* Journal de physique, théorique et appliquée.)
52. Journal für praktische Chemie.
53. Journal of the Russian Physico-Chemical Society. (Chemical part.)
54. Journal of the Society of Chemical Industry.
55. Kolloid-Zeitschrift. (*Formerly* Zeitschrift für Chemie und Industrie der Kolloide.)
57. Monatshefte für Chemie und verwandte Teile anderer Wissenschaften.
58. Nature (London).
59. Nuovo Cimento.
60. Översikt av Finska Vetenskaps-Societetens Förhandlingar. (*Discontinued with* Vol. 64, 1921–22.)
61. Oversigt over det Kongelige Danske Videnskabernes Selskabs Forhandlinger.
62. Philosophical Transactions of the Royal Society of London, Series A, Physical and Mathematical.

62B. Philosophical Transactions of the Royal Society of London, Series B, Biological.

63. Physikalische Zeitschrift, vereinigt mit dem Jahrbuch der Radioaktivität und Elektronik.

64P. Proceedings of the Royal Academy of Sciences of Amsterdam.

64V. Verslag koninklijke Akademie van Wetenschappen te Amsterdam.

65. Proceedings of the American Academy of Arts and Sciences.
66. Proceedings of the American Society for Testing Materials.
67. Proceedings of the Physical Society of London.
68. Proceedings of the Royal Society of Edinburgh.
69. Proceedings and Transactions of the Royal Society of Canada.
70. Recueil des travaux chimiques des Pays-Bas.
71. Rendiconti dell'accademia delle scienze fisiche e matematiche. (Classe della società reale di Napoli.)
72. Rendiconti reale istituto Lombardo di scienze e lettere.
74. Revue de métallurgie.

74E. Revue de métallurgie, Extraits.

75. Sitzungsberichte Akademie der Wissenschaften in Wien, mathematisch-naturwissenschaftliche Klasse.
76. Sitzungsberichte der preussischen Akademie der Wissenschaften.
77. Stahl und Eisen.
78. Transactions of the American Electrochemical Society.
80. Transactions of the American Institute of Mining and Metallurgical Engineers.
83. Transactions of the Faraday Society.
86. University of Illinois, Engineering Experiment Station, Bulletin.
88. Verhandlungen der physikalischen Gesellschaft zu Berlin. *See also* No. 96.
89. Wissenschaftliche Abhandlungen der physikalisch-technischen Reichsanstalt.
92. Zeitschrift für angewandte Chemie.
93. Zeitschrift für anorganische und allgemeine Chemie. (*Name changed in 1915 from* Zeitschrift für anorganische Chemie.)
94. Zeitschrift für Krystallographie. (*Name changed in 1921 from* Zeitschrift für Krystallographie und Mineralogie.)
95. Zeitschrift für Metallkunde. (*Formerly* Internationale Zeitschrift für Metallographie.)
96. Zeitschrift für Physik. (Verhandlungen der physikalischen Gesellschaft zu Berlin, 1882–1898; Verhandlungen der deutschen physikalischen Gesellschaft, 1899–1902; Berichte der deutschen physikalischen Gesellschaft, 1903–1919; Zeitschrift für Physik, 1920– .)
97. Zeitschrift für technische Physik.
98. Zeitschrift des Vereines deutscher Ingenieure.
99. Zeitschrift für wissenschaftliche Photographie, Photophysik und Photochemie.
101. Elektrotechnische Zeitschrift.
105. Journal of the Society of Glass Technology.
107. Electrical World.
114. Electric Journal.
115. Engineering.
116. Sibley Journal of Engineering.
117. Scientific Proceedings of the Royal Dublin Society.
119. Proceedings of the American Institution of Electrical Engineers. (*Discontinued in 1919.*)
120. General Electric Review.
121. Electrician.
125. Archiv für Elektrotechnik. (*Supplement to* No. 101.)
126. Bulletin de la société française des électriciens.
128. Journal of the Washington Academy of Sciences.
129. Transactions of the American Institute of Electrical Engineers.
132. Anales de la sociedad española de fisica y quimica.
133. British Association for the Advancement of Science, Reports.
134. Bulletin de l'académie des sciences de l'union des républiques soviétiques socialistes. (*Formerly* Bulletin de l'académie impérial des sciences de St. Pétersbourg; *name changed in 1917 to* Bulletin de l'académie des sciences de Russie; *present name dates from 1925.*)

135. Chemical News and Journal of Industrial Science. (*Name changed in 1921 from* Chemical News and Journal of Physical Science.)
137. Kongelige Danske Videnskabernes Selskab, Mathematisk-fysiske Meddelelser.
139. Ferrum.
140. Journal of the Iron and Steel Institute (London).
141. Journal of Biological Chemistry.
143. Journal of the Franklin Institute.
147. Meddelanden från K. Vetenskapakademiens Nobelinstitut.
148. Zeitschrift für die gesamte Kälte-Industrie.
149. Archives des sciences physiques et naturelles. (Bibliothèque britannique, 1796–1815; Bibliothèque universelle des sciences, belles-lettres et arts, 1816–1835; Bibliothèque universelle de Genève, 1836–1845; Supplément à la bibliothèque universelle de Genève. Archives des sciences physiques et naturelles, 1846–1847; Bibliothèque universelle de Genève. Archives des sciences physiques et naturelles, 1848–1857; Bibliothèque universelle, revue suisse et étrangère. Archives des sciences physiques et naturelles, 1858–1861; Bibliothèque universelle et revue suisse. Archives des sciences physiques et naturelles, 1862–1877; Bibliothèque universelle. Archives des sciences physiques et naturelles, 1878– .)
151. Mémoires de l'académie royale des sciences de l'institute de France.
152. Carnegie Institution of Washington, Publications.
154. Iowa Geological Survey, Bulletin.
159. Science Reports of the Tôhoku Imperial University. Series I, Mathematics, Physics and Chemistry.
159B. Science Reports of the Tôhoku Imperial University. Series III, Petrology, Mineralogy and Mineral Deposits.
165. Bulletin internationale de l'académie des sciences de Cracovie. (*Name changed to* Bulletin internationale de l'académie Polonaise des sciences et des lettres.)
166. Science.
168. Communications from the Physical Laboratory at the University of Leiden.
169. Annales de l'Institut Polytechnique Pierre-le-Grand, Pétrograd.
170. Memorie della reale accademia nazionale dei Lincei, Roma.
171. Sitzungsberichte der Heidelberger Akademie der Wissenschaften. Mathematisch-naturwissenschaftliche Klasse. Abteilung A.
172. International Congress of Applied Chemistry.
174. Transactions of the Royal Society of Edinburgh.
175. Annales academiae scientiarum fennicae.
176. Chemisch Weekblad (Amsterdam).
177. Annales scientifiques de l'université de Jassy.
178. Archivio di fisiologia (Florence).
182. Proceedings of the Chemical Society, London.
186. Bulletin de la classe des sciences, académie royale de Belgique.
187. Metall und Erz, Zeitschrift für Metalhüttenwesen und Erzbergbau, einschl. Aufbereitung.
188. Nachrichten von der königlichen Gesellschaft der Wissenschaften zu Göttingen. Geschäftliche Mitteilungen; mathematisch-physikalische Klasse.
189. Centralblätt für Mineralogie, Geologie und Paläontologie.
190. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie.
190B. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage Band.
191. Bulletin de la société française de minéralogie.
192. Metallurgie. (*Divided into* Nos. 139 and 187.)
197. Proceedings of the National Academy of Sciences.
199. Le Radium. (*Merged into* No. 51 *in 1920.*)
200. Jahrbuch der Radioaktivität und Elektronik. (*Combined with* No. 63 *in 1924.*)
201. Proceedings of the Cambridge Philosophical Society.
202. Zeitschrift für physiologische Chemie.
204. Photographic Journal.
205. Biochemische Zeitschrift.
208. Physica, Nederlandsch Tijdschrift voor Natuurkunde.
211. Abhandlungen der mathematisch-physischen Klasse der sächsischen Akademie der Wissenschaften zu Leipzig.
213. Sitzungsberichte der mathematisch-physikalischen Klasse der bayerischen Akademie der Wissenschaften zu München.
214. Kongelige Danske Videnskabernes Selskab, Skrifter naturvidenskabelig og mathematisk Afdeling.
215. Lunds Universitets Årsskrift.
217. U. S. Coast and Geodetic Survey, Special Publications.
218. Naturwissenschaften.
219. Proceedings of the Physico-Mathematical Society of Japan.
221. Berichte über die Verhandlungen der sächsischen Akademie der Wissenschaften zu Leipzig. Mathematisch-physische Klasse.
231. U. S. Public Health Service, Public Health Reports.
236. Ergebnisse der Physiologie.
237. Fortschritte der Chemie, Physik und physikalischen Chemie.
241. Proceedings of the American Philosophical Society.
242. Vierteljahrsschrift der naturforschenden Gesellschaft, Zürich.
243. Zeitschrift für Instrumentenkunde.
250. Bulletin de séances de la société française de physique (1873–1910). *From 1873–1901 as Its* Séances; *continued as* No. 51.)
268. Terrestrial Magnetism.
269. Mineralogical Magazine and Journal of the Mineralogical Society.
273. Berichte der deutschen pharmazeutischen Gesellschaft. *See also* No. 293.
278. Archiv für die gesamte Physiologie des Menschen und der Tiere. (Pflüger.)
281. Zeitschrift für Psychologie und Physiologie der Sinnesorgane.
284. Journal of the American Pharmaceutical Association.
285. Journal of Mathematics and Physics (Massachusetts Institute of Technology).
286. Chemical Reviews.
289. Journal of Physiology.
290. Journal of the Society of Dyers and Colourists.
291. Arbeiten aus dem Reichsgesundheitsamte.
292. Proceedings and Transactions of the Nova Scotian Institute of Science.
293. Archiv der Pharmazie. (*Combined with* No. 273 *in 1924 to form* Archiv der Pharmazie und Berichte der deutschen pharmazeutischen Gesellschaft.)
294. Mémoires de l'académie de Belgique.
313. United States Bureau of Mines. Reports of Investigations.
325. Proceedings of the Royal Institution of Great Britain.
327. Annales de la société scientifique de Bruxelles.
329. Mining and Metallurgy. (Transactions of the American Brass Founders' Association, 1908–11; Transactions of the American Institute of Metals, 1912–16; Journal of the American Institute of Metals, 1917–18; *discontinued in 1918 and incorporated with* Bulletin of the American Institute of Mining Engineers; *with* No. 148, *1919, this Bulletin became* Bulletin of the American Institute of Mining and Metallurgical Engineers; *with* No. 154, *1919, name changed again to* Mining and Metallurgy.)
337. Bulletin of the National Research Council.
338. Researches of the Electro-Technical Laboratory (Tokyo).
339. American Journal of Mathematics.
362. Chemické Listy pro vedu a prumysl.
365. Bureau of Standards, Circulars.
384. Le génie civil (Paris).
403. Proceedings of the Institution of Mechanical Engineers.

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420. Bulletin de la société d'encouragement pour l'industrie nationale.
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426. Acta societatis fennicae. (*1839–1842,* Commentationes societatis fennicae.)
427. Physikalische Berichte. (Beiblätter zu den Annalen der Physik und Chemie; Beiblätter *united with* Fortschritte der Physik *and* Halbmonatliches Literaturverzeichnis *to form* Physikalische Berichte.)
428. Repertorium für Experimental-Physik für physikalische Technik für mathematische und astronomische Instrumentenkunde. (*Before 1867 was* Repertorium für physikalische Technik für mathematische und astronomische Instrumentenkunde; *also known as* Carl's Repertorium.)
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440. Metal Industry and the Iron Foundry (London).
453. Proceedings of the Iowa Academy of Science.
468. Kongliga Svenska Vetenskaps-Akademien, Handlingar.
481. Tschermak's mineralogische und petrographische Mitteilungen.
502. Archives du Musée Teyler (Haarlem).
506. Monthly Weather Review.
507. Meteorologische Zeitschrift.
512. Proceedings of the Indian Association for the Cultivation of Science.
520. Monthly Notices of the Royal Astronomical Society (London).
523. Gesammelte Abhandlungen zur Kenntnis der Kohle.
524. Abhandlungen der k. Akademie der Wissenschaften, Berlin. (K. preussische Akademie der Wissenschaften.)
529. Proceedings of the Institute of Radio Engineers (New York).
530. American Architect and the Architectural Review.
533. Deutsche Bunsen-Gesellschaft für angewandte physikalische Chemie, Abhandlungen.
534. Proceedings of the National Electric Light Association.
535. Transactions of the International Electrical Congress.
536. Abhandlungen der k. Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse.
537. Gesellschaft zur Beförderung der gesammten Naturwissenschaften (Marburg). Schriften.
539. Proceedings of the Royal Irish Academy. Section A, Mathematical, Astronomical and Physical Science. Section B, Biological, Geological and Chemical Science.
540. Radio Review. (*Now merged into* Wireless World.)
541. Transactions of the Society of Naval Architects and Marine Engineers.
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549. Naturhistorisch-medizinischer Verein (Heidelberg). Verhandlungen.
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552. Rensselaer Polytechnic Institute, Engineering and Science Series.
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B98. Sonderabdruck aus der Festschrift zur Feier des siebzigsten Geburtstages Richard Dedekind. Braunschweig, Vieweg, 1901.

B101. de Broglie, Les Rayons-X. Paris, Blanchard, 1922.

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REFRACTIVITY

REFRACTIVITY OF ALL GASES AND VAPORS AND OF ELEMENTARY SUBSTANCES IN THE ISOTROPIC SOLID AND LIQUID STATES

J. J. Fox and F. G. H. Tate

SYMBOLS

Symbols and formulae that occur in a single table are explained there.

d Density.
F Formula-weight in accordance with the printed formula.
g As subscript, g indicates that the quantity pertains to the gas.
H As subscript, H indicates that the quantity pertains to hydrogen, H_2.
M Molecular weight.
n Index of refraction referred to a vacuum.
p Pressure.
λ Wave-length.
λ_μ Value of λ when the unit is $1\mu = 10^4$ Å; $\lambda_\mu = 10^{-4}\lambda_{\text{Å}}$.

SYMBOLE

Symbole und Formeln, die in einer einzelnen Tabelle vorkommen, sind dort erklärt.

d Dichte.
F Formelgewicht entsprechend der gedruckten Formel.
g Als untergeschriebende Index bedeutet g, dass sich die Grösse auf ein Gas bezieht.
H Als untergeschriebende Index bedeutet H, dass sich die Grösse auf Wasserstoff, H_2 bezieht.
M Molekulargewicht.
n Brechungsindex auf das Vakuum bezogen.
p Druck.
λ Wellenlänge.
λ_μ Wert von λ, wenn als Einheit $1\mu = 10^4$ Å gilt; $\lambda_\mu = 10^{-4}\lambda_{\text{Å}}$.

SYMBOLES

Les symboles et formules qui se présentent dans une seule table sont expliqués à cette place.

d Densité.
F Formule-poids en accord avec la formule imprimée.
g Comme souscrit, g indique que la quantité se rapporte à un gaz.
H Comme souscrit, H indique que la quantité se rapporte à l'hydrogène, H_2.
M Poids moléculaire.
n Indice de réfraction par rapport au vide.
p Pression.
λ Longeur d'onde.
λ_μ Valeur de λ lorsque l'unité est $1\mu = 10^4$ Å; $\lambda_\mu = 10^{-4}\lambda_{\text{Å}}$.

SIMBOLI

I simboli e le formule che si incontrano in ogni singola tabella sono ivi spiegate.

d Densità.
F Formula-peso corrispondente alla formula stampata.
g Quando viene posto sotto, g indica che la quantità si riferisce allo stato gasoso.
H Quando viene posto sotto, H indica che la quantità si riferisce all'idrogeno, H_2.
M Peso molecolare.
n Indice di rifrazione riferito al vuoto.
p Pressione.
λ Lunghezza d'onda.
λ_μ Valore di λ quando l'unità è $1\mu = 10^4$ Å; $\lambda_\mu = 10^{-4}\lambda_{\text{Å}}$.

The indices for solids and liquids are given for the actual temperatures at which they were determined; those for gases and vapors have in most cases been reduced to 0°C and 760 mm of Hg by some one of several, not always concordant, formulae. As values obtained previous to 1898 have been collected by Dufet (**23**), such values are, in general, omitted from this section if more recent data of equal or superior accuracy are available; a discussion of them will usually be found in the recent papers.

The variation of the refractivity with temperature and pressure has been given special consideration in the case of air; for other gases and vapors the available data are included with the refractivities in Table 4, if there is an indication that the ideal gas laws do not apply.

REFRACTIVITY OF AIR

Except as the contrary is stated, the following data refer to dry air containing the normal amount (0.03%) of CO_2. Doubling this amount of CO_2 will increase n by less than 1 in 10^7 (**54**).

TABLE 1.—REFRACTIVITY OF DRY AIR

For dispersion formulae, *see* Table 2; unit of λ = 1 Å; of p = 1 mm of Hg; temperature = t,°C

(*A*) Range: λ = 2218 to 8999, p = 760 mm (**54**). Observations were made at constant t, and gave directly the values of n for pressures near 760; these were reduced to p = 760 on the assumption that over this short range $(n - 1)/p$ is independent of p. For smoothed values, *see* Table 3.

t	0°C	15°C	30°C
λ	$(n - 1)10^6$		
2218Cu			298.27
2246Cu			296.04
2303Cu			290.75
2369Cu			287.90
2392Cu	322.34	305.00	286.71
2406Cu	322.27		286.94
2441Cu	320.90	304.66	286.23
2492Cu	319.66	301.22	285.77
2618Cu	314.58	296.24	283.36
2739Fe	310.17	293.20	280.40
2766Cu	313.94	295.05	278.71
2824Cu	310.38	294.08	277.93
2851Fe	308.58		276.83
2882Cu	308.06	292.10	277.41
2918Fe	307.98	291.23	275.21
2961Cu	307.83	291.40	274.62
2987Fe	307.37	291.80	274.48
2997Cu	307.42	291.53	274.26
3010Cu	307.82	289.48	275.19
3036Cu	308.41	290.82	274.50
3055Fe		291.05	
3063Cu	306.61	290.12	275.07
3075Fe			274.73
3116Fe	304.89	288.98	274.64
3175Fe	303.43	289.40	272.02
3205Fe	303.82	288.49	272.71
3280Fe	302.89	287.25	273.25
3347Fe	302.27	285.70	272.08

Refractivity: Dry Air.—(*Continued*)

t	0°C	15°C	30°C
λ	$(n-1)10^6$		
3413Fe	302.36	285.97	271.56
3485Fe	300.45	285.70	
3513Fe	301.00	285.80	271.60
3594Fe	298.89	284.50	271.49
3640Fe	298.61	284.24	270.00
3659Fe	299.87	283.63	269.96
3701Fe	299.64	283.42	267.90
3753Fe	298.80	283.18	268.80
3787Fe		283.16	
3790Fe		282.91	
3843Fe	297.75	282.92	268.95
3846Fe			268.22
3865Fe		282.61	
3867Fe	298.14		
3906Fe	299.33	282.16	267.61
3935Fe	297.98	281.48	268.91
3969Fe		281.98	
3977Fe	296.62	281.59	268.14
3983Fe	297.37	282.14	267.73
4005Fe		281.75	
4021Fe	297.17	281.57	266.99
4076Fe	297.04	281.64	268.87
4095Fe	296.66	280.95	267.60
4118Fe	297.34	280.93	
4147Fe		280.78	266.68
4191Fe		280.77	
4210Fe	297.00	280.81	266.87
4213Fe	296.36	280.53	266.97
4233Fe		280.71	
4245Fe	296.59	280.47	266.80
4282Fe	295.61	280.76	265.07
4315Fe	296.08	280.04	266.38
4352Fe	296.75	280.59	266.28
4369Fe	295.42	279.61	266.39
4375Fe		279.83	
4422Fe	295.47	279.28	266.44
4427Fe		279.67	
4484Fe	295.09		
4494Fe		279.64	265.62
4531Fe		279.44	
4547Fe	294.73	278.90	265.50
4592Fe	294.34	279.19	265.49
4602Fe		279.07	
4647Fe	294.63	278.78	265.49
4691Fe	294.30	278.52	264.97
4736Fe	293.89	278.92	265.36
4789Fe	293.57	277.84	264.74
4859Fe	293.80	278.76	264.65
4903Fe	293.76	278.32	264.71
4966Fe	293.32	278.91	264.60
5001Fe	293.55		264.20
5012Fe		278.30	
5051Fe	293.59	276.40	264.20
5110Fe	293.05	278.43	264.33
5167Fe	292.68	277.93	263.90
5171Fe	293.09	277.69	263.73
5232Fe	293.42	277.92	263.64
5266Fe	293.87		263.65
5324Fe	293.61	277.59	263.08
5397Fe	293.01	277.19	263.61
5455Fe	292.44	277.34	263.43
5506Fe	292.26	277.28	263.60

Refractivity: Dry Air.—(*Continued*)

t	0°C	15°C	30°C
λ	$(n-1)10^6$		
5569Fe	292.59	277.90	263.13
5624Fe	293.13	277.61	263.26
5658Fe	292.37	277.07	263.00
5709Fe	293.16	277.13	262.82
5763Fe	292.51	276.75	262.41
5852Ne		276.92	262.96
5881Ne		276.81	262.99
5883Fe	292.46	276.75	
5934Fe		276.71	263.88
5944Ne		276.36	262.99
6003Fe	292.85	276.58	
6029Fe			263.41
6065Fe	291.89	276.70	262.40
6074Ne		276.42	262.61
6096Ne		276.36	262.61
6136Fe	291.52	276.60	262.34
6143Ne		276.49	262.59
6163Ne		276.21	262.66
6191Fe	291.33	276.70	262.07
6217Ne		276.15	262.57
6219Fe		276.29	
6230Fe		276.79	
6246Fe		276.73	
6252Fe	291.26	276.07	262.07
6266Ne		276.49	262.48
6297Fe	290.40	274.65	
6304Ne		275.77	262.38
6318Fe		276.74	
6334Ne		276.16	262.47
6335Fe	291.06	275.81	262.10
6382Ne		276.36	262.40
6393Fe	291.11	276.37	262.03
6400Fe		276.51	
6402Ne		276.32	262.39
6430Fe	291.04	276.14	261.53
6462Fe	290.55	276.90	262.18
6494Fe	290.70	276.18	261.80
6506Ne		276.22	262.15
6532Ne		276.10	262.27
6546Fe	290.90	276.10	261.98
6563H		276.02	
6598Ne		276.02	261.96
6609Fe	291.69	276.28	261.25
6663Fe	291.36	275.96	262.74
6678Ne		275.46	
6678Fe	290.75	276.02	261.82
6717Ne		276.02	261.81
6750Fe	290.19	276.24	262.68
6752A		275.60	
6841Fe	290.70		
6843Fe			260.94
6871A		275.09	
6916Fe			263.33
6929Ne		275.76	261.84
6937A		275.45	
6945Fe	289.97	274.93	262.13
6965A		274.87	
6978Fe	290.39	275.08	261.45
7016Fe		276.54	
7023Fe	290.91		
7030A		274.90	
7032Ne		275.71	261.74

REFRACTIVITY: DRY AIR.—(*Continued*)

t	0°C	15°C	30°C
λ	$(n-1)10^6$		
7038Fe			261.01
7059Ne		273.70	
7067A		274.87	
7068Fe	290.24	276.71	262.41
7090Fe	290.53		
7130Fe	289.87	275.76	260.90
7147A		274.99	
7164Fe	289.50	276.12	261.36
7173Ne		275.67	
7187Fe		274.93	262.64
7207Fe		275.29	
7223Fe	290.57		260.89
7245Ne		275.26	261.66
7272A		274.88	
7293Fe	291.45		262.24
7372A		275.12	
7383A		274.66	
7389Fe	289.77		261.18
7411Fe	290.06	275.19	262.02
7438Ne		274.24	
7445Fe	290.36	275.62	260.94
7495Fe	290.68	276.45	261.27
7503A		274.83	
7511Fe		274.97	
7514A		274.89	
7531Fe	289.72	274.07	261.66
7568Fe			260.68
7586Fe	290.30		261.66
7620Fe		274.81	259.47
7635A		274.61	
7664Fe	289.58	274.81	261.12
7710Fe			261.12
7724A		274.49	
7748Fe	289.02	274.17	260.31
7780Fe	289.74	274.73	260.29
7832Fe	290.23	275.06	261.12
7937Fe	288.78	274.55	261.54
7945Fe	290.49	274.71	261.27
7948A		274.54	
7998Fe	288.67	274.87	260.66
8006A		274.58	
8014A		274.36	
8046Fe	289.03	275.01	260.56
8085Fe	290.26	273.92	261.00
8103A		274.28	
8115A		274.20	
8220Fe	289.52	273.61	261.22
8264A		274.25	
8327Fe	289.43	273.88	260.66
8387Fe	289.04	274.12	259.93
8408A		274.36	
8424A		274.27	
8468Fe	290.01		260.66
8514Fe		274.59	260.42
8521A		274.63	
8611Fe			259.90
8661Fe	288.10	274.07	260.10
8674Fe			261.26
8688Fe	288.73	273.41	260.48
8824Fe		273.55	260.54
8999Fe		273.56	259.15

(*B*) Values by various observers. Range: $\lambda = 2\,652$ to $130\,000$. For older values, *see* (23, 54, 58). Data reduced by the formula

$$r_0 = r \cdot \frac{760}{p} \cdot \frac{1 + \alpha t}{1 + \gamma p};\ r = (n-1)10^6$$

λ	r_0	λ	r_0	λ	r_0
$\gamma = 0, \alpha = 1/273$ (29)		$\gamma = 7(10)^{-7}$, $\alpha = 0.003670$ (35)		(81)	
2 652	314.00	5 894	292.98	5 461	291.41
2 894	309.02	67 094	288.06	(25)	
2 967	307.37	86 784	288.75	4 359	295.2
3 022	306.62			5 461	292.9
3 188	304.30				
3 965	298.00	$\gamma = 7(10)^{-7}$,			
4 471	295.55	$\alpha = 0.003670$ (75)*			
4 713	294.40	10 000	290	(84)	
5 016	293.50	20 000	289	8 000	290.9
5 876	291.96	30 000	289	10 000	289.7
6 678	291.20	40 000	289	20 000	288.2
$\gamma = 0, \alpha = 1/273$		* Based on preceding value for $\lambda = 5894$, Koch (35)		30 000	288.5
(14)				40 000	288.0
4 861	295.11			50 000	287.9
5 461	293.60			63 000	287.3
5 790	292.98	(62)		80 000	287.8
6 563	291.92	5 461	293.42	130 000	286.9

Variation of Refractivity of Air with Temperature, Pressure and Humidity

Temperature.—$(n-1)_0 = (n-1)_t \cdot (1 + \alpha t)$. Meggers and Peters (54) find $\alpha = 0.00367 + \frac{0.000003}{\lambda_\mu^3}$; Koch (35) and Statescu (75) used $\alpha = 0.003670$; Pèrard (59) used $\alpha = 0.003716$; Cuthbertson (14), Howell (29), and most of the other workers have used $\alpha = 0.003663 = 1/273$. At $t = -189$ to -188°C, Ayres (3) obtained the following values, agreeing with those of Scheel (68):

λ		507	735	914 mm of Hg
5461 Å	$(n-1)10^6 =$	654.3	954.1	1189.9
5780 Å	$(n-1)10^6 =$	653.3	951.1	1186.4

Pressure.—For small ranges in p, t constant, $(n-1)/p$ may be regarded as a constant. Opinions differ regarding the effect of relatively great changes. Mathews (53) concludes that $(n-1)/p$ is constant over the range $p = 26$ to $p = 760$ mm, but many consider that Mascart's relation, $(n-1)/p = K(1 + \gamma p)$, fits the observations better; the following values have been used for γ, the unit of p being 1 mm of Hg:

λ	5 461	5 461	5 462
p	0 to 760	0 to 760	760 to 7 600
$10^8\gamma$	357 ± 39	667 ± 87	51 ± 5
Lit.	(62)	(81)	(58)

λ	4 359	4 000 to 6 500	5 000 to 86 000
p	760 to 7 600	near 760	0 to 760
$10^8\gamma$	53 ± 5	240	70
Lit.	(58)	(59)	(35)

For the range $\lambda = 4050$ to 5090 Å, $p = 30$ to 100 atm., $t = 9$ to 14°C, it has been found (70, 71, 73) that, whatever the pressure,

$$\frac{(n-1)_\lambda}{(n-1)_{5461}} = 0.98086\left\{1 + \frac{0.0056376}{\lambda_\mu^2} + \frac{54.01(10)^{-6}}{\lambda_\mu^4}\right\}$$

For variation with p at $t = -188$°C, *see* preceding text.

Humidity.—If n_d and n_m = index for dry air and for air in which the partial pressure of water vapor is m mm of Hg, then Lorenz (43) concludes that $n_d = n_m + \frac{41m(10)^{-6}}{760}$.

TABLE 2.—DISPERSION FORMULAE FOR DRY AIR

$\lambda_\mu = 10^{-4}\lambda_A$, unit of λ_A = 1 Å

For the formula $(n - 1)10^6 = \beta/(\mu - \lambda_\mu^{-2})$, Cuthbertson (14) finds $\beta = 51\,626$, $\mu = 179.17$; for the Cauchy formula $(n - 1)\,10^6 = A + B\lambda_\mu^{-2} + C\lambda_\mu^{-4}$, the following values have been found, those of (54) being the best. Temperature is t, °C; pressure = 760 mm of Hg, except as noted.

t, °C	A	B	C	$1000B/A$	$10^6C/A$	Lit.
0	287.566	1.3412	0.03777	4.6641	131.35	(54)
15	272.643	1.2288	0.03555	4.5070	130.39	(54)
30	258.972	1.2259	0.02576	4.7337	99.47	(54)
0	287.987*	1.804*	0	6.264*	0	(65)
0	288.02	1.482	0.0309	5.145	107.3	(59)
11				5.638†	54.01†	(70, 71, 73)

* Freed of CO_2.

† For pressures between 30 and 100 atm., t = 12°C, 4050 Å $< \lambda <$ 5090 Å.

TABLE 3.—CORRECTIONS FOR CONVERTING WAVE-LENGTHS AND THEIR RECIPROCALS IN AIR AT 15°C AND 760 MM OF HG TO THEIR VALUES IN A VACUUM (54)

If λ_a, λ_v = values in air and in vacuum, respectively, then $\lambda_v = \lambda_a + \delta_\lambda$ and $1/\lambda_a = 1/\lambda_v + \delta_\nu$, where δ_λ and δ_ν have the values given in the table. The values of $(n - 1)$ are those computed by means of the equation $(n - 1)10^6 = 272.643 + 1.2288\lambda_\mu^{-2} + 0.03555\lambda_\mu^{-4}$ which was derived from the observations in Table 1, section A. Unit of λ and δ_λ = 1 Å; of δ_ν = 1 cm^{-1} = 10^8 Å^{-1}.

λ	$(n - 1)10^6$	δ_λ	δ_ν
2 000	325.582	0.6512	16.274
2 050	322.012	0.6601	15.703
2 100	318.786	0.6695	15.175
2 150	315.863	0.6791	14.687
2 200	313.207	0.6891	14.232
2 250	310.787	0.6993	13.808
2 300	308.575	0.7097	13.412
2 350	306.550	0.7204	13.041
2 400	304.691	0.7313	12.692
2 450	302.981	0.7423	12.363
2 500	301.405	0.7535	12.053
2 550	299.948	0.7649	11.759
2 600	298.600	0.7764	11.481
2 650	297.350	0.7880	11.217
2 700	296.188	0.7997	10.967
2 750	295.108	0.8115	10.728
2 800	294.100	0.8235	10.500
2 850	293.160	0.8355	10.283
2 900	292.280	0.8476	10.076
2 950	291.457	0.8598	9.877
3 000	290.685	0.8721	9.687
3 050	289.960	0.8844	9.504
3 100	289.279	0.8968	9.329
3 150	288.638	0.9092	9.160
3 200	288.033	0.9217	8.998
3 250	287.463	0.9343	8.842
3 300	286.924	0.9469	8.692
3 350	286.415	0.9595	8.547
3 400	285.933	0.9722	8.407
3 450	285.476	0.9849	8.272
3 500	285.043	0.9977	8.142
3 550	284.632	1.0104	8.016
3 600	284.241	1.0233	7.893
3 650	283.869	1.0361	7.774
3 700	283.516	1.0490	7.660
3 750	283.179	1.0619	7.550
3 800	282.858	1.0749	7.442
3 850	282.551	1.0878	7.337
3 900	282.259	1.1008	7.235
3 950	281.979	1.1138	7.137
4 000	281.712	1.1268	7.041
4 050	281.456	1.1399	6.948
4 100	281.211	1.1530	6.857
4 150	280.976	1.1661	6.769
4 200	280.751	1.1792	6.683
4 250	280.536	1.1923	6.599
4 300	280.329	1.2054	6.517
4 350	280.130	1.2186	6.437
4 400	279.939	1.2317	6.360
4 450	279.755	1.2449	6.285
4 500	279.578	1.2581	6.211
4 550	279.408	1.2713	6.139
4 600	279.244	1.2845	6.069
4 650	279.086	1.2978	6.000
4 700	278.934	1.3110	5.933
4 750	278.788	1.3242	5.868
4 800	278.646	1.3375	5.804
4 850	278.509	1.3508	5.741
4 900	278.378	1.3640	5.680
4 950	278.250	1.3773	5.620
5 000	278.127	1.3906	5.561
5 050	278.008	1.4039	5.503
5 100	277.893	1.4173	5.447
5 150	277.781	1.4306	5.392
5 200	277.674	1.4439	5.336
5 250	277.569	1.4572	5.285
5 300	277.468	1.4706	5.234
5 350	277.370	1.4839	5.183
5 400	277.275	1.4973	5.133
5 450	277.183	1.5106	5.084
5 500	277.094	1.5240	5.037
5 550	277.007	1.5374	4.990
5 600	276.923	1.5508	4.944
5 650	276.841	1.5642	4.899
5 700	276.762	1.5775	4.854
5 750	276.685	1.5909	4.811
5 800	276.610	1.6043	4.768
5 850	276.537	1.6177	4.726
5 900	276.466	1.6311	4.685
5 950	276.398	1.6446	4.644
6 000	276.331	1.6580	4.604
6 050	276.265	1.6714	4.565
6 100	276.202	1.6848	4.527
6 150	276.140	1.6983	4.489
6 200	276.080	1.7117	4.452
6 250	276.022	1.7251	4.415
6 300	275.965	1.7386	4.379
6 350	275.909	1.7520	4.344
6 400	275.855	1.7655	4.309
6 450	275.802	1.7789	4.275
6 500	275.751	1.7924	4.241
6 550	275.700	1.8058	4.208
6 600	275.651	1.8193	4.175
6 650	275.604	1.8328	4.143
6 700	275.557	1.8462	4.112
6 750	275.511	1.8597	4.081
6 800	275.467	1.8732	4.050
6 850	275.423	1.8866	4.020
6 900	275.381	1.9001	3.990

TABLE 3.—(*Continued*)

λ	$(n-1)10^6$	δ_λ	δ_ν
6 950	275.339	1.9136	3.961
7 000	275.299	1.9271	3.932
7 050	275.259	1.9406	3.903
7 100	275.221	1.9541	3.875
7 150	275.183	1.9676	3.847
7 200	275.146	1.9811	3.820
7 250	275.110	1.9945	3.793
7 300	275.074	2.0080	3.767
7 350	275.039	2.0215	3.741
7 400	275.006	2.0350	3.715
7 450	274.972	2.0485	3.690
7 500	274.940	2.0620	3.665
7 550	274.908	2.0756	3.640
7 600	274.877	2.0891	3.616
7 650	274.846	2.1026	3.592
7 700	274.817	2.1161	3.568
7 750	274.788	2.1296	3.545
7 800	274.759	2.1431	3.522
7 850	274.731	2.1566	3.499
7 900	274.703	2.1702	3.476
7 950	274.676	2.1837	3.454
8 000	274.650	2.1972	3.432
8 050	274.624	2.2107	3.410
8 100	274.599	2.2243	3.389
8 150	274.574	2.2378	3.368
8 200	274.549	2.2513	3.347
8 250	274.525	2.2648	3.326
8 300	274.502	2.2784	3.306
8 350	274.478	2.2919	3.286
8 400	274.456	2.3054	3.266
8 450	274.434	2.3190	3.246
8 500	274.412	2.3325	3.227
8 550	274.390	2.3460	3.208
8 600	274.369	2.3596	3.189
8 650	274.349	2.3731	3.170
8 700	274.328	2.3867	3.152
8 750	274.309	2.4002	3.134
8 800	274.289	2.4137	3.116
8 850	274.270	2.4273	3.099
8 900	274.251	2.4408	3.080
8 950	274.232	2.4544	3.063
9 000	274.214	2.4679	3.046
9 050	274.196	2.4815	3.029
9 100	274.179	2.4950	3.012
9 150	274.161	2.5086	2.995
9 200	274.144	2.5221	2.979
9 250	274.128	2.5357	2.963
9 300	274.111	2.5492	2.947
9 350	274.095	2.5628	2.931
9 400	274.079	2.5763	2.915
9 450	274.064	2.5899	2.899
9 500	274.048	2.6035	2.884
9 550	274.033	2.6170	2.869
9 600	274.018	2.6306	2.854
9 650	274.004	2.6441	2.839
9 700	273.989	2.6577	2.824
9 750	273.975	2.6713	2.809
9 800	273.961	2.6848	2.795
9 850	273.947	2.6984	2.780
9 900	273.934	2.7119	2.766
9 950	273.920	2.7255	2.752
10 000	273.907	2.7391	2.738

TABLE 4.—REFRACTIVITY OF GASES AND VAPORS

For dispersion formulae, *see* Table 5

Order: Elementary substances, pure compounds, mixtures. The formula used for reducing the observations is indicated, if known, by *I*, *II*, or *III*: *I*, $r_0 = r\cdot\frac{760(1+\alpha t)}{p(1+\gamma p)}$, unless other values are given, $\gamma = 0$ and $\alpha = 1/273$; *II*, $r_0 = rd_0/d$; *III*, $r_0 = r[(F/d)_0]_{t,p} \times [(d/M)_H]_{0,760}$; $r = (n-1)10^6$. If the gas is ideal and diatomic, and if $\gamma = 0$ and $\alpha = 1/273 (= 0.003663)$, all three formulae give the same value, and $r_0 = 10^6(n-1)_{0,760}$. $K \equiv r_0/p$. Unit of λ = 1 Å; of p = 1 mm of Hg; temperature = t,°C.

I. λ-Table.—Elementary Substances

A, Argon; *cf.* (82)*

λ	r_0
I (65)	
2 441.6	303.78
2 492.1	302.80
2 618.4	300.38
2 766.4	298.11
2 824.4	297.14
2 961.2	295.50
3 349.3	291.62
4 275.1	286.34
4 651.1	284.99
5 105.6	283.79
5 153.2	283.67
5 218.2	283.50
5 700.2	282.55
5 782.2	282.47
III (16); *cf.* (12)	
4 800	283.8
5 086	283.1
5 209	282.8
5 461	282.3
5 769	281.7
5 790	281.7
6 438	280.9
(7)	
4 861	286.0
5 016	285.6
5 461	284.6
5 876	283.8
5 896	283.7
6 563	282.9
(1)†	
4 359	285.1
5 461	281.6
5 770	280.2
5 790	280.2
6 439	279.6

* At 0°C and 760 mm Hg, (82) finds r_0 = 282.70 for λ = 5462.3.

† Less accurate than those of (16).

As₂, Arsenic

III (20)

λ	r_0
5 461	1 579
5 893	1 552

Br₂, Bromine

III (18)

λ	r_0
5 461	1 184.9
5 600	1 179.6
5 700	1 176.2
5 750	1 174.1
5 800	1 173.5
6 000	1 166.2
6 438	1 157.0
6 708	1 152.5

Cd₂, Cadmium

III (20)

λ	r_0
5 183	2 780
5 461	2 725
5 893	2 675
6 562	2 675

Cl₂, Chlorine

III (18)

λ	r_0
4 799.9	791.66
5 085.8	787.91
5 209.1	786.51
5 460.7	784.00
5 769.5	781.35
5 790.5	781.21
6 438.5	777.03
6 707.85	775.63

F₂, Fluorine

III (21)

λ	r_0
5 893	195 *ca.*

H₂, Hydrogen*

λ	r_0
I (14)	
4 861	140.64
5 461	139.71
5 780	139.33
6 563	138.66
I (35, 36); *cf.* (34)	
2 303	159.435
2 379	157.693
2 448	156.300
2 465	155.978
2 536	154.694
2 577	154.017
2 676	152.538
2 754	151.510
2 761	151.423
2 858	150.268
2 894	149.873
2 926	149.530
2 968	149.118
3 127	147.717
3 133	147.661
3 342	146.130
3 545	144.950
3 664	144.321
3 705	144.103
3 908	143.246
3 985	142.979

H_2.—(*Continued*)

λ	r_0
4 048	142.749
4 079	142.642
4 109	142.550
4 360	141.785
4 917	140.527
5 462	139.660
5 895	139.24
6 710	138.53
67 094	136.10
86 784	136.06
(43)	
5 896	138.7
6 708	138.0
I (48)	
$\gamma = 0$, $\alpha = 0.00381$	
5 085	139.2
5 896	138.7
6 438	138.3
(60)	
4 677	140.8
4 800	140.6
5 085	140.0
5 378	139.3
5 896	139.0
6 438	138.5
I (68)	
4 358	140.6
4 712	139.8
4 922	139.6
5 780	138.9
6 676	137.6
I (29)	
2 753	151.87
2 894	150.61
3 022	149.73
3 341	147.37
4 026	144.40
4 471	142.80
4 713	142.38
4 916	142.03
5 876	141.05
I (33)	
1 854.6	175.996
1 862.7	175.541
1 935.8	171.824
1 990.5	169.395
2 303	159.418
2 379	157.681
2 536	154.690
2 754	151.500
2 894	149.859
2 968	149.101
3 342	146.133
4 048	142.741
4 079	142.632
4 360	141.773
5 461	139.650†

* For the range $56 < p < 2760$ mm of Hg and t = constant, $(n - 1)10^6 = kp$, even at very low temperatures; for $\lambda = 5461$, $k = 0.615$ if $t = -187.5°C$, and $k = 0.687$ if $t = -191.1°C$; for $\lambda = 5780$, $t = -191.1°C$, $k = 0.683$ per mm of Hg (3).

† Same value found by Schacherl (67).

He, Helium; *cf.* (82)

λ	r_0
III (16)	
4 800	35.04
5 086	34.99
5 209	34.98
5 461	34.95
5 769	34.82
5 791	34.92
6 438	34.86
I (37)	
2 303	36.258
2 379	36.146
2 448	36.063
2 465	36.046
2 536	35.959
2 577	35.916
2 676	35.827
2 754	35.760
2 761	35.749
2 858	35.672
2 894	35.646
2 926	35.624
2 968	35.605
3 342	35.396
3 545	35.133
3 861	35.197
3 985	35.173
4 109	35.139
4 917	34.989
5 462	34.925
I (7)	
4 861	35.10
5 016	35.08
5 461	35.04
5 876	35.00
5 896	35.00
6 563	34.95

Hg_2, Mercury

III (20)	
5 183	1 885
5 461	1 882
5 893	1 866
6 562	1 799

I_2, Iodine*

III (18)	
5 000	2 12$_0$
5 005	2 16$_0$
5 100	2 21$_0$
5 250	2 25$_0$
5 600	2 17$_0$
6 180	2 13$_0$
6 215	2 13$_0$
6 438	2 10$_0$
6 708	1 97$_0$

* Not very accurate.

K, Potassium*

* For dispersion near absorption bands, *see* Bevan (5).

Kr, Krypton

III (16)	
4 799.9	431.80
5 085.8	430.34
5 029.1	429.78
5 460.7	428.74
5 769.5	427.64

Kr.—(*Continued*)

λ	r_0
5 790.5	427.61
6 438.5	425.80
6 707.8	425.33

N_2, Nitrogen;* *cf.* (83)

I (14)	
4 861	301.21
5 461	299.77
6 563	298.16
I (37)	
$\alpha = 0.003675$	
2 379	326.09
2 448	324.11
2 465	323.64
2 536	321.80
2 577	320.84
2 676	318.71
2 754	317.21
2 760	317.08
2 858	315.42
2 894	314.84
2 926	314.34
2 968	313.74
3 342	309.37
3 545	307.64
3 705	306.36
3 908	305.11
3 985	304.73
4 079	304.24
4 109	304.06
4 917	301.06
5 461	299.77
I (68)	
$\alpha = 0.003675$	
4 358	302.0
4 712	301.4
4 922	299.9
5 461	298.2
5 780	297.6
6 576	296.1
7 056	294.5
I (66)	
3 342	307.0
3 650	303.4
4 046	301.0
4 358	299.5
5 461	296.7
5 769	296.6

(3)

$t = -189.2°C$; $\lambda = 5461$ Å

$\Delta\ddagger = 0.03_6p$

p†	$(n - 1)10^6$
10.1 cm	133.3
21.9	288.2
35.5	461.8
42.8	558.9
76.2	1 004.0
76.4	1 009.9
76.6	1 008.6
100.9	1 347.0
101.0	1 349.3
122.8	1 662.5
122.8	1 659.0
143.4	1 961.1
143.5	1 962.9
149.5	2 049.7

N_2.—(*Continued*)

$t = -190.6°C$; $\lambda = 5461$ Å

$\Delta\ddagger = 0.03_5p$

p†	$(n - 1)10^6$
10.8 cm	144.1
22.2	294.4
35.6	470.6
39.0	515.3
72.6	975.4
76.3	1 023.3
110.4	1 508.3
123.3	1 692.4
132.3	1 829.9

$t = -191.6°C$; $\lambda = 5461$ Å

$\Delta\ddagger = 0.2_3p$

p†	$(n - 1)10^6$
11.0 cm	149.8
20.2	278.5
33.9	456.6
75.8	1 034.3
119.6	1 669.5

* At 21°C, $\lambda = 5461$ Å, and d between $70d_0$ and $200d_0$, d_0 = density at 0°C and 760 mm, $\frac{n^2 - 1}{n^2 + 2} \cdot \frac{d_0}{d}$ (= 199.7×10^{-6}) is more nearly constant than either $(n^2 - 1)/d$ or $(n - 1)/d$ (57).

† If computed by van der Waals's equation with $a = 126\,070$, $b = 1.325$, then both $(n - 1)/d$ and $(n^2 - 1)/(n^2 + 2)d$ are constant within 2 %.

‡ $\Delta \equiv (n_{5461} - n_{5780}) \times 10^6$, where 5780 is the mean λ of the yellow lines of Hg; p is expressed in cm of Hg. At −191.6°C the coefficient of p is nearly 7 times as great at −190.6°C.

Na, Sodium*

* For dispersion near absorption bands, *see* Bevan (5).

Ne, Neon

III (16)	
4 799.9	67.31
5 085.8	67.23
5 209.1	67.21
5 460.7	67.16
5 769.5	67.10
5 790.5	67.10
6 438.5	67.02

O_2, Oxygen*

I (14)	
4 861	273.45
5 461	271.70
5 790	270.99
6 563	269.75
I (29)	
2 753	324.23
2 894	293.60
3 022	291.19
3 188	287.93
3 889	279.65
4 471	276.31
4 713	275.11
5 016	274.01
5 876	271.84
6 678	270.83

O_2.—(*Continued*)

λ	r_0

(1)

4 359	274.7
5 461	270.6
5 780	270.1
6 439	269.2

I (66)

3 342	283.2
4 047	277.6
4 359	275.2
5 461	272.5
5 771	271.9

I (35); *cf.* (34)

$\gamma = 11(10)^{-7}$; $\alpha = 0.003674$

4 359.6	274.30
5 462.3	270.44
5 893	269.68
6 709.7	268.31
67 094	264.30
86 784	265.03

III (18)

4 800	273.66
5 085	272.72
5 209	272.37
5 461	271.70
5 770	271.02
5 790	270.98
6 438	269.88
6 708	269.52

* At −189.9°C, λ = 5461 Å, and $54 < p < 372$ mm of Hg, $(n - 1)10^6 = 1.185p$ (3). At 20°C, λ = 5461 Å, and d between $50d_0$ and $200d_0$, d_0 = density at 0°C and 760 mm, $(n^2 - 1)d_0/(n^2 + 2)d$ ($= 181.4 \times 10^{-6}$) is more nearly constant than either $(n^2 - 1)/d$ or $(n - 1)/d$ (57).

O_3, Ozone

III (18)

4 800	532.90
5 085	526.21
5 209	523.75
5 461	520.00
5 770	516.24
5 790	515.14

O_3.—(*Continued*)

λ	r_0
6 438	509.68
6 708	507.64

P_2, Phosphorus

III (10)

5 893	1 197

Rb, Rubidium*

* For dispersion near absorption bands, *see* Bevan (5).

S_2, Sulfur

III (10)

5 893	1 101

Se_2, Selenium

III (20)

5 461	1 570
5 540	1 560
5 893	1 565
6 540	1 530
6 562	1 535

Te_2, Tellurium

III (20)

5 461	2 620
5 893	2 495
6 562	2 370

Xe, Xenon

III (16)

4 799.9	712.8
5 085.8	709.2
5 209.1	707.9
5 460.7	705.5
5 769.5	702.9
5 790.5	702.8
6 438.5	698.7
6 707.8	697.3

Zn_2, Zinc

III (20)

5 183	2 070
5 461	2 150
5 630	2 020
5 893	2 050
5 893	2 065
6 562	1 960

II. 𝔅-Table.—Chemical Compounds, Standard Arrangement; *v.* Vol. III, p. viii

H_2O, Water

λ	r_0

III (18)

4 799.9	254.95
5 085.8	253.80
5 209.1	253.45
5 460.7	252.70
5 769.5	251.95
5 790.5	251.91
6 438.5	250.69
6 707.8	250.28

HCl, Hydrochloric acid

III (18)

4 799.9	451.87
5 085.8	450.07
5 209.1	449.30

HCl.—(*Continued*)

λ	r_0
5 460.7	448.00
5 769.5	446.66
5 790.5	446.56
6 438.5	444.44
6 707.8	443.75

HBr, Hydrobromic acid

III (18)

4 799.9	621.60
5 085.8	618.24
5 209.1	617.04
5 460.7	614.90
5 769.5	612.56
5 790.5	612.45
6 438.5	608.78
6 707.8	607.52

HI, Hydriodic acid

λ	r_0

III (18)

4 799.9	939.00
5 085.8	932.57
5 209.1	930.15
5 460.7	925.80
5 769.5	921.06
5 790.5	920.87
6 438.5	913.34
6 707.8	910.87

SO_2, Sulfur dioxide

III (15)

5 000	668.63
5 461	663.97
5 800	661.26
6 500	657.10
6 700	656.40

I (77)

4 359	696.3
5 461	682.0
6 708	660.6

*III** (31)

5 350	665.5
5 889	661.0
6 707	656.7

(79)

5 893	676

* Reduced to this basis by Cuthbertson (15).

SO_3, Sulfur trioxide

III (19)

5 893	737

H_2S, Hydrogen sulfide

III (15)

4 861	650.98
5 461	644.03
5 790	641.17
6 563	636.22

SF_6, *I* (63)

5 893	783

SeF_6, *I* (63)

5 893	895

TeF_6, *I* (63)

5 893	991

NO, *III* (18)

4 799.9	297.76
5 085.8	296.66
5 209.1	296.22
5 460.7	295.50
5 769.5	294.74
5 790.5	294.68
6 438.5	293.44
6 707.8	293.06

NO_2, *I* (17)

6 438	508.7

N_2O_4, *I* (17)

6 438	1 123

N_2O, *III* (18)

4 799.9	514.15
5 085.8	512.08
5 209.1	511.45
5 460.7	510.00
5 769.5	508.57

N_2O.—(*Continued*)

λ	r_0
5 790.5	508.48
6 438.5	506.16
6 707.8	505.44

(50)*; *cf.* (83)

4 800.2	523.0
5 086.1	520.7
5 378.9	519.2
6 439.2	513.2

* Gas not pure.

NH_3, *III (18)**

4 799.9	383.00
5 085.8	380.83
5 209.1	380.02
5 460.7	378.60
5 769.5	377.07
5 790.5	377.01
6 438.5	374.55
6 707.8	373.76

I† (47)

$\alpha = 0.00390$

4 358	396.1
4 861	391.8
5 461	387.0
5 875	384.8
6 563	382.6

* Data given with reserve.

† Reduced to 0°C and 760 mm by using $\alpha = 0.003914$, then reduced this value to what it would be if $(n - 1)/p$ were constant and p had such a value that the number of formula-weights per unit volume was equal to the number of moles of H_2 per unit volume at 0°C and 760 mm. These would agree with the following data (47) if reduced in the same way.

PH_3 (24)

White	789

PCl_3 (51)

5 893	1 740

CO; *cf.* (83)

I (11)

4 800	339.20
5 085	337.82
5 209	337.32
5 461	336.40
5 770	335.42
5 790	335.35
6 438	333.79
6 708	333.27

(28)

4 472	340.8
4 713	339.4
4 922	338.3
5 016	337.9
5 876	334.9
6 678	333.4

I (35, 38)

$\alpha = 0.003667$

2 379	386.7
2 448	382.3
2 465	381.3
2 536	377.4
2 577	375.4
2 676	371.0

CO.—(*Continued*)

λ	r_0
2 754	368.0
2 761	367.7
2 858	364.4
2 894	363.3
2 926	362.3
2 968	361.2
3 342	353.0
3 545	349.8
3 681	347.9
3 861	345.8
3 985	344.6
4 109	343.4
4 359	341.6
4 917	338.3
5 462	336.0
5 893	334.9
67 094	332.5
86 784	332.5

(60)

4 679	338.7
4 801	338.2
5 087	336.8
5 380	335.7
5 896	334.2
6 440	332.8

I (48)

$\alpha = 0.00367$

4 801	338.9
5 087	337.4
5 380	336.3
5 896	335.0
6 440	333.9

(84)

5 890	334.8
8 000	330.9
10 000	329.5
20 000	326.9
22 500	327.3
23 500	327.6
24 500	327.7
27 000	326.3
30 000	325.1
35 000	323.0
38 000	322.3
40 000	318.1
41 500	315.9
42 000	316.9
43 000	305.2
44 000	294.9
44 500	288.1
45 000	282.1
45 500	272.9
47 500	378.9
48 000	374.6
49 000	359.8
50 000	350.8
51 000	347.4
52 000	343.6
54 000	340.1
56 000	338.0
58 000	336.2
63 000	333.7
70 000	333.7

CO.—(*Continued*)

λ	r_0
80 000	330.7
90 000	331.2
130 000	328.0

CO_2, *I** (11)

λ	r_0
$\alpha = 0.00371$	
4 800	453.42
5 085	452.01
5 209	451.48
5 461	450.50
5 770	449.47
5 790	449.40
6 438	447.71
6 708	447.14

III† (11)

4 800	449.99
5 085	448.58
5 209	448.06
5 461	447.10
5 770	446.08
5 790	446.01
6 438	444.34
6 708	443.77

I (29)

2 753	476.17
2 894	471.37
3 022	469.29
3 188	465.49
3 820	456.38
4 026	454.14
4 471	451.19
4 713	449.06
5 016	447.50
5 876	445.31
6 678	443.79

I (35, 38); *cf.* (34)

$\alpha = 0.003716$

2 379	497.30
2 448	493.70
2 465	492.86
2 536	489.55
2 577	487.80
2 676	483.98
2 754	481.31
2 760	481.09
2 858	478.13
2 926	476.22
2 968	475.18
3 342	467.45
3 545	464.41
3 681	462.49
3 861	460.46
3 985	459.32
4 109	458.17
4 360	456.27
4 917	452.89
5 461	450.56
5 893	449.16
6 709	447.07
67 094	480.38
86 784	457.92

CO_2.—(*Continued*)

λ	r_0
I (77)	
4 359	458.9
5 461	451.1
6 708	446.6

II‡ (61)

4 358	456.68
5 461	450.88
5 790	449.54

I (76)

$\alpha = 0.003716$

5 893	450.8
8 000	446.3
10 000	441.4
20 000	433.6
30 000	418.5
40 000	289.0
50 000	531.6
67 000	483.8
87 000	458.0
110 000	447.2
131 900	400.4

(57)

$t = 21°C, \lambda = 5461$ Å

d/d_0§	$(n-1)10^6$§
27	$1\ 216_0$
35	$1\ 581_0$
45	$2\ 034_0$
60	$2\ 715_0$
70	$3\ 169_0$

(3)

$t = -78.3°C, \lambda = 5461$ Å

p, cm	$(n-1)10^6$
9.3	77.5
16.6	138.0
20.6	171.0
50.7	423.3
51.0	422.4
53.0	441.8
62.4	522.1
73.0	609.9
73.4	611.0
76.1	633.0
76.1	623.5
76.6	643.4
81.1	682.9
85.4	699.0

$(n-1)10^6 = 8.31_6 p$

For $\lambda = 5780$ Å

$(n-1)10^6 = 8.29_3 p$

(62)

5 461	451.55

For $p < 760$ mm

$K = 0.5519$

$10^6\gamma = 10.63 \pm 0.55$

CO_2.—(*Continued*)

(58)

$760 \text{ mm} < p < 7600 \text{ mm}$

For $\lambda = 5462$ Å

$K = 0.5468$

$10^6\gamma = 8.72 \pm 0.32$

For $\lambda = 4359$ Å

$K = 0.5533$

$10^6\gamma = 8.71 \pm 0.30$

(84)

λ	r_0
5 890	454.3
8 000	451.6
10 000	450.0
20 000	441.1
24 000	435.1
25 000	431.9
26 000	428.7
26 500	427.4
27 000	429.5
27 500	431.6
28 000	432.2
29 000	426 9
30 000	423.2
33 000	405.2
36 000	375.0
38 000	329.5
39 000	288.0
40 000	217.0
40 500	139.0
41 000	+ 92.0
42 000	−238.0
43 500	+974.0
44 000	834.0
44 500	696.0
45 000	670.7
46 000	617.6
47 000	584.9
49 000	548.1
52 000	523.6
56 000	507.0
62 000	492.0
70 000	483.2
80 000	472.7
90 000	468.2
100 000	457.7
110 000	445.5
122 000	423.8
132 000	371.0
137 500	317.0

* Also corrected for factor A in $[(PV)_{760} - (PV)]/(PV) = A(P - 760)$, using $A = 10.2 \times 10^{-6}$ per mm of Hg.

† Derived from same observations as preceding data.

‡ At 34°C, $\lambda = 5461$ Å, $0.10 < d < 0.74$, $\left(\frac{n^2+2}{n^2-1}\right)d = 6.581(1 + 0.0172 \times d^2)$.

§ $(n^2-1)/(n^2+2)d$ is more nearly constant than either $(n^2-1)/d$ or $(n-1)/d$; d_0 = density at 0°C and 760 mm of Hg.

C-Compounds.—ℭ-Arrangement; *v.* Vol. III, p viii

CCl_2O, Carbonyl chloride (24)

λ	r_0
White	1 159

CCl_4, Carbon tetrachloride

(50,* 52)	
5 893	1 779

CS_2, Carbon disulfide (51)

5 893	1 485
(43)	
5 893	1 478
6 710	1 457

$CHCl_3$, Chloroform (50,* 52)

5 893	1 464
(43)	
5 893	1 442
6 708	1 435

CHN, Hydrocyanic acid (51)

5 893	438

CH_3Br, Methyl bromide (50,* 52)

5 893	964

CH_3Cl, Methyl chloride

(50,* 52)	
5 893	870

CH_3F, Methyl fluoride (10)

5 893	449

CH_3I, Methyl iodide (50,* 52)

5 893	1 273
(64)	
5 893	1 265
6 708	1 253

CH_4, Methane

I (44, 46)	
5 290	447.8
5 718	445.4
5 935	443.5
6 375	441.1
6 585	440.4
(30)	
4 359	450.5
5 461	443.5
5 780	441.9
6 435	438.7
I (35)	
$\alpha = 0.003670$	
4 359	447.5
5 461	440.7
5 895	439.1
6 709	436.7
65 570	419.2
86 784	450.1

CH_4O, Methyl alcohol

(50,* 52)	
5 893	623
(64)	
5 893	552
6 708	550

* Data given with reserve.

C_2N_2, Cyanogen (31.1)

λ	r_0
5 350	789
5 893	784
6 708	780
I (77)	
4 359	870.8
5 461	853.8
6 708	843.1
II (9)	
5 893	844.6
(48)	
5 893	820.2

C_2H_2, Acetylene

I (44, 46)	
5 461	569.8
5 769	566.3
5 896	565.1
6 375	562.7
6 708	560.4
I (77)	
4 359	619.0
5 461	605.1
6 708	597.7
(52)	
5 893	610

C_2H_3N, Acetonitrile (50,* 52)

5 893	776

C_2H_4, Ethylene

I (45)	
5 230	662.0
5 461	661.4
5 790	658.8
5 896	657.1
6 185	653.1
6 677	651.6
(30)	
4 359	739.4
5 461	720.3
5 780	716.9
6 435	713.1
I (77)	
4 359	742.8
5 461	731.5
6 708	716.8

$C_2H_4Cl_2$, 1, 1-Dichloroethane

(64)	
5 893	1 415
6 708	1 408

$C_2H_4Cl_2$, Ethylene chloride

(50,* 52)	
5 893	1 417
(64)	
5 893	1 349
6 708	1 341

C_2H_4O, Acetaldehyde (50,* 52)

5 893	811

* Data given with reserve.

C_2H_5Br, Ethyl bromide

λ	r_0
(50,* 52)	
5 893	1 223

C_2H_5Cl, Ethyl chloride

(50,* 52)	
5 893	1 179

C_2H_5I, Ethyl iodide (50,* 52)

5 893	1 608
(43)	
5 893	1 646
6 708	1 632

C_2H_6, Ethane

I (45, 46)	
5 230	756.8
5 461	756.6
5 790	754.2
5 896	752.8
6 185	750.9
6 677	747.8
I (77)	
4 359	782.4
5 461	769.0
6 708	762.9

C_2H_6O, Ethyl alcohol (50,* 52)

5 893	885
(43)	
5 893	873
6 708	868

C_2H_6O, Methyl ether (50,* 52)

5 893	891

C_3H_4, Allylene (50,* 52)

5 893	1 188

C_3H_5Cl, 3-Chloropropylene

(50,* 52)	
5 893	1 444

C_3H_6, Propylene (50,* 52)

5 893	1 120

C_3H_6O, Acetone (50,* 52)

5 893	1 100
(64)	
5 893	1 082
6 708	1 076

* Data given with reserve.

$C_3H_6O_2$, Ethyl formate

λ	r_0
(50,* 52)	
5 893	1 191
(64)	
5 893	1 199
6 708	1 193

$C_3H_6O_2$, Methyl acetate

(50,* 52)	
5 893	1 138
(64)	
5 893	1 193
6 708	1 187

C_3H_7I, Propyl iodide (64)

5 893	1 788
6 708	1 775

$C_4H_8O_2$, Ethyl acetate

(50,* 52)	
5 893	1 408
(43)	
5 893	1 586
6 708	1 578

$C_4H_8O_2$, Methyl propionate

(64)	
5 893	1 477
6 708	1 469

$C_4H_{10}O$, Ethyl ether (50,* 52)

5 893	1 544
(43)	
5 893	1 521
6 708	1 514

C_5H_{10}, Amylene (50,* 52)

5 893	1 693

C_5H_{12}, Pentane (50,* 52)

5 893	1 711

C_6H_6, Benzene (50,* 52)

5 893	1 823
(80)	
5 893	1 820
(64)	
5 893	1 705
6 708	1 691

* Data given with reserve.

Mixtures

x = vol. % of second substance (or mixture); subscripts $_{\text{mix.}}$, $_1$ and $_2$, refer to the mixture and to first and second substance, respectively. The refractivities are said to be additive if $(n-1)_{\text{mix.}} = (n-1)_1 + x\{(n-1)_2 - (n-1)_1\}$. Reduced refractivity and density of the mixture are defined as $(n-1)_r = (n-1) \times \frac{760}{p} \cdot \frac{T}{273}$ and $d_r = d \cdot \frac{760}{p} \cdot \frac{T}{273}$.

Mixture	λ	Remarks	Lit.
Air.		*See* Tables 1, 2, 3	
$O_2 + O_3$.	4800 to 6708	Additive	(18)
$NO_2 + N_2O_4$.	6438	$10^6(n-1)_r = 298.34d_r - 105.33$*	(17)
$H_2 + CO_2$	5780	Additive	(78)
$H_2 + (He + Ne)$. . .	5780	Additive	(78)

* 272°K < T < 343°K; 55 mm < p < 238 mm.

TABLE 5.—DISPERSION FORMULAE FOR GASES AND VAPORS

$\lambda_\mu = 10^{-4}\lambda_A$; unit of λ_A = 1 Å. The table is divided into 4 sections, each, except *D*, devoted to a single type of formula. In general, the data refer to 0°C and 760 mm of Hg. Certain of the parameters depend upon the formula used in reducing the observations to 0° and 760 mm; these formulae are indicated by *I*, *II*, *III* (*see* Table 4) placed at head of section or in column (2).

A. $(n-1)10^6 = A + B\lambda_\mu^{-2} + C\lambda_\mu^{-4}$ (Formula *I*)

(1)	*A*	*B*	*C*	1000*B*/*A*	$10^6C/A$	Lit.
A.......	277.826	1.558	0	5.608	0	(65)
H_2*.....	136.102	1.0246	0.009906†	7.528_2	72.78	(33)
H_2......				7.337‡	89‡	(69, 72, 74)
O_2......	269.74	0.372	0.126	1.379	467	(66)
CO_2.....				6.787§	−6.14§	(70, 71, 73)
Air......	*See* Table 2					

* Those authors who use only *A* and *B*, find values of *B* varying from 0.90 to 1.00; *see* (14).

† Author uses a fourth term, $D\lambda_\mu^{-6}$; $D = 70.51 \times 10^{-6}$, $D/A = 5.181 \times 10^{-7}$.

‡ For all pressures between 25 and 70 atmospheres, t = 20°C, 4050 Å < λ < 5090 Å.

§ For all pressures between 20 and 47 atmospheres, t = 12°C, 4050 Å < λ < 5090 Å.

B. $(n-1)10^6 = \beta'/(\mu' - \lambda_\mu^{-2}) + \beta''/(\mu'' - \lambda_\mu^{-2})$

In most cases, β'' and $\mu'' = 0$; when β'' and μ'' are not zero, their values are written below those of β' and μ', with which they are connected by {.

(1)	(2)	β	μ	Lit.
A................	*III*	52 404	188.99	(16)
Br_2..............	*III*	47 598	43.54_7	(18)
Cl_2..............	*III*	81 257	106.99_3	(18)
H_2..............	*I*	18 800	137.88	(14)
H_2..............	*I*	{ 12 200.7 5 811.98	118.63_7 175.32_7 }	(33)
He................	*III*	13 470.9	388.80	(16)
Kr................	*III*	59 385	141.86_6	(16)
N_2..............	*I*	55 939	189.94	(14)
Ne................	*III*	28 814	432.40	(16)
O_2..............	*I*	37 744	142.27	(14)
Xe................	*III*	68 010	99.75_4	(16)
H_2O..............	*III*	29 190	118.86	(18)
HCl..............	*III*	51 583	118.49	(18)
HBr..............	*III*	57 162	96.316	(18)
HI................	*III*	64 333	72.849	(18)
SO_2..............	*III*	$63\ 64_0$	99.21	(15)
H_2S..............	*III*	$53\ 71_1$	86.76	(15)
NO................	*III*	39 122	135.73	(18)
N_2O..............	*III*	62 983	126.84	(18)
NH_3..............	*III*	32 953	90.392	(18)
NH_3..............	*I*	30 998	83.442	(47)
CO................	*III*	40 452	123.60	(11)
CO_2..............	*I*	69 049	156.63	(11)
CO_2..............	*III*	68 524	156.63	(11)

C. $\frac{3}{2}\left(\frac{n^2-1}{n^2+2}\right)10^6 = \beta'/(\mu' - \lambda_\mu^{-2}) + \beta''/(\mu'' - \lambda_\mu^{-2})$ (Formula *I*)

(1)	β′	μ′	β″	μ″	Lit.
N_2..............	39 534	152.294	−8 373.4*	−240.651*	(37)
CO_2..............	74 203	172.400	485.22	45.038	(38)

* Note the minus sign here.

D. Miscellaneous formulae

H_2	*I*	$(n^2-1)10^6 = 272.16 + 2.112/(\lambda_\mu^2 - 0.00776)$ (35)
He	*I*	$\frac{2}{3}\cdot\frac{n^2+2}{n^2-1} = 28\ 860.8 - \frac{67.763}{\lambda_\mu^2}$ (37)
O_2	*I*	$(n^2-1)10^6 = 528.42 + 3.696/(\lambda_\mu^2 - 0.007000)$* (35)

* After correcting misprints in original article.

TABLE 6.—INDEX OF REFRACTION OF ISOTROPIC, NON-METALLIC SOLID AND LIQUID ELEMENTARY SUBSTANCES

Double refracting solids, p. 16; metals, Vol. V, p. 248. *n* = index of refraction; *l* = liquid; *s* = solid. Unit of λ = 1μ = 10^{-4} cm. Temperature = *t*, °C.

(1)	λ	*n*	*t*	Lit.
Br *l*................	*D*0.589	1.661	15	(29)
Cl *l*................	*D*0.589	1.385	20	(22)
Cl *l*................	*D*0.589	1.367	14	(6)
H *l*................	0.579	1.097_4	−252.83	(2)
I *s*................	*D*0.589	3.34		(55)
N *l*................	0.579	1.197_5	−195.83	(2)
N *l*................	*D*0.589	1.205_3	−190	(40)
O *l*................	*D*0.589	1.221	−181	(41, 42)
P *s**..............	*D*0.589	2.1442	25	(27)
S *s*†..............	*D*0.589	1.998		(56)
S *l*................	*D*0.589	1.929	110	(4)
S *l*................	*D*0.589	1.890	130	(4)
Se *s*†..............	*D*0.589	2.92		(56)

* Yellow P. † Amorphous.

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(For a key to the periodicals see end of volume)

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REFRACTIVITY OF SELECTED SOLIDS AND LIQUIDS

CHARLES CHÉNEVEAU

Scope.—The substances included in this section are those pure solids and liquids which have been studied with special care on account of their practical importance or of some unusual behavior. All are listed in Table 1.

Sujet traité.—Les substances mentionnées dans cette section, sont les solides et liquides purs qui ont été étudiés avec un soin spécial, soit à cause de leur importance pratique, soit à cause de leur façon de se comporter inaccoutumée. Elles sont toutes mentionnées dans la Table 1.

Umfang.—Die in diesem Abschnitt enthaltenen reinen festen und flüssigen Stoffe sind solche, welche zufolge ihrer praktischen Bedeutung oder ihres ungewöhnlichen Verhaltens mit besonderer Sorgfalt studiert worden sind. Alle sind in der Tafel 1 angeführt.

Sostanze incluse.—Le sostanze incluse in questo capitolo sono quei solidi e liquidi puri che sono stati studiati con cura speciale sia per la loro importanza pratica o per il loro anormale comportamento. Essi sono riuniti nella Tabella 1.

Units.—Unit of $\lambda = 1\mu = 10^4$ Å $= 10^{-4}$ cm; of $t = 1°$C; of $p = 1$ atm.; of $d = $ g/cm.^{3}

TABLE 1.—REFRACTIVITY OF PURE SOLIDS AND LIQUIDS: SELECTED SUBSTANCES

$N_D[n_D]$ = index of refraction relative to vacuum [to air at 1 atm. and same temperature as the substance] for the Fraunhofer line D ($\lambda = 0.5893\mu$); similarly for n_C, n_F, etc.; $(10)^{-4}\Delta_{C-D} = (n_C - n_D)/(\lambda_C - \lambda_D)$, etc.; $(10)^{-5}\Delta_{tD} = (n_{t''} - n_{t'})/(t'' - t')$ for $\lambda = 0.5893(D)$; Δ_λ = mean value of $dn/d\lambda$ throughout visible spectrum; $dn/dt = A_t(10)^{-6}$; $dN/dp = A_p(10)^{-6}$; C = crystal of cubic system; d = density; f = solidified from fusion; s = solid. Temperature (t) is 20°C, except as noted; $\lambda_C - \lambda_D = 0.0670\mu$, $\lambda_D - \lambda_F = 0.1032\mu$, $\lambda_F - \lambda_{G'} = 0.0520\mu$.

Substance			n_D	$-\Delta_{C-D}$	$-\Delta_{D-F}$	$-\Delta_{F-G'}$	Lit.	$-\Delta_{tD}$	t', °C	t'', °C	Lit.
H_2O	Water (*see* Table 2)............		1.3330	276	401	617		8	10	25	
NH_4Cl	Sal ammoniac.................	*s*	1.6422	$\Delta_\lambda = -0.109$			(21)				
C	Diamond* (15°C).............	*s*	2.4173		1747		(67)	$(A_t)_D$, 18° = +19			(56)
CCl_4	Carbon tetrachloride...........		1.460	402	649	1057	(63)	50	11.1	25	(7)
CS_2	Carbon disulfide†.............		1.629	1401	2412	4269	(6)	79	−20	+40	(26)
$CHCl_3$	Chloroform...................		1.446	373	610	1038	(33)	55	18	30	(20)
CH_2O_2	Formic acid..................		1.371	328	465	711	(23, 29)	43	19	21	(28)
CH_3I	Methyl iodide................		1.530	805	1230	2192	(22)	78	16	29.5	(20)
CH_4O	Methyl alcohol...............		1.329	239	368	576	(9, 30)	36	18	30	(20)
$C_2H_4Br_2$	Ethylene bromide.............		1.540	597	978	1634	(63)	57	0	35	(69)
C_2H_4O	Acetaldehyde.................		1.333	268	416	673	(22, 28)	60	6	12	(28)
$C_2H_4O_2$	Acetic acid..................		1.372	298	445	711	(11, 15, 24)	51	18	26	(15)
C_2H_5I	Ethyl iodide.................		1.513	686	1133	1923	(22, 24)	69	10	20	(33)
C_2H_6O	Ethyl alcohol‡................		1.361	268	416	653	(54)	40	0	45	(27)
C_3H_6O	Acetone§.....................		1.359	283	455	750	(6, 24)	53	0	45	(27)
C_3H_8O	Isopropyl alcohol.............		1.377	283	436	692	(4)				
$C_3H_8O_3$	Glycerol‖.....................		1.474¶	343**	532**	846**	(29; 32)	20	18	22	(29)
$C_4H_8O_2$	Butyric acid..................		1.398	313	475	788	(4)	40	19	21.7	(65)
$C_4H_{10}O$	Butyl alcohol.................		1.399	298	475	711	(4)	41	15.5	80.2	(16)
$C_4H_{10}O$	Ethyl ether††................		1.352	268	416	634	(6, 9)	59	0	35	(38)
$C_5H_{12}O$	Isoamyl alcohol...............		1.407	313	484	750	(4)	40	16	26	(9)
$C_6H_5NO_2$	Nitrobenzene..................		1.553	1044	1773		(4)	51	25	38	(20)
C_6H_6	Benzene†......................		1.501	701	1162	2000	(6)	64	12	30	(69)
C_6H_6O	Phenol........................		1.550	880	1279	2307	(29)				
C_6H_7N	Aniline.......................		1.586	1013	1753	3153	(4)	54	11.2	90.1	(41)
C_7H_8	Toluene‡‡.....................		1.495	656	1114	1923	(6)	58	10	90	(41)
C_8H_{10}	*o*-Xylene†....................		1.507	656	1104	1884		57	11	42	(5)
$C_8H_{10}N_2O$	*p*-Nitrosodimethylaniline........	*s*	1.808		§§		(10)				
$C_{10}H_7Br$	Bromonaphthalene‖‖...........		1.658	1313	2296	4211	(6)	46	16.5	77.6	(37)
$C_{20}H_{20}ClN_3$	Fuchsin.......................	*s*	2.64	*See* Table 5			(42, 44)				
$C_{23}H_{25}ClN_2$	Malachite green...............	*s*	1.33	*See* Table 5			(42)				
$C_{26}H_{32}ClN_3$	Hofmann violet................	*s*	2.20	*See* Table 5			(42, 46)				
$C_{27}H_{18}N_4O_8S$	Diamond green.................	*s*	1.27	*See* Table 5			(43, 46)				
$C_{29}H_{35}IN_2.\frac{3}{2}H_2O$	Cyanin........................	*s*	1.71	*See* Table 5			(42, 43)				
$C_{30}H_{20}N_4.HCl$	Magdala red....	*s*	1.90	*See* Table 5			(42)				

TABLE 1.—(*Continued*)

Substance		Form	t, °C	n_D	$-\Delta_\lambda$	Lit.
SiO_2; *see* Vol. VI, p. 341						
$Pb(NO_3)_2$¶¶	*s*	*C*		1.7820	0.197	(64)
AgCl	*s*	*f,C*		2.061	0.290	(70)
AgBr	*s*	*f,C*		2.253	0.470	(70)
AgI	*s*	*f,C*		2.181	0.740	(70)
$(NH_4)_2SO_4.Fe_2(SO_4)_3.24H_2O$	*s*	*C*		1.4848	0.081	(59)
$(NH_4)_2SO_4.Cr_2(SO_4)_3.24H_2O$	*s*	*C*		1.4841	0.065	(59)
B_2O_3	*s*	*f*	15	1.4636	0.042	(1.1)
$(NH_4)_2SO_4.Al_2(SO_4)_3.24H_2O$*	*s*	*C*	15 to 21	1.4594	0.052	(59)
CaF_2*	*s*	*C*	18	1.4338	0.0284	(36, 55)
$Ba(NO_3)_2$	*s*	*C*		1.5711	0.095	(64)
NaCl*	*s*	*C*	18	1.5443	0.0804	
$NaClO_3$*	*s*	*C*	19	1.5152	0.0458	(3)
$Na_2B_4O_7$	*s*	*f*	16	1.5147	0.070	(1.1)
$Na_2SO_4.Al_2(SO_4)_3.24H_2O$	*s*	*C*		1.4388	0.044	(59)
KCl*	*s*	*C*	18	1.4904	0.0705	
KBr	*s*	*C*		1.5593	0.100	(64)
KI	*s*	*C*		1.6666	0.169	(64)
$K_2SO_4.Fe_2(SO_4)_3.24H_2O$	*s*	*C*		1.4816	0.078	(59)
$K_2SO_4.Cr_2(SO_4)_3.24H_2O$	*s*	*C*		1.4813	0.0638	(59)
$K_2SO_4.Al_2(SO_4)_3.24H_2O$*	*s*	*C*	21	1.4560	0.052	(59)

* *See also* Table 3.

† *See also* Table 4.

‡ For 99.7 to 99.9 % C_2H_5OH. For pure C_2H_5OH, $n^2 = 1.839 + \frac{0.006795}{\lambda^2 - 0.01716}$ if $0.215\mu < \lambda < 0.420\mu$. If $t' = 0°$ and $t'' = 45°$, $\Delta_{tC} = -40.3$, $\Delta_{tD} = -40.4$, $\Delta_{tF} = -41.0$, $\Delta_{tG'} = -41.5$ (27). If $\lambda = 0.5893$ (*D*), $A_p = +40$ at 10°; +42, 20°; +44, 25°; +45, 27.5° (48).

§ If $t' = 0°$ and $t'' = 45°$, $\Delta_{tC} = -52.8$, $\Delta_{tD} = -53.0$, $\Delta_{tF} = -53.8$, $\Delta_{tG'} = -54.9$ (27).

‖ If $\lambda = 0.5893$ (*D*), $A_p = +11$ at 20°C (26).

¶ For pure $C_3H_8O_3$; deduced by extrapolation from 94.6 % $C_3H_8O_3$.

** For glycerol of $d = 1.259$ g cm^{-3} at 20°C.

†† If $\lambda = 0.5893$ (*D*), $A_p = +60$ at 5°; +63, 10°; +69, 20°; +72, 25°; +75, 27.5°C (48).

‡‡ If $t' = 10°$ and $t'' = 90°$, $\Delta_{tC} = -57.2$, $\Delta_{tD} = -57.7$, $\Delta_{tF} = -59.2$ (41).

§§ *p*-Nitrosodimethylaniline, *p*-$(CH_3)_2NC_6H_4NO$, at 20°C (10):

λ	0.4878	0.5042	0.5189	0.5270(*E*)	0.5603	0.5857	0.6170	0.6497
n	2.146	2.024	1.957	1.926	1.847	1.813	1.785	1.762

‖‖ If $t' = 16.5°$ and $t'' = 77.6°$, $\Delta_{tC} = -45.4$, $\Delta_{tD} = -46.1$; $\Delta_{tF} = -47.8$ (37).

¶¶ Isotopic $Pb(NO_3)_2$ at 20°C. Pb = 207.20, $n_D = 1.7815$; Urano-Pb = 206.41, $n_D = 1.7814$ (47).

TABLE 2.—REFRACTIVITY OF WATER (H_2O)

Variation with wave-length (λ), with temperature (t) and pressure (p), and with source. $N[n]$ = index of refraction with reference to vacuum [to air at 1 atm. and same temperature as the water]; met. r. = metallic reflection.

Variation with λ: Except as noted, t = 20°C. At 18°C, $n^2 = -0.013414\lambda^2 + 1.76148 + \frac{0.0065438}{\lambda^2 - (0.11512)^2}$, if $0.224\mu < \lambda < 1.256\mu$.

Radiation		n
S	λ	
(12)		
	0.1151	met. r.
Ag	0.1829	1.46379
Al	0.1862	1.45343
Al	0.1990	1.42572
(17, 34, 57)		
Cd	0.2144	1.40397
Cd	0.2195	1.39883
Cd	0.2265	1.39257
Cd	0.2313	1.38878
(17, 34, 57)		
Au	0.2428	1.38103
Cd	0.2573	1.37349
Au	0.2676	1.36904
Cd	0.2749	1.36637
Al	0.3082	1.35671
Cd	0.3404	1.35044
Cd	0.3611	1.34738
Mean of many observers		
Al	0.3944	1.34366
Ca(*H*)	0.3968	1.34352
Hγ(*G'*)	0.4341	1.34035
Hg	0.4360	1.34030
Cd	0.4416	1.33981
Cd	0.4678	1.33815
Cd	0.4800	1.33750
Hβ(*F*)	0.4861	1.33714
Cd	0.5338	1.33499
Tl	0.5350	1.33490
Hg	0.5460	1.33447
Mean of many observers		
Hg	0.5770	1.33342
Hg	0.5790	1.33333
Na(*D*)	0.5893	1.33300
Hα(*C*)	0.6563	1.33115
Li	0.6708	1.33079
K(*A'*)	0.7682	1.32888
(49)		
	0.871	1.3270
	0.943	1.3258
	1.028	1.3245
	1.130	1.3230
	1.256	1.3210
Residual rays (51)		
CaF_2	25.5 to 26	1.41
NaCl	49.6 to 53.6	1.36
KBr	75.6 to 86.5	1.41
Electromagnetic (62)		
	4 000	5.3
	27 000	9.0

Variation with temperature (t) and pressure (p): $n_t = n_{20} - 10^{-5} \times [0.124(t - 20) + 0.1993(t^2 - 400) - 0.000005(t^4 - 160\ 000)]$; $dn/dt = A_t(10)^{-6}$ (mean result of many observers). Values of dN/dp apply if 1.5 atm. $< p <$ 8 atm.; $dN/dp = A_p(10)^{-6}$.

λ	0.4341	0.4861	0.5893	0.6563		0.5893
t	$n_{G'}$	n_F	n_D	n_C	$-A_t$	A_p*
−10	(Liquid H_2O)		1.3338†			(46, 48, 72)
0			1.3340		1	+16.8
+ 5			1.3339			+16.2
10	1.3411	1.3378	1.3337	1.3318	41	+15.8
15			1.3334			+15.4
20	1.34035	1.33714	1.33300	1.33115	79	+15.2
25			1.3325			+14.8
30	1.3392	1.3360	1.3320	1.3302	115	
40	1.3379	1.3347	1.3306	1.3288	148	
50	1.3364	1.3332	1.3290	1.3274	176	
60	1.3346	1.3315	1.3272	1.3257	197	
70	1.3325	1.3294	1.3252	1.3237	212	
80			1.3231		218	
90			1.3207			

Variation with source of water: Natural waters at 20°C (13, 60). For $\lambda = 0.5893$ (*D*), n is as follows: Pure distilled H_2O, 1.33300; city supply, Paris, 1.33304; river, Seine, 1.33305; ocean, Mediterranean, 1.337; H_2O saturated with CO_2 at 1 atm., 1.33297.

*At 18.2°C			
	λ = 0.486	0.589	0.686
	A_p = 15.4	15.2	15.1

† For liquid (undercooled) H_2O, n_D passes through a maximum (1.33412) between −1°C and −2°C (45).

TABLE 3.—REFRACTIVITY OF SOME REMARKABLE CUBIC CRYSTALS

Includes: Sylvite (KCl), rock salt (NaCl), fluorite (CaF_2), sodium chlorate ($NaClO_3$), diamond (C), ammonium alum [$Al_2(SO_4)_3.(NH_4)_2SO_4.24H_2O$] and potassium alum [$Al_2(SO_4)_3.K_2SO_4.24H_2O$]. For SiO_2, *see* Vol. VI, p. 341. n = index of refraction with reference to air at 1 atm. and same temperature as crystal; $A_t(10)^{-6} = dn/dt$; abs. = strong absorption; met. r. = metallic reflection. $n^2 = -k'(10)^{-7}\lambda^4 - k(10)^{-4}\lambda^2 + a + \frac{b_1(10)^{-3}}{\lambda^2 - \beta_1^2} + \frac{b_2(10)^{-3}}{\lambda^2 - \beta_2^2}$ if $0.185\mu < \lambda < 22.30\mu$. $n^2 = n_\infty^2 + \frac{M_1}{\lambda^2 - \lambda_1^2} + \frac{M_2}{\lambda^2 - \lambda_2^2}$ if $\lambda' < \lambda < \lambda''$.

Table 3.—(*Continued*)

Parameter	18°C		
	KCl*	NaCl†	CaF_2
k'	1.67587	2.86086	28.94
k	5.13495	9.28584	32.055
a	2.174967	2.330165	2.03913
b_1	6.98382	5.343924	6.125
$100\beta_1^2$	2.555521	2.547407	0.0078925
b_2	8.344206	12.78635	
$100\beta_2^2$	1.190826	1.484985	
n_∞^2	4.5531	5.1790	6.0104
M_1	0.0150	0.018496	0.00612093
M_2	10 747	8 977	5 099.15
λ_1^2	0.0234	0.01621	0.008884
λ_2^2	4 517.1	3 149.3	1 258.47
λ'	0.434	0.434	0.185
λ''	22.30	22.30	9.4291

Radiation		KCl	NaCl		CaF_2	
S	λ	n	n	A_t	n	A_t
		(35)	(2, 8)	(36)	(19, 55)	(36)
Al	0.18540	1.82704	1.89322		1.50989	− 2.96
Al	0.19352	(abs.)	1.82800		1.50123	− 4.02
Al	0.19898	1.72432	1.79570		1.49621	− 4.64
Au	0.20821	1.68302	1.75403	+18.4	1.48885	− 5.82
Cd	0.21443	1.66182	1.73210	+ 8.51	1.48460	− 6.37
Cd	0.21946	1.64739	1.71700	+ 2.35	1.48150	− 6.55
Cd	0.23128	1.62037	1.68825	− 7.57	1.47516	− 7.32
Au	0.24280	1.60041	1.66699	−14.0	1.47009	− 7.70
Cd	0.25730	1.58119	1.64608	−19.79	1.46480	− 8.11
Cd	0.27486	1.56380	1.62690	−23.96	1.45967	− 8.55
Au	0.29136	1.55134	1.61312	−26.3	1.45586	− 8.90
Al	0.30821	1.54130	1.60190	−28.3	1.45257	− 9.21
Cd	0.30436	1.52720	1.58605	−30.68	1.44774	− 9.61
Cd	0.36117	1.52042	1.57842	−31.94	1.44535	− 9.79
			(35)		(55)	
H*δ*(*h*)	0.41018	1.50901	1.56547	−33.4	1.44112	−10.04
Cd	0.44157	1.50384	1.55962	−34.25	1.43920	−10.28
Cd	0.50859	1.49614	1.55087	−35.17	1.43618	−10.56
Na(*D*)	0.58930	1.49038*	1.54433	−36.22	1.43385	−10.89
Li	0.67080	1.48663	1.54002	−36.5	1.43226	
K	0.76822	1.48374	1.53666		1.43093	
		(40)	(31, 39)		(31, 39)	
2*D*	1.1786	1.47821	1.53037		1.42786	
3*D*	1.7679	1.47579	1.52744		1.42502	
4*D*	2.3572	1.47465	1.52586		1.42198	
5*D*	2.9465	1.47373	1.52453		1.41822	
6*D*	3.5358	1.47295	1.52317		1.41379	
8*D*	4.7144	1.47102	1.51999		1.40238	
10*D*	5.8930	1.46870	1.51601		1.38719	
12*D*	7.0716	1.46591	1.51106		1.36805	
14*D*	8.2502	1.46263	1.50529		1.34444	
16*D*	9.4288	1.45875	1.49850		1.31612	
		(52, 53)	(52, 53)			
20*D*	11.786	1.44909	1.48182			
24*D*	14.143	1.43712	1.46055			
27*D*	15.911	1.42607	1.44103			
30*D*	17.679	1.41393				
	20.60	1.3882	1.3730			
	22.30	1.372	1.3403			
	51.2		(met. r.)			
	66.1	(met. r.)				
		(50)	(50)		(50)	
	57 000	2.17	2.40		2.60	
	τ‡	9.50	11.28		17.14	mm

Table 3.—(*Continued*)

Radiation		n			
		$NaClO_3$§	C,‖ 15°C	Al Alum¶	
S	λ			NH_4	K
		(*t*, 19°C) (3)	(35)	(*t*, 13°C) (3)	
Cd	0.21443			1.54349	1.53825
Cd	0.21946			1.53782	1.53280
Cd	0.22650			1.53106	1.52615
Cd	0.23128	1.61586		1.52684	1.52209
Cd	0.25730			1.50943	1.50514
Cd	0.27486			1.50096	1.49675
Cd	0.31332		2.5254		
Cd	0.3261	1.54931			
Cd	0.34036		2.5008	1.48180	1.47814
Cd	0.36117	1.53917	2.4853	1.47799	1.47436
			(67)	(*t*, 15 to 21°C) (58)	(*t*, 21°C) (61)
Ca(*H*)	0.39685		2.46476		1.46907
H(*F*, H_β)	0.48615		2.43539	1.46481	1.46140
Na(*D*)	0.58930	1.51523	2.41734**	1.45939	1.45602††
		(*t*, 23°C) (14)			
O(*B*)	0.6867	1.51163			
(*a*)	0.71734			1.45509	1.45175
O(*A*)	0.75938		2.40245		1.45057

* For KCl (35) at 18°C; $(A_t)_D = -35$. For visible spectrum, mean $dn/d\lambda = -0.0705$.

† In visible spectrum, mean $dn/d\lambda = -0.0804$.

‡ Thickness of plate used in finding n for the electromagnetic radiation ($\lambda = 57\ 000\mu = 5.7$ cm) is τ mm.

§ For $NaClO_3$ (14) $(n_{23°} - n_{0°})/23 = -57 \times 10^{-6}$ per 1°C if $0.686\mu > \lambda > 0.486\mu$.

‖ Diamond.

¶ In visible spectrum, mean $dn/d\lambda = -0.052$.

** For diamond (56) at 15°C, $(A_t)_D = +19$.

†† At 21°C (56) $(A_t)_D = -14$.

Table 4.—Refractivity of Some Remarkable Organic Liquids

$$n^2 = -k\lambda^2 + a + \frac{b_1}{\lambda^2 - \beta_1^2};\ n^2 = n_\infty^2 + \frac{M_1}{\lambda^2 - \lambda_1^2}.\quad \frac{dn}{dt} = A_t(10)^{-6}.$$

$10^{-5}\Delta_{t\lambda} = (n_{t''\lambda} - n_{t'\lambda})/(t'' - t')$. $\frac{dN}{dp} = A_p(10)^{-6}$; d = density, abs. = strong absorption, met. r. = metallic reflection.

CS_2

$t = 18°$, $d = 1.266$; $k = 0.0003$, $a = 2.51516$, $b_1 = 0.041695$, $\beta_1^2 = 0.04731930$, if $0.260 < \lambda < 1.998$ (34); $n_\infty^2 = 2.511$, $M_1 = 0.04736$, $\lambda_1^2 = 0.0334$, limits of λ not indicated (1).

λ		n	A_t
		(17, 18, 34)	(25)
Al	0.2175	met. r.	
Fe	0.260	2.160	
Cd	0.2677	2.110	−1750
Cd	0.2749	2.008	−1500
Cd	0.2881	1.912	
Cd	0.2981	1.875	
Fe	0.304	1.852	
Sn	0.317	1.807	
Fe	0.321	abs.	
Cd	0.3261	1.782*	
Zn	0.335	1.791*	
Cd	0.3610	1.740	− 960

CS_2.—(*Continued*)

λ		n	A_t
		(6)	
Al	0.3944	1.704	− 900
H*γ*	0.4341	1.6766	− 870
Cd	0.4416	1.673	− 860
Cd	0.4678	1.661	− 840
Cd	0.4800	1.656	− 830
H*β*	0.4861	1.6544	− 830
Cd	0.5086	1.647	− 820
Cd	0.5338	1.640	− 810
(*D*)	0.5893	1.6295	− 800
H*α*	0.6563	1.6201	− 780
		(49)	
	0.8	1.607	
	1.0	1.598	
	1.5	1.588	
	2.0	1.585	
	5.8	met. r.	

* Anomalous dispersion (CS_2) from λ = 0.3261 to λ = 0.355.

CS_2.—(*Continued*)

λ		t, °C	A_p
			(48)
(*D*)	0.5893	5	+60
(*D*)	0.5893	10	+62
	0.486	15	+67
(*D*)	0.5893	15	+64
	0.686	15	+62
(*D*)	0.5893	20	+66
(*D*)	0.5893	25	+68
(*D*)	0.5893	27.5	+69

	λ		$\Delta_{t\lambda}$
t′, −20°; t″, +40° (26)	*G′*	0.4340	−87.2
	F	0.4861	−83.4
	D	0.5893	−79.4
	C	0.6563	−77.9

C_6H_6, Benzene

d = 0.880, t = 20°C; n_∞^2 = 2.194, M_1 = 0.02409, λ_1^2 = 0.01714, limits of λ not indicated (1).

λ		n	A_t
		(57)	(69)
	0.1745	met. r.	
Cd	0.2763	1.625	
Cd	0.2837	1.619	
Cd	0.2881	1.612	
Cd	0.2981	1.598	
Cd	0.3081	1.587	
Cd	0.3133	1.582	
Cd	0.3261	1.570	
Cd	0.3404	1.560	
Cd	0.3466	1.556	
Cd	0.3610	1.548	
		(6)	
Hγ	0.4341	1.523	−670
Cd	0.4678	1.516	
Cd	0.4800	1.514	
Hβ	0.4861	1.513	−660
Cd	0.5086	1.509	
(*D*)	0.5893	1.501	−650
Hα	0.6563	1.496	−640
		(49)	
	0.8	1.489	
	1.0	1.485	
	1.5	1.480	
	1.85	1.478	

C_6H_6.—(*Continued*)

For λ = 0.5893 (*D*).

t, °C	A_p(48)
5	+46
10	+47
20	+51
25	+52
27.5	+53

t′ = 12°C; t″ = 30°C.

λ		$\Delta_{t\lambda}$ (69)
G′	0.4340	−67.4
F	0.4861	−66.8
D	0.5893	−64.6
C	0.6563	−64.5

C_8H_{10}, Xylene

Mixture of *o*-, *m*-, and *p*-; d = 0.866, t = 20°C; n_∞^2 = 2.177, M_1 = 0.02037, λ_1^2 = 0.0246, limits of λ not indicated (1).

λ		n (57)
Cd	0.2981	1.586
Cd	0.3081	1.575
Cd	0.3133	1.570
Cd	0.3261	1.560
Cd	0.3404	1.550
Cd	0.3466	1.546
Cd	0.3610	1.539
		(5)
Hγ	0.4341	1.517
Cd	0.4678	1.509
Cd	0.4800	1.507
Hβ	0.4861	1.507
Cd	0.5086	1.503
(*D*)	0.5893	1.496
Hα	0.6563	1.492
		(49)
	0.8	1.486
	1.0	1.482
	1.5	1.477
	1.88	1.476

TABLE 5.—REFRACTIVITY OF DYES

All dyes in this table are isotropic solids which exhibit selective reflection. n is determined either by prism or by reflection, as indicated, and is with reference to air at the same (room) temperature. Designations of Fraunhofer lines are in italics; *e.g.* (*D*).

Fuchsin, $C_{20}H_{20}ClN_3$

λ		n
Prism (42, 44)		
	0.344	1.60
	0.360	1.52
	0.399	1.24
	0.405	1.38
Hδ	0.410	1.17
	0.413	1.15
Hγ	0.434	1.04
Sr	0.461	0.83
Hβ	0.486	1.05
Tl	0.535	1.95
(*D*)	0.589	2.64
Li	0.671	2.34
	0.703	2.30
Reflection (68)		
(*H*)	0.397	1.32
	0.425	1.00
(*G*)	0.431	0.95
	0.455	0.847
Hβ	0.486	1.074
(*E*)	0.527	1.912
(*D*)	0.589	2.684
	0.634	2.412
Hα	0.656	2.310
(*B*)	0.687	2.161
(*a*)	0.719	2.086
	0.760	2.019

Malachite green, $C_{23}H_{25}ClN_2$

λ		n
Prism (42)		
Hδ	0.410	1.28
	0.416	1.37
Hγ	0.434	1.38
Hβ	0.486	1.45
Tl	0.535	1.16
(*D*)	0.589	1.33
Li	0.671	2.50
	0.703	2.49

Hofmann violet, $C_{26}H_{32}ClN_3$

λ		n
Prism (42, 66)		
	0.376	1.58
	0.403	1.47
	0.423	1.45
Hγ	0.434	1.32
	0.445	1.23
Hβ	0.486	0.86
Tl	0.535	1.27
(*D*)	0.589	2.20
	0.650	2.42
Li	0.671	2.53
	0.703	2.57

Diamond green, $C_{27}H_{18}N_4O_8S$

λ		n
Prism (43)		
(*G*)	0.431	1.48
	0.475	1.70
Hβ	0.486	1.60
	0.517	1.41
(*E*)	0.527	1.31
	0.553	1.09
(*D*)	0.589	1.27
Hα	0.656	2.01
(*a*)	0.719	2.42
Reflection (68)		
(*G*)	0.431	1.46
	0.475	1.54
Hβ	0.486	1.44
	0.517	1.24
(*E*)	0.527	1.14
	0.553	1.03
(*D*)	0.589	1.27
Hα	0.656	2.15
(*a*)	0.719	2.41

Cyanin, $C_{29}H_{35}IN_2.1.5H_2O$

λ		n
Prism (42, 43)		
	0.288	1.71
	0.350	1.70
	0.378	1.69
	0.407	1.68
Hγ	0.434	1.61
(*e*)	0.438	1.59
Sr	0.461	1.49
Hβ	0.486	1.43
	0.505	1.28
	0.520	1.19
Tl	0.535	1.20
	0.540	1.25
	0.565	1.39
(*D*)	0.589	1.71
	0.620	1.94
	0.645	2.23
	0.656	2.19
	0.671	2.11
	0.700	2.03
	0.703	1.98
Prism (71)		
	0.395	1.58
Hδ	0.410	1.57
	0.421	1.55
	0.440	1.52
	0.455	1.47
	0.467	1.42
	0.484	1.35
	0.493	1.29
	0.497	1.25
	0.504	1.17
	0.508	1.12
	0.648	2.35
	0.660	2.25
	0.668	2.19
	0.685	2.12
	0.700	2.06
	0.723	2.02
(*A*)	0.745	1.97
	0.765	1.93

Magdala red, $C_{30}H_{20}N_4.HCl$

λ		n
Prism (42)		
Hδ	0.410	1.76
Hγ	0.434	1.72
Hβ	0.486	1.54
Tl	0.535	1.56
D	0.589	1.90
Li	0.671	2.06
	0.703	2.06

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(For a key to the periodicals see end of volume)

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REFRACTIVITY OF BIREFRINGENT CRYSTALS

H. E. MERWIN

These tables have to do primarily with variations of refractive index with wave-length and temperature. For refractive indices at a single wave-length, for $2V$ or $2E$, for orientations, etc., *see* Vol. I, p. 166, 279, 320; and (56, 81.1, 115, 116.1, 235.1). For dispersion of birefringence, *see* (59–62); for refractivity of metallic crystals, *see* Vol. V, p. 248; for isotropic substances, *see* Vol. I, p. 165 (*cf.* p. 106), Vol. VII, p. 12, and for elementary substances, *see* Vol. VII, p. 1.

Ces tables concernent principalement les variations de l'indice de réfraction avec la longueur d'onde et avec la température. Pour les indices de réfraction concernant une seule longueur d'onde, pour $2V$ ou $2E$, pour les orientations, etc., *voir* Vol. I, p. 166, 279, 320; et (56, 81.1, 115, 116.1, 235.1). Pour la dispersion de la biréfringence, *voir* (59–62); pour le pouvoir réfractif des cristaux métalliques, *voir* Vol. V, p. 248; pour les substances isotropiques, *voir* Vol. I, p. 165 (*cf.* p. 106), Vol. VII, p. 12, et pour les éléments, *voir* Vol. VII, p. 1.

Diese Tafeln behandeln vor allem die Änderung des Brechungsindexes mit der Wellenlänge und der Temperatur. Für die Brechungsindexes einzelner Wellenlängen, für $2V$ oder $2E$, Orientierung, etc., *siehe* Bd. I, S. 166, 279, 320; ferner (56, 81.1, 115, 116.1, 235.1). Für die Dispersion der Doppelbrechung, *siehe* (59–62); für das Brechungsvermögen von Metallkristallen, *siehe* Bd. V, S. 248; für isotropischen Stoffe, *siehe* Bd. I, S. 165 (*cf.* S. 106), Bd. VII, S. 12, und für Elemente, *siehe* Bd. VII, p. 1.

Queste tabelle si riferiscono principalmente alle variazioni dell'indice di birifrangenza in funzione della lunghezza d'onda e della temperatura. Per gli indici di rifrazione ad una sola lunghezza d'onda, per $2V$ e $2E$, per le orientazioni, ecc., *vedi* Vol. I, p. 166, 279, 320; e (58, 81.1, 115, 116.1, 235.1). Per la dispersione della birifrangenza, *vedi* (59–62); per la refrattività dei cristalli metallici, *vedi* Vol. V, p. 248; per le sostanze isotropiche, *vedi* Vol. I, p. 165 (*cf.* p. 106), Vol. VII, p. 12, e per le elementi, *vedi* Vol. VII, p. 1.

LIST OF BIREFRACTING MINERALS IN TABLE 1

Those for which the dispersion of the index has been most accurately and extensively measured are indicated by a "(*d*)."

Name	Serial No., Table 1	Name	Serial No., Table 1
Acmite	209	Avogadrite	260.1
Adularia	261	Barite	(*d*)182
Afwillite	147	Barylite	187.1
Åkermanite	170	Beckelite	165
Albite	(*d*)218	Beryl	(*d*)120
Allactite	61	Beryllonite	222
Anatase	(*d*)14	Blödite	224
Andalusite	101	Boracite	134
Andesine	229	Borax	215
Anglesite	(*d*)19	Borgströmite	73
Anhydrite	137.1	Boussingaultite	123
Anorthite	159	Brookite	15
Apatite	(*d*)140	Brucite	121
Apophyllite	(*d*)267	Calamine	39
Aragonite	(*d*)141	Calcite	(*d*)142
Augite	169	Calomel	46

LIST.—(*Continued*)

Name	Serial No., Table 1	Name	Serial No., Table 1
Cancrinite	228	Diamond*	11.1
Carborundum	(*d*)13	Diopside	(*d*)169
Cassiterite	18	Dioptase	52
Celestite	173	Dolomite	(*d*)168
Cerussite	25	Elpidite	207
Chalcanthite	49	Epididymite	223
Chrysoberyl	118	Epidote	161
Chrysolite	(*d*)131	Epsomite	(*d*)122
Cinnabar	48	Euclase	119
Clinozoisite	161	Eudialite	227
Colemanite	157	Feldspars	261
Copiapite	72	Finnemanite	23
Cordierite	(*d*)136	Forsterite	(*d*)126
Corundum	(*d*)97	Goethite	63
Cotunnite	18.1	Goslarite	32
Cyanite	99	Greenockite	42
Cyanochroite	249	Gypsum	(*d*)138
Danburite	158		

ELECTRIC AND MAGNETIC BIREFRINGENCE

H. MOUTON

Introduction.—While a non-crystalline substance is in either an electric or a magnetic field it acts optically as a uniaxial crystal with its axis parallel to the field intensity, Kerr (23), Cotton and Mouton (7, 12). Some act as positive (+) others as negative (−) crystals. Crystalline substances are excluded from this section. The molecules of "crystalline" liquids seem to be completely aligned by the applied field and the order of the resulting birefringence is 10^6 times as great as that of the liquids here considered.

General Relations.—If n = index of refraction of the substance when in zero field, n_e and n_o = indices when in a field of strength E (electric) or H (magnetic), λ = wave-length of the light *in vacuo*, l = actual length of path of the light in the substance and perpendicular to the field, δ = difference in the equivalent optical paths of the components with electric vector parallel and perpendicular, respectively, to the field, then the *coefficients of birefringence* (C_e, C_m) are defined by the equations $\delta/\lambda = (n_e - n_o)l/\lambda = C_e l E^2$ (or $= C_m l H^2$), or $(n_e - n_o) = C_e \lambda E^2$ (or $= C_m \lambda H^2$). C_e and C_m depend upon λ, the temperature (t), and the substance; for any given gas, C_e is proportional to its density (19, 27). C_e is sometimes called Kerr's constant; it should not be confused with Kerr's magneto-optic constant, Vol. VI, p. 435.

Variation with λ.—For any substance at a constant temperature, Havelock (20, 21) concludes that $n(n_e - n_o) = k(n^2 - 1)^2$, or $C_e \lambda n/(n^2 - 1)^2 = k_e$, $C_m \lambda n/(n^2 - 1)^2 = k_m$, where k, k_e, k_m are pure numbers which are independent of λ, *cf.* (30, 31, 37). For anisole (C_7H_8O), phenetole ($C_8H_{10}O$), and *m*-xylene (C_8H_{10}), k_e has been found to be independent of λ; for toluene (C_7H_8) and ethyl *n*-butyrate ($C_6H_{12}O_2$), k_e varies slightly with λ; and for ethyl ether ($C_4H_{10}O$) and acetal ($C_6H_{14}O_2$), $C_e\lambda$ varies less than this relation indicates (4). For a number of substances (37, 40), including nitrobenzene ($C_6H_5NO_2$) (8, 12), k_m has been found to be independent of λ.

Variation with *t*.—For a given λ, Langevin (25) concludes that $C_e nT/\{d(n^2 + 2)^2(\epsilon + 2)^2\} = \varphi_e$ and $C_m nT/\{d(n^2 + 2)^2\} = \varphi_m$, where d = density, ϵ = dielectric constant, and φ_e and φ_m are independent of absolute temperature (T). The constancy of φ_e has been verified for ethyl ether ($C_4H_{10}O$) and for CS_2 from −78.5°C to + 18°C (29), and for nitrobenzene ($C_6H_5NO_2$) from 6.14°C to 25°C and for 5 values of λ (38). The value of φ_m frequently varies non-linearly by several parts in 1000 per 1°C; *cf.* Table 5. In Tables 1, 2, 3, coefficients for linear interpolation over short ranges are given if available.

Time Effects.—The time required for C_e to reach its equilibrium value after the field is applied or removed is approximately proportional to C_e and is of the order of 10^{-8} sec = 0.01μ sec (1, 2, 3, 5.1, 17, 36); *see* CS_2 (Table 1), and C_7H_8 and $C_{10}H_7Br$ (Table 3). The effect of electrostriction (*see* Vol. VI, p. 207) and the heating produced by the conduction current complicate the determination of $(n_e - n)$ and $(n_o - n)$ in electric birefringence. Both effects are reduced by applying the field quickly and maintaining it for a very short time (τ); *see* following.

Ratio of Changes in Index.—Different theories of electric birefringence predict different values for $\rho \equiv (n_e - n)/(n_o - n)$. That which makes the birefringence (electric or magnetic) depend upon the orientation of the molecules makes $\rho = -2$; Voigt's theory (43) which makes it depend upon a modification of the intraatomic forces makes $\rho = +3$, and a more general form of this theory, Enderle (16), makes ρ vary with λ and approach +3 for frequencies which are small as compared with those characteristic of the electrons. Using very short times (τ) so as to minimize effects of electrostriction (Vol. VI, p. 207) and heating, Pauthenier (35) found for nitrobenzene ($C_6H_5NO_2$) and $\tau = 0.46$, 0.92, 1.6, and 2.7μ sec ($=10^{-6}$ sec), $\rho = -2.01$, −1.99, −2.03, and −2.04, respectively; the same was found for red, yellow-green and blue light; Himstedt (22) found $\rho = -1.92$; McComb (31), $\rho = -1.88$ for $0.540\mu < \lambda < 0.660\mu$. For CS_2, electrostriction compensates the change in $(n_o - n)$, making the apparent (ρ') value of ρ infinite, when $\tau = 8.1\mu$ sec. If electrostriction alone increases the index from n to $n + \delta'$, and we write $\beta \equiv \delta'(n_o - n)$, then $\rho' = (\beta + 2)/(\beta - 1)$; for CS_2, Pauthenier (35) found as follows:

τ	0.65	1.3	2.5	4.9	7	8.1	9.8
β	0	0	0.12	0.36	0.74	1	1.4

τ	20	25	30.7	41.7	49	65.6μ sec
β	2	1.47	1	1.3	1.1	1.1

Relation between Electric and Magnetic Birefringence.—The preceding temperature relations indicate that $C_e/\{C_m(\epsilon + 2)^2\} = \varphi_e/\varphi_m$ is independent of T. Cotton and Mouton (12) have proposed the simpler relation $C_e/(C_m\epsilon)$ = const., and have found it more satisfactory for nitrobenzene ($C_6H_5NO_2$); their values are as follows, a and b being arbitrary constants:

t	aC_e	bC_m	ϵ	$\frac{a}{b} \cdot \frac{C_e(10)^4}{\epsilon C_m}$	$\left(\frac{C}{C_{16^\circ}}\right)_e$	$\left(\frac{C}{C_{16^\circ}}\right)_m$
6°C	68	129	39.4	133.9	1.18	1.08
16	57.6	119.5	37.4	129.0	1.00	1.00
33	45.8	105.2	34.2	127.4	0.79_6	0.88_1
54	37.2	90.8	30.6	133.9	0.64_6	0.76_0

Units.—Unit of $\lambda = 1\mu = 10^4$ Å $= 10^{-4}$ cm.

TABLE 1.—ELECTRIC BIREFRINGENCE OF CS_2 (6, 18, 29, 30)

$n_e - n_o = C_e\lambda E^2$. $A \times 10^{-7} = C_e$ when λ is expressed in cm and E in cgs electrostatic units. Time required for A_{20} to attain equilibrium value is 0.014μ sec = 14×10^{-9} sec (17). $A_{15} = 1.025\ A_{20}$, $A_{28} = 0.966\ A_{20}$; approximately $A_t = A_{20}\ [1 - 0.005\ (t - 20)]$ if $18^\circ < t < 28^\circ$C (26, 27); for lower temperatures, *see* below. For effect of electrostriction, *see* above.

λ	A	$A\lambda$	t'	$A_{t'}/A_{18^\circ}$
	(t = 20°C)			(29)
0.589	+3.226* ±0.005		+18°C	1.000
0.440	+4.97	2.187	0	1.089
0.460	+4.63	2.130	−18.5	1.205
0.480	+4.32	2.073	−37.7	1.397
0.500	+4.06	2.030	−47.3	1.497
0.520	+3.83	1.991	−68.3	1.708
0.540	+3.63	1.960	−78.5	1.819
0.546	+3.577†	1.953		
0.560	+3.45	1.932		
0.578	+3.310†	1.913		
0.580	+3.30	1.914		
0.589	+3.226†	1.900		
0.600	+3.15	1.890		
0.630	+2.95	1.858		
0.660	+2.78	1.835		

* Basis of reference (6).

† (6).

TABLE 2.—MAGNETIC BIREFRINGENCE OF NITROBENZENE ($C_6H_5NO_2$) (9, 12)

$(n_e - n)/(n_o - n) = -2.00$, $k_m \equiv C_m\lambda n/(n^2 - 1)^2 = 1.11 \times 10^{-16}$ at 19 to 20°C, is independent of λ. $\varphi_m = C_m nT/\{d(n^2 + 2)^2\}$ varies non-linearly with T; $C_e/C_m\epsilon$ is nearly independent of t. $C_{m_t} = C_{m_{20}}\ [1 - \alpha(t - 20)]$; if $10^\circ\text{C} < t < 25^\circ\text{C}$, $\alpha = 1/35$; near 20°C, $\alpha = 1/44$; mean variation per 1°C between 6.4°C and 53.9°C is $1/38$ of mean value of C_m (8, 12). $n_e - n_o = C_m\lambda H^2$; $A \times 10^{-12} = C_m$, if λ is expressed in cm and H in cgsm (gauss). t = 20°C; 1μ = 10^{-4} cm.

λ	0.578	0.436	0.486	0.546	0.578	0.656
A	2.46 ±0.02*	3.62	3.10	2.66	2.46	2.14
$A\lambda$		1.580	1.509	1.450	1.422	1.405

* Basis of reference; derived from A = 2.53 ± 0.02 at 16.3°C (9).

TABLE 3.—ELECTRIC AND MAGNETIC BIREFRINGENCE OF PURE SUBSTANCES: RELATIVE VALUES

For most inorganic liquids C_e and C_m are inappreciable, but magnetic birefringence should be exhibited by those paramagnetic substances which have quite anisotropic molecules (*cf.* aqueous solution of erbium nitrate, Table 4). For organic substances containing only C, H and O, C_m is very small or zero if they are acyclic, and, so far as they have been studied, it is inappreciable if they contain a cyclic nucleus without a double bond.

In this table $\gamma_e/100 \equiv (C/C_{CS_2})_e$, where C and C_{CS_2} refer to the same temperature (20°C) and the same radiation (usually D-line, $\lambda = 0.589\mu$), and $\gamma_m/100 \equiv (C/C_{C_6H_5NO_2})_m$ where $C_6H_5NO_2$ = nitrobenzene, C and $C_{C_6H_5NO_2}$ refer to the same temperature (t_m) and to the yellow mercury line ($\lambda = 0.578\mu$). For most substances γ_e is nearly independent of λ; as a first approximation, γ_m is independent of t_m. Available data for variation of C_e and γ_e with t and λ are given in footnotes; for variation of C_m and γ_m, *see* Table 5. For $C_e(CS_2)$ and $C_m(C_6H_5NO_2)$, *see* Tables 1 and 2.

Data for γ_e are from (26) unless another source is indicated in a footnote: those for γ_m are from (9, 12). g = gas at 20°C and 1 atm., l = liquid, b. = boils at, m. = melts at.

Pure inorganic substances

Formula		γ_e	γ_m	t, °C	Lit.
H_2O	l	123		17	(35)
SO_2	g	0.051		17.3	(38, 41)
HNO_3	l		+2.5	15.5	(9, 12)
NH_3	g	0.0185		20	(26, 27)
	g	0.0181		17.9	(38, 41)
CO_2	g	0.007		20	(26, 27)
	g	0.0074		17.5	(38, 41)

Glasses (Schott and Gen.) (42), t = 20°C

Number	γ_e	% PbO	% SiO_2	Number	γ_e	% PbO	% SiO_2
O378	0.288	27.5	59.3	O41	2.950	61.0	34.7
O569	1.096	36.3	54.1	O165	3.277	65.5	31.2
O118	1.845	43.8	46.6	O198	3.951	71.0	27.2

Carbon compounds (ℭ-arrangement)

Formula	Substance	γ_e	γ_m	t_m
CCl_4	Carbon tetrachloride	+ 2.3	0	14.6
CCl_3NO_2	Chloropicrin	− 55.7	+ 3.4	14.2
CN_4O_8	Tetranitromethane	+ 3	+ 1.0	14.2
CS_2	Carbon disulfide	+ 100.00*	− 19.6	15.5
$CHBr_3$	Bromoform	− 86	− 6.8	14.6
$CHCl_3$	Chloroform	− 100	− 2.8	17.2
CHN	Hydrocyanic acid (g)	+ 0.55		
CH_2Cl_2	Methylene chloride	− 36		
CH_2I_2	Methylene iodide		− 12.3	16
CH_3Br	Methyl bromide (g)	+ 0.216		
CH_3Cl	Methyl chloride (g)	+ 0.163		
CH_3I	Methyl iodide	+ 208†	− 2.9	14
CH_3NO_2	Nitromethane	+ 330	+ 3.6	18.4
C_2Cl_4	Tetrachloroethylene	+ 24		
C_2HCl_3	Trichloroethylene	+ 43		
C_2HCl_5	Pentachloroethane	− 20		
$C_2H_2Br_4$	1, 1, 2, 2-Tetrabromoethane	− 103		
$C_2H_2Cl_2$	1, 2-Acetylene dichloride	+ 40		
$C_2H_2Cl_4$	1, 1, 2, 2-Tetrachloroethane	− 88.7	− 1.3	16
$C_2H_3Cl_3$	1, 1, 2-Trichloroethane	+ 50		
$C_2H_4Br_2$	Ethylene bromide	+ 89	− 7.1	16.4
$C_2H_4Cl_2$	Ethylene chloride	+ 181	− 2.1	14
$C_2H_4Cl_2$	1, 1-Dichloroethane		− 1.8	14
$C_2H_4O_2$	Acetic acid (17°)	+ 130‡		
C_2H_5Cl	Ethyl chloride (g)	+ 0.270		
C_2H_5I	Ethyl iodide	+ 343		
C_2H_6O	Ethyl alcohol	+ 23.8‡	+ 0	14.6
C_3H_5Cl	3-Chloropropylene	+ 174		
C_3H_5ClO	Epichlorohydrin	+ 185		
$C_3H_5ClO_2$	Ethyl chloroformate	+ 354		
C_3H_5NS	Ethyl isothiocyanate		− 8.4	14.6
C_3H_6O	Acetone	+ 505	+ 1.6	20.2

TABLE 3.—(*Continued*)

Formula	Substance	γ_e	γ_m	t_m
$C_3H_6O_2$	Propionic acid	+ 44		
$C_3H_6O_2$	Ethyl formate	+ 138		
C_3H_7Br	*n*-Propyl bromide	+ 318		
C_3H_7Cl	*n*-Propyl chloride	+ 234		
C_3H_8O	*n*-Propyl alcohol	− 78		
$C_3H_8O_2$	Methylal	+ 0.3		
C_4H_4S	Thiophene		+ 15.6	14.8
$C_4H_5Br_3O_2$	Ethyl tribromoacetate		− 2.2	16
$C_4H_5Cl_3O_2$	Ethyl trichloroacetate	+ 161		
C_4H_5N	Pyrrole	+ 12§	+ 7 *ca.*	16
C_4H_8O	Methyl ethyl ketone	+ 420		
$C_4H_8O_2$	Isobutyric acid	+ 6		
$C_4H_8O_2$	Ethyl acetate	+ 52		
C_4H_9Br	Isobutyl bromide	+ 271.5		
$C_4H_{10}O$	*n*-Butyl alcohol	− 113		
$C_4H_{10}O$	Isobutyl alcohol	− 137		
$C_4H_{10}O$	*tert.*-Butyl alcohol	+ 154		
$C_4H_{10}O$	Ethyl ether	− 20.5‖		
$C_4H_{10}S$	Ethyl sulfide	+ 10.6		
$C_4H_{10}S_2$	Ethyl disulfide	− 168		
$C_4H_{11}N$	Diethylamine	− 15.3		
$C_5H_4O_2$	Furfural		+ 45 *ca.*	17
C_5H_5N	Pyridine	+ 632	+ 27 *ca.*	18.5
C_5H_6	Cyclopentadiene	+ 14.1	(b. 40 to 43°C)	
$C_5H_7NO_2$	Ethyl cyanoacetate	+ 1 200	+ 0	14.6
C_5H_8	Isoprene		2.7	16.3
$C_5H_8O_2$	Acetylacetone		+ 4.2	16.3
C_5H_{10}	Amylene	+ 8	(b. 36 to 37°C)	
$C_5H_{10}O_2$	*n*-Valeric acid	+ 8.4		
$C_5H_{10}O_2$	Methyl *n*-butyrate	+ 24		
$C_5H_{10}O_3$	Diethyl carbonate	+ 9.6		
$C_5H_{11}Cl$	Isoamyl chloride	+ 108		
$C_5H_{11}Cl$	*tert.*-Amyl chloride	+ 345		
C_5H_{12}	*n*-Pentane	+ 2.0		
C_5H_{12}	2-Methylbutane	+ 1.6		
$C_5H_{12}O$	*n*-Amyl alcohol¶	− 98		
$C_5H_{12}O$	*tert.*-Amyl alcohol	+ 40		
$C_5H_{13}N$	Isoamylamine	− 0.3		
$C_6H_3ClN_2O_4$	2, 4-Dinitrochlorobenzene	(Fused)	108	(?)
$C_6H_3N_3O_7$	2, 4, 6-Trinitrophenol	+ 45		
$C_6H_4Cl_2$	*o*-Dichlorobenzene	+ 1 320§		
$C_6H_4Cl_2$	*m*-Dichlorobenzene	+ 218§		
C_6H_5Br	Bromobenzene	+ 374	+ 25.7	15.7
C_6H_5Cl	Chlorobenzene	+ 385	+ 28.8	20
C_6H_5ClO	*o*-Chlorophenol	+ 189		
$C_6H_5ClO_2S$	Benzenesulfone chloride	+ 2 775		
C_6H_5F	Fluorobenzene	+ 191**	+ 25.5	13
C_6H_5I	Iodobenzene	+ 288	+ 24.8	16.4
$C_6H_5NO_2$	Nitrobenzene (21.3°)	+10 070††	+100.0††	13.4
C_6H_6	Benzene	+ 12	+ 23.3	18.3
C_6H_7N	Aniline	− 50.7§	+ 16.0	13.4
$C_6H_8N_2$	Phenylhydrazine‡‡	+ 0	+ 29.6	20.4
$C_6H_{10}O_3$	Ethyl acetoacetate	+ 145		
$C_6H_{11}NO_2$	Ethyl *β*-aminocrotonate	+ 960		
C_6H_{12}	Cyclohexane	+ 2.2	+ 0	
$C_6H_{12}O$	Cyclohexanol	− 286		
$C_6H_{12}O_2$	Caproic acid	+ 8.7		
$C_6H_{12}O_2$	Ethyl *n*-butyrate	+ 21§§		
$C_6H_{12}O_3$	Paraldehyde	− 713	+ 0	
C_6H_{14}	*n*-Hexane	+ 1.7		
$C_6H_{14}O_2$	Acetal	− 19‖‖		
$C_7H_4F_3NO_2$	*p*-Nitrophenylfluoroform		+ 58.0	15
C_7H_5ClO	Benzoyl chloride		+ 66	13.6
$C_7H_5Cl_3$	Phenylchloroform		+ 25.4	17
$C_7H_5F_3$	Phenylfluoroform		+ 26.7	16.8
C_7H_5N	Benzonitrile		+ 39.5	14
	Benzonitrile (λ = 0.550*μ*)		+ 36.2	20.2
$C_7H_6Cl_2$	Benzylidene chloride	+ 318	+ 23.8	16.6
C_7H_6O	Benzaldehyde	+ 2 496	+ 59.5	15.2
C_7H_7Cl	*o*-Chlorotoluene	+ 270¶¶		
C_7H_7Cl	*p*-Chlorotoluene	+ 711¶¶		
C_7H_7Cl	Benzyl chloride		+ 24.2	16.6
C_7H_7NO	Benzaldoxime‡‡		+ 67.6	12.5
$C_7H_7NO_2$	*o*-Nitrotoluene	+ 5 400	+ 58 *ca.*	16.5
$C_7H_7NO_2$	*m*-Nitrotoluene	+ 5 500	+ 77 *ca.*	22
$C_7H_7NO_2$	*p*-Nitrotoluene‡‡	+ 6 900		
C_7H_8	Toluene	+ 24***	+ 24.5	17.5
C_7H_8O	Benzyl alcohol	− 477	+ 26.0	15.8

TABLE 3.—(*Continued*)

Formula	Substance	γ_e	γ_m	t_m
C_7H_8O	*m*-Cresol	+ 657		
C_7H_8O	Phenyl methyl ether†††	+ 35.5	+ 22.2	16.5
C_7H_9N	*o*-Toluidine	− 73		
C_7H_9N	*m*-Toluidine	− 128		
$C_7H_{12}O_4$	Diethyl malonate	+ 48		
C_7H_{14}	Methylcyclohexane	+ 2		
$C_7H_{14}O$	Heptaldehyde	+ 125		
$C_7H_{14}O$	Dipropyl ketone	+ 157		
$C_7H_{14}O$	1-Methylcyclohexanol	− 172		
	2-Methylcyclohexanol	− 163		
	3-Methylcyclohexanol	− 319		
$C_7H_{14}O_2$	Heptylic acid	+ 8.2		
$C_7H_{14}O_2$	*n*-Amyl acetate	+ 38		
$C_7H_{14}O_2$	Ethyl *n*-valerate	+ 10		
C_7H_{16}	*n*-Heptane	+ 3.3		
$C_7H_{16}O$	*n*-Heptyl alcohol	− 233		
C_8H_6	Phenylacetylene		+ 27.5	14.1
C_8H_7ClO	*m*-Chloroacetophenone	+ 2 140		
C_8H_7N	Benzyl cyanide		+ 22.5	14.2
C_8H_8	Styrene (redistilled)		+ 36.8	15.2
C_8H_8O	Acetophenone‡‡	+ 2 060	+ 49	21.7
$C_8H_8O_2$	Methyl benzoate		+ 40.3	14.8
C_8H_9ClO	*p*-Chlorophenetole		+ 26.4	15.1
C_8H_9FO	*p*-Fluorophenetole		+ 30.8	17.8
C_8H_9N	Benzylidenemethylamine		+ 45.8	13.6
C_8H_{10}	*o*-Xylene	+ 41	+ 27.8	14
C_8H_{10}	*m*-Xylene‡‡‡	+ 24	+ 25.0	16.2
C_8H_{10}	*p*-Xylene	+ 23	+ 26.6	20
C_8H_{10}	Ethylbenzene	+ 25.6	+ 21.5	17.4
$C_8H_{10}O$	Phenylethyl alcohol		+ 19.0	13.8
$C_8H_{10}O$	Phenetole‡‡‡	+ 41	+ 21.8	14.8
$C_8H_{11}N$	Dimethylaniline	+ 312		
$C_8H_{14}O_3$	Ethyl dimethylacetoacetate	+ 137.5		
C_8H_{16}	*n*-Octylene	+ 13	(b. 116 to 126°C)	
C_8H_{16}	1, 3-Dimethylcyclohexane	+ 3		
$C_8H_{16}O_2$	*n*-Caprylic acid	+ 9.4		
C_8H_{18}	*n*-Octane	+ 4.2	(b. 110 to 125°C)	
$C_8H_{18}O$	*n*-Octyl alcohol	− 236		
C_9H_7N	Quinoline	+ 466§	+ 83.0	14.9
C_9H_8	Indene		+ 44.6	13.8
C_9H_{10}	Hydrindene		+ 28.4	15.2
$C_9H_{10}O$	Hydratropaldehyde	+ 314		
$C_9H_{10}O_2$	Benzyl acetate		+ 33 *ca.*	(?)
$C_9H_{10}O_2$	Ethyl benzoate		+ 37	16
$C_9H_{10}O_3$	Ethyl salicylate	+ 607		
$C_9H_{11}N$	*Py*-Tetrahydroquinoline		+ 36.5	16.8
C_9H_{12}	Cumene	+ 102§§§	+ 26.0	14.5
C_9H_{12}	Mesitylene	+ 19	+ 22.2	16
C_9H_{12}	*n*-Propylbenzene		+ 20.3	18.3
C_9H_{12}	Pseudocumene	+ 30	+ 28.0	15.6
$C_9H_{18}O_2$	Pelargonic acid	+ 8.3		
$C_{10}H_7Br$	*α*-Bromonaphthalene‖‖‖	+ 332	+ 99	17
$C_{10}H_7Cl$	*α*-Chloronaphthalene		+108	15
$C_{10}H_9N$	*α*-Methylquinoline	+ 25.6	+ 93.6	16.5
$C_{10}H_{10}$	Phenylbutadiene		+ 64	15.4
$C_{10}H_{10}O_2$	Safrol		+ 24.1	17.2
$C_{10}H_{10}O_2$	Isosafrol		+ 49.5	17.2
$C_{10}H_{12}O$	Anethole		+ 74.1	21.4
$C_{10}H_{12}O_2$	Eugenol		+ 20.9	15.8
$C_{10}H_{12}O_2$	Isoeugenol		+ 36.0	16.8
$C_{10}H_{12}O_2$	*n*-Propyl benzoate		+ 33	13.4
$C_{10}H_{14}O$	Carvacrol	+ 83	+ 15.1	13
$C_{10}H_{14}O$	Carvone	+ 730¶¶¶		
$C_{10}H_{14}O$	Thymol‡‡		+ 17.7	13.4
$C_{10}H_{15}N$	Diethylaniline	+ 323		
$C_{10}H_{16}$	Limonene	+ 18¶¶¶	(d_{18} = 0.845 g cm^{-3})	
$C_{10}H_{16}O$	Camphor	+ 159¶¶¶		
$C_{10}H_{18}$	Dihydropinene		+ 0	
$C_{10}H_{18}$	Dihydrolimonene		+ 0	
$C_{10}H_{18}O$	Cineol		+ 0	
$C_{10}H_{22}$	Diisoamyl	+ 2.2		
$C_{10}H_{23}N$	Diamylamine	− 6.05		
$C_{11}H_7N$	*α*-Naphthyl cyanide‡‡		+166	17
$C_{11}H_{10}$	*α*-Methylnaphthalene	+ 66		
$C_{11}H_{12}O_2$	Ethyl cinnamate	+ 228	+ 60 *ca.*	17
$C_{11}H_{12}O_3$	Ethyl benzoylacetate	+ 495		
$C_{11}H_{24}O_2$	Methyl diamyl ether	+ 0		

TABLE 3.—(*Continued*)

Formula	Substance	γ_e	γ_m	t_m
$C_{12}H_{16}O_2$	Amyl benzoate		+ 27 *ca.*	19.7
$C_{13}H_{10}O$	Benzophenone‡‡		+ 57.2	14
$C_{13}H_{10}O_3$	Salol‡‡ (m. 41.5°C)		+ 62****	16
$C_{13}H_{16}O_3$	Ethyl benzylacetoacetate	− 68		
$C_{14}H_{12}$	1, 1-Diphenylethylene		+ 48	16.4
$C_{14}H_{12}O_2$	Benzyl benzoate		+ 38.4	15.8
$C_{14}H_{18}O_4$	Diethyl benzylmalonate	− 48		
$C_{17}H_{12}O_3$	Naphthyl salicylate‡‡		+160	18
$C_{18}H_{34}O_2$	Oleic acid		+ 0	14.6
	Petroleum ether††††		+ 0	15.5

* *See* Table 1.

† γ_e = 207 to 210

‡ From (35).

§ From (28).

‖ For $\lambda = 0.589\mu$ and 20°C, $C_e = -0.621 \times 10^{-7}$ and $\gamma_e = -19.2$ (41). $C_e\lambda$ varies with λ less rapidly than is indicated by Havelock's relation (p. 109) (4); variation with t satisfies Langevin's relation (p. 109) from −78.5° to + 18°C, giving (29):

t	18	0	−21.7	−38.9	−60.5	−78.5°C
$C_{et}/C_{e_{18}°}$	1.000	1.220	1.547	1.927	2.707	3.880

¶ Free of pyridine (C_5H_5N).

** γ_e = 184 to 191.

†† $\gamma_e/100$ = 100.7 at 21.3°, 99.5 at 22.5°, 65.7 at 49°C. Lippmann (28) gives γ_e = 11 390 at room temperature. Near 20°C, $C_{et} = C_{e_{20°}} \{1 - \frac{1}{68}(t - 20)\}$, and mean change per 1°C between 0 and 47°C is $\frac{1}{68}$ of mean value of C_e (12, 13); between 6.14 and 25°C, change of C_e with t satisfies Langevin's relation (p. 109) (38); $(n_e - n)/(n_o - n) = -2.00$ (p. 109) (22, 30, 31, 35). For C_m and its variation with λ and t, *see* Table 2.

‡‡ Undercooled.

§§ Slight departure from Havelock's relation (p. 109).

‖‖ Variation of $C_e\lambda$ with λ is less than that indicated by Havelock's relation (p. 109).

¶¶ For o-C_7H_7Cl, γ_e = 261 to 270; for p-C_7H_7Cl, γ_e = 690 to 711 (28).

*** Slight departure from Havelock's relation (p. 109). Time for C_e to reach equilibrium = 0.017μ sec = 17×10^{-9} sec (17).

††† Phenyl methyl ether = anisole; Havelock's relation for C_e is satisfied (p. 109).

‡‡‡ Havelock's relation for C_e is satisfied (p. 109).

§§§ Boils at 160 to 178°C.

‖‖‖ Time for C_e to reach equilibrium = 0.006μ sec = 6×10^{-9} sec (17). Mean decrease of C_m per 1°C increase between 11.8 and 47.9°C = $\frac{1}{308}$ of mean value of C_m (8, 9, 10, 11, 12, 13).

¶¶¶ Obtained from solution in hexane (C_6H_{14}) using $\lambda = 0.546\mu$ (Hg); value computed for camphor is independent of concentration; electric birefringence and rotary power are superposed without change in either (32).

**** Between −17 and +50.5°C, C_m varies sensibly linearly and $C_{m_t} = C_{m_{20°}}\{1 - \frac{1}{480}(t - 20)\}$ (8, 9, 10, 11, 12, 13).

†††† Mixture of saturated hydrocarbons.

TABLE 4.—ELECTRIC AND MAGNETIC BIREFRINGENCE OF SOLUTIONS AND MIXTURES

(Values of γ_e for limonene ($C_{10}H_{16}$), camphor ($C_{10}H_{16}O$), and carvenone ($C_{10}H_{16}O$) as deduced from solutions in n-hexane (C_6H_{14}) are given in Table 3.)

$\gamma_e/100 = (C/C_{CS_2})_e$, $\gamma_m/100 = (C/C_{C_6H_5NO_2})_m$; $C_6H_5NO_2$ = nitrobenzene. Generally γ can not be readily computed from the composition (Comp.) of the mixture or solution. If γ_e for one constituent of a binary mixture is very great the curve γ_e *vs.* Comp. is usually convex towards axis of Comp.; if γ_e for one is negative and not too nearly zero, the curve is concave towards this axis, and may pass through a maximum at an intermediate Comp.

TABLE 4.—(*Continued*)

Mol % = molecular per cent, Vol. % = volume % = 100 d'/d, where d' = mass of constituent in unit volume of mixture, and d = density of same constituent when pure. ⩾ = very much greater than.

H_2O

C_2H_6O, Ethyl alcohol (35)

t = 17°C

Vol. % B	γ_e
0	123
24.2	94
46.3	69.1
66.3	45.4
85.5	26.8
93.5	20.7
96.7	20.0
100	23.8

$Er(NO_3)_3.5H_2O$, Erbium nitrate(14, 15). $\lambda = 0.503\mu$; t = *ca.* 18(?)°C. For H = 26.3 kilogauss and Comp. equivalent to 0.56 g Er_2O_3 per cm³, γ_m = 800.

$C_6H_5NO_2$

Nitrobenzene (11)

t = *ca.* 18°C

CCl_4, Carbon tetrachloride

Vol % A	γ_m
0	0
19.9	9.8
39.8	23.8
59.6	42.1
79.0	65.6
100	100.0

$C_2H_4Br_2$, 1, 1-Dibromoethane

0	Small
x	$<x$
100	100.0

C_2H_6O, Ethyl alcohol

0	0
51.4	37.4
100	100.0

C_3H_6O, Acetone

0	1.6
x	$<x$
100	100.0

C_6H_6, Benzene; *see* Benzene

C_6H_6

Benzene (28)

t = room temperature

CCl_4, Carbon tetrachloride

Mol % B	γ_e
0	11.3
2.54	11.0
10.99	10.4
64.51	5.3
100	2.3

CH_2Cl_2, Methylene chloride

0	+11.3
7.19	+ 8.8
9.30	+ 8.3
12.78	+ 3.7
100	−36

$C_2H_2Br_4$, 1, 1, 2, 2-Tetrabromoethane

0	+ 11.3
1.98	+ 9.9
8.36	+ 3.6
100	−102.9

$C_2H_4Cl_2$, Ethylene chloride

0	11.3
2.01	11.0
5.10	11.2
15.21	14.0
28.57	22.1
45.2	37.7
100	181

$C_6H_4Cl_2$, o-Dichlorobenzene

0	11.3
2.75	29.9
5.61	49.6
11.74	96
26.47	224
55.23	546.4
100	1 320

$C_6H_4Cl_2$, m-Dichlorobenzene

0	11.3
2.75	13.5
4.53	15.3
11.72	24.3
27.28	47.4
48.15	83.3
100	218.4

$C_6H_5NO_2$, Nitrobenzene

Mol % B	γ_e
0	11.3
2.77	73.6
5.20	131
10.32	288
14.2	401
49.13	2 185
100	11 390

C_6H_7N, Aniline

0	+11.3
4.31	+12.6
13.20	+14.0
17.52	+13.9
36.13	+ 9.6
100	−50.7

$C_7H_7NO_2$, m-Nitrotoluene

0	11.3
3.12	96
9.54	279
19.5	635
36.3	1 363
100	5 664

C_7H_9N, m-Toluidine

0	+ 11.3
4.32	+ 10.3
7.50	+ 9.3
100	−128

C_9H_7N, Quinoline

0	11.3
1.58	13.9
3.49	17.8
13.30	44.3
38.08	133.5
100	466

$C_{10}H_7Br$

α-Bromonaphthalene (11)

t = *ca.* 18°C

CCl_4, Carbon tetrachloride

Vol. % A	γ_m
0	0
x	⩾3.32x
100	332

C_6H_{12}, Cyclohexane

0	0
x	⩾3.32x
100	332

TABLE 5.—MAGNETIC BIREFRINGENCE: VARIATION WITH TEMPERATURE AND WAVE-LENGTH

α_m = mean temperature coefficient of C_{mt} between t' and t''; $\Delta/100 \equiv (\varphi_{mt} - \varphi_{m_{20}})/\varphi_{m_{20}}$ where $\varphi_{mt} \equiv C_{mt}nT/\{d(n^2+2)^2\}$, T = absolute temperature corresponding to t. $k_m \equiv C_m\lambda n/(n^2-1)^2$; $C_m \equiv (n_e - n_o)/(\lambda H^2)$. If λ is expressed in cm, $C_m = A \times 10^{-12}$, $k_m = B \times 10^{-17}$. $\gamma_m/100 = (C/C_{C_6H_5NO_2})_m$, t and λ same for each C. C_{550}, γ_{550}, etc. = value for $\lambda = 0.550\mu$, etc.

Variation with Temperature (39)

Formula	Substance	α_m	t', °C	t'', °C	Δ_t'	Δ_t''
C_6H_5Br	Bromobenzene	$\frac{1}{444}$	4.7	54.7	5.2	−6.6
C_6H_5Cl	Chlorobenzene	$\frac{1}{139}$	5.2	55.1	5.7	−7.4
$C_6H_5NO_2$	Nitrobenzene	$\frac{1}{136}$	5.4	56.3	6.7	−7.9
	Nitrobenzene (9, 12)	$\frac{1}{135}$*	10	25		
	Nitrobenzene (12)	$\frac{1}{144}$	20	20		
	Nitrobenzene (12)	$\frac{1}{138}$	6.4	53.9		
C_9H_{12}	Pseudocumene	$\frac{1}{143}$	5.1	54.5	4.0	−4.8
$C_{10}H_7Br$	α-Bromonaphthalene	$\frac{1}{218}$	5.7	52.4	0.4	−0.8
	α-Bromonaphthalene (12)	$\frac{1}{303}$	11.8	47.9		
$C_{13}H_{10}O_3$	Salol (12) (m. 41.5°C)	$\frac{1}{480}$†	−17	50.5		

Variation with Wave-length (40), H = 10.11 kilogauss

Formula	Substance	t, °C	B	A_{550}	A_{589}	γ_{550}	γ_{589}
C_6H_5Br	Bromobenzene	20.2	3.29	8.01	7.27	30.5	30.6
C_6H_5Cl	Chlorobenzene	19.8	4.14	8.79	8.14	33.4	33.6
$C_6H_5NO_2$	Nitrobenzene					100.0	100.0
C_7H_5N	Benzonitrile	20.2	4.37	9.60	8.66	36.2	36.3
C_7H_5ClO	Benzoyl chloride	19.9	2.27	19.5	15.9	66.0	66.3
C_7H_8	Toluene	19.4	3.85	7.23	6.71	27.7	28.0
C_7H_8O	Benzyl alcohol	20.2	2.79	6.31	5.91	24.0	24.3
C_8H_{10}	*m*-Xylene	20.2	3.61	6.99	6.33	26.2	26.4
C_8H_{10}	*p*-Xylene	19.7	3.73	7.03	6.53	26.8	27.2
C_9H_7N	Quinoline	19.7	6.85	21.1	19.5	81.1	81.2
$C_{10}H_{12}O$	Anethole	19.1	7.81	19.2	17.4	72.7	72.5

* Of $C_{m_{20^\circ}}$.

† Of $C_{m_{20^\circ}}$; variation is sensibly linear, $C_{mt} = C_{m_{20^\circ}}\{1 - \frac{1}{480}(t-20)\}$.

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KINETICS OF CHEMICAL PROCESSES

CHEMICAL KINETICS[1]

ANTON SKRABAL

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[1] The Editors are greatly indebted to Prof. W. C. Bray for his careful editing of the translated text.

TABLE 5.—MAGNETIC BIREFRINGENCE: VARIATION WITH TEMPERATURE AND WAVE-LENGTH

α_m = mean temperature coefficient of C_{mt} between t' and t''; $\Delta/100 \equiv (\varphi_{mt} - \varphi_{m_{20}})/\varphi_{m_{20}}$ where $\varphi_{mt} \equiv C_{mt}nT/\{d(n^2+2)^2\}$, T = absolute temperature corresponding to t. $k_m \equiv C_m\lambda n/(n^2-1)^2$; $C_m \equiv (n_e - n_o)/(\lambda H^2)$. If λ is expressed in cm, $C_m = A \times 10^{-12}$, $k_m = B \times 10^{-17}$. $\gamma_m/100 = (C/C_{C_6H_5NO_2})_m$, t and λ same for each C. C_{550}, γ_{550}, etc. = value for $\lambda = 0.550\mu$, etc.

Variation with Temperature (39)

Formula	Substance	α_m	t', °C	t'', °C	Δ_t'	Δ_t''
C_6H_5Br	Bromobenzene..........	$\frac{1}{444}$	4.7	54.7	5.2	−6.6
C_6H_5Cl	Chlorobenzene..........	$\frac{1}{139}$	5.2	55.1	5.7	−7.4
$C_6H_5NO_2$	Nitrobenzene...........	$\frac{1}{136}$	5.4	56.3	6.7	−7.9
	Nitrobenzene (9, 12).....	$\frac{1}{135}$*	10	25		
	Nitrobenzene (12).......	$\frac{1}{144}$	20	20		
	Nitrobenzene (12).......	$\frac{1}{138}$	6.4	53.9		
C_9H_{12}	Pseudocumene..........	$\frac{1}{143}$	5.1	54.5	4.0	−4.8
$C_{10}H_7Br$	α-Bromonaphthalene.....	$\frac{1}{218}$	5.7	52.4	0.4	−0.8
	α-Bromonaphthalene (12)	$\frac{1}{303}$	11.8	47.9		
$C_{13}H_{10}O_3$	Salol (12) (m. 41.5°C)....	$\frac{1}{480}$†	−17	50.5		

Variation with Wave-length (40), H = 10.11 kilogauss

Formula	Substance	t, °C	B	A_{550}	A_{589}	γ_{550}	γ_{589}
C_6H_5Br	Bromobenzene.....	20.2	3.29	8.01	7.27	30.5	30.6
C_6H_5Cl	Chlorobenzene.....	19.8	4.14	8.79	8.14	33.4	33.6
$C_6H_5NO_2$	Nitrobenzene......					100.0	100.0
C_7H_5N	Benzonitrile.......	20.2	4.37	9.60	8.66	36.2	36.3
C_7H_5ClO	Benzoyl chloride...	19.9	2.27	19.5	15.9	66.0	66.3
C_7H_8	Toluene...........	19.4	3.85	7.23	6.71	27.7	28.0
C_7H_8O	Benzyl alcohol.....	20.2	2.79	6.31	5.91	24.0	24.3
C_8H_{10}	*m*-Xylene.........	20.2	3.61	6.99	6.33	26.2	26.4
C_8H_{10}	*p*-Xylene.........	19.7	3.73	7.03	6.53	26.8	27.2
C_9H_7N	Quinoline..........	19.7	6.85	21.1	19.5	81.1	81.2
$C_{10}H_{12}O$	Anethole..........	19.1	7.81	19.2	17.4	72.7	72.5

* Of $C_{m_{20^\circ}}$.

† Of $C_{m_{20^\circ}}$; variation is sensibly linear, $C_{mt} = C_{m_{20^\circ}}\{1 - \frac{1}{480}(t - 20)\}$.

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KINETICS OF CHEMICAL PROCESSES

CHEMICAL KINETICS[1]

ANTON SKRABAL

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[1] The Editors are greatly indebted to Prof. W. C. Bray for his careful editing of the translated text.

FORMAL TREATMENT

Mathematical treatment of homogeneous, heterogeneous, isothermal and adiabatic reactions.

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THEORIES OF REACTION RATE

Reaction rate as a function of temperature and nature of the medium. Applications of statistical mechanics, theories of radiation (quantum theory) and activation theories.

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GENERAL INTRODUCTION

Isothermal Monomolecular First-Order Reactions: A ⟶.

$$\frac{\mathrm{dx}}{\mathrm{d}t} = k(\mathrm{a} - \mathrm{x}) \text{ or } -\frac{\mathrm{d}C}{\mathrm{d}t} = kC \tag{I}$$

Integration gives:

$$k = \frac{1}{t}\log_e \frac{\mathrm{a}}{\mathrm{a} - \mathrm{x}} \text{ or } k = \frac{1}{t}\log_e \frac{C_0}{C} \tag{II}$$

and

$$k = \frac{1}{t_2 - t_1}\log_e \frac{\mathrm{a} - \mathrm{x}_1}{\mathrm{a} - \mathrm{x}_2} \text{ or } k = \frac{1}{t_2 - t_1}\log_e \frac{C_1}{C_2} \tag{III}$$

If $\log_{10}$ is used instead of $\log_e$, the constant will become $k' = 0.4343k$; a or C_0 = the initial concentration of the reacting substance and $(\mathrm{a} - \mathrm{x_n})$, or C_n, its concentration at a time t_n units later.

Reversible First-Order Reactions.

$$\mathrm{A} \underset{k_2}{\overset{k_1}{\rightleftarrows}} \mathrm{B}$$

$$\frac{\mathrm{dx}}{\mathrm{d}t} = k_1(\mathrm{a} - \mathrm{x}) - k_2(\mathrm{b} + \mathrm{x}) \tag{IV}$$

$$k_1 + k_2 = \frac{1}{t}\log_e \frac{\mathrm{x}_\infty}{\mathrm{x}_\infty - \mathrm{x}} \text{ or } = \frac{1}{t_2 - t_1}\log_e \frac{\mathrm{x}_\infty - \mathrm{x}_1}{\mathrm{x}_\infty - \mathrm{x}_2} \tag{V}$$

where

$$\mathrm{x}_\infty = \mathrm{x} \text{ for } t = \infty, \simeq \mathrm{x} \text{ at equilibrium,}$$

where

$$\frac{\mathrm{b} + \mathrm{x}_\infty}{\mathrm{a} - \mathrm{x}_\infty} = \frac{k_1}{k_2} = K_E, \text{ the ``equilibrium constant''} \tag{VI}$$

If π be any property of the reacting mixture such that

$$\pi = \mathrm{p}(\mathrm{a} - \mathrm{x}) + \mathrm{q}(\mathrm{b} + \mathrm{x}), \tag{VII}$$

where p and q are proportionality factors, then

$$k_1 + k_2 = \frac{1}{t}\log_e \frac{\pi_0 - \pi_\infty}{\pi - \pi_\infty} \text{ or } = \frac{1}{t_2 - t_1}\log_e \frac{\pi_1 - \pi_\infty}{\pi_2 - \pi_\infty}, \tag{VIII}$$

where the subscript identifies the time to which the π value belongs.

If A and B are optical antipodes,

$$k_1 = k_2 = k,\ k_1 + k_2 = 2k, \text{ and } K_E = 1 \tag{IX}$$

Isothermal Bimolecular Second-Order Reactions: A + B ⟶.

$$\frac{\mathrm{dx}}{\mathrm{d}t} = k(\mathrm{a} - \mathrm{x})(\mathrm{b} - \mathrm{x}) \tag{X}$$

$$k = \frac{1}{t(\mathrm{b} - \mathrm{a})}\left(\log_e \frac{\mathrm{a}}{\mathrm{a} - \mathrm{x}} - \log_e \frac{\mathrm{b}}{\mathrm{b} - \mathrm{x}}\right)$$

or

$$k = \frac{1}{(t_2 - t_1)(\mathrm{b} - \mathrm{a})}\left(\log_e \frac{\mathrm{a} - \mathrm{x}_1}{\mathrm{a} - \mathrm{x}_2} - \log_e \frac{\mathrm{b} - \mathrm{x}_1}{\mathrm{b} - \mathrm{x}_2}\right) \tag{XI}$$

or if b = a

$$k = \frac{1}{t\mathrm{a}}\frac{\mathrm{x}}{\mathrm{a} - \mathrm{x}} \text{ or } = \frac{1}{t_2 - t_1}\left(\frac{1}{\mathrm{a} - \mathrm{x}_2} - \frac{1}{\mathrm{a} - \mathrm{x}_1}\right) \tag{XII}$$

If a differs but slightly from b, a series expansion of Eq. (XI) may be used; or k may be taken as the geometrical mean of the values obtained from Eq. (XII) by putting, 1st, a = a and 2nd, a = b.

The differential equation is given in case the rate does not follow a simple law, and the integrated expression is then often omitted.

Progressive Change in k.—↓ (resp. ↑) = "the value of k is greatest at the beginning (resp. end) of the reaction."

Temperature Coefficient.—The effect of temperature will be exhibited approximately by $Q_{10} = \frac{k_{\theta+10}}{k_\theta}$ where k_θ is the value of k at $\theta°$; or more exactly by the constant A in the equation $\log_e k = \mathrm{A}/T + J$ or $\log_{10} k' = -\mathrm{A}'/T + J'$ where A' (resp. J') = $0.4343 \times \mathrm{A}$ (resp. $\times J$). E (= RA, where R is the gas constant) has been called the "internal energy" (Rice), the "critical energy" (Marcelin), the "critical energy increment" (McC. Lewis) or the "activation heat" (Arrhenius).

EXPERIMENTAL DATA

First-Order Gas Reactions

Nearly all reactions of this class take place almost entirely on the surface of the containing vessel as shown by the increase of k with increasing ratio of surface to volume; and several investigators have expressed the opinion that *true* first-order reactions do not exist (417). However, as a result of recent work, several examples are known; *cf.* $SO_2Cl_2 \longrightarrow SO_2 + Cl_2$ and $N_2O_5 \longrightarrow N_2O_4 + 1/2O_2$ below. For nearly all these first-order gas reactions k has been shown to decrease at very low pressure (254.5, 411.5); and new theories have been advanced (419.5). The important qualitative result is that the new evidence favors the collision mechanism and not the radiation theory.

Decomposition of Phosphine

$$4PH_3 \longrightarrow P_4 + 6H_2$$

Manometric method; t in seconds (309).

T, °K	845	785	719	640	583
10^6k	540	2.1	0.81	0.19	0.053

The observed values have been smoothed by graphing. The calculated values are computed from the equation:

$$\log_{10} k = \frac{-18\,963}{T} + 2 \log_{10} T + 12.130; \textit{ cf. } (160)$$

% G = % of reaction in the gas phase; 100 − % G = % on walls; t in seconds (517).

T, °K	10^3k obs.	10^3k calc.	% G	T, °K	10^3k obs.	10^3k calc.	% G
956	18.3	18.0	100	940	8.3	8.0	96
953	15.0	15.5	100	936	7.1	6.5	92
948	12.0	12.0	100	933	6.3	5.6	89
945	10.2	10.3	100	929	5.5	4.5	82
942	9.1	8.9	98	928	4.6	3.3	72
				918	3.8	2.5	66

Measurements in quartz vessels with and without addition of quartz powder; t in seconds; S/V = surface/volume; even at 1044°K the reaction is obviously not a homogeneous one (258).

S/V = 1 cm^{-1};	T, °K	1044	1018	998	970	946		
E = 49 500	10^3k	74	26.7	19.5	10.9	5.29		
S/V = 8.6 cm^{-1};	T, °K	1007	979	956	917	894	858	828
E = 41 800	10^3k	110	49	32	13.2	5.92	2.41	1.19
S/V = 15.7 cm^{-1};	T, °K	983	963	919	890	864		
E = 34 100	10^3k	110	70.7	30.8	19.2	8.89		

Rearrangement of Trimethylene to Propylene

$$(CH_2)_3 \longrightarrow CH_3CH{=}CH_2$$

Bodenstein and Wolgast's gas-stream method with analysis of condensate by density; t in seconds; E = 54 800 to 70 400; Q_{10} = 1.55; the reaction is influenced by the walls, whose effect can, however, be largely diminished (519).

°C	550	570	580	600	600	650
10^3k	6.87	15.2	22.2	44.7	45.7	146

Decomposition of Hydrogen Peroxide

$$H_2O_2 \longrightarrow H_2O + \tfrac{1}{2}O_2$$

Manometric method; t in minutes; k = 0.22 to 0.38 at 76.0°C; wall reaction (257).

Decomposition of Sulfuryl Chloride

$$SO_2Cl_2 \rightleftarrows SO_2 + Cl_2$$

Manometric method; t in minutes; wall reaction (257); at temperatures above 200°C in the dark, the equilibrium concentration of SO_2Cl_2 is negligibly small (514.5).

°C	$\dfrac{\log_e 2}{k}$	Q_{10}	E
211	172		
237	26.5	2.06	35 000
283	1.6	1.85	34 000

Decomposition of Sulfuryl Chloride.—(*Continued*)

Manometric method; t in minutes; at 320°C rate is uninfluenced by a 200-fold increase of the ratio of surface to volume. Concluded to be a *true* first-order reaction at and above this temperature (491.5).

T, °K	552.3	572.5	593.1	602.4
10^5k	6.09	27.1	132.1	274.2
E		46 400	51 850	55 700

Decomposition of Formic Acid

$$HCO_2H \longrightarrow H_2O + CO; \; k_{CO}$$
$$HCO_2H \longrightarrow H_2 + CO_2; \; k_{CO_2}$$

Manometric method; wall reaction dependent on nature of glass used; t in minutes; % P = % of $(CO_2 + H_2)$ formed (256); for catalysis by Al_2O_3, *v.* (16, 17).

°C	137.5	158	236	236	239	302	302	350
$10^4k'_{CO}$	0.49	3.6	12.1	11.4	14.4	46.5	58.0	159
% P	1.5	1.6	2.5	9.0	3.4	10.8	14.4	29.1

°C	237	302	302	350	E = 12 000 (CO)
$10^4k'_{CO_2}$	0.66	5.6	9.8	65	E = 24 500 (CO_2)

Decomposition of Nitrogen Pentoxide

$$N_2O_5 \longrightarrow N_2O_4 + \tfrac{1}{2}O_2$$

Manometric method with correction for NO_2 formation; t in minutes;

$$E = 24\,700; \; \log_e k = \frac{-12\,443}{T} + 35.56 \; (132)$$

°C		65	55	45	35	25
10^3k	obs.	290*	90.0	29.9	8.08	2.03
	calc.	286	93.2	28.3	7.90	(2.03)

°C		25	20	15	0
10^3k	obs.	1.91†	1.17†	0.624†	0.0472†
	calc.	2.03	0.992	0.475	0.0440

* Average using Bodenstein's calculations (51).

† Vapor saturated with solid N_2O_5; values less accurate.

Effect of NO_2 at the beginning of the reaction

According to later measurements by Daniels *et al.* (133, 134, 560), traces of NO_2 are necessary for a smooth monomolecular course of the reaction, which would thus have an autocatalytic induction period. However, White and Tolman (549.5) have found no evidence of this effect at the lowest concentration measurable, and conclude that the reaction is monomolecular in its initial stage.

Colorimetric method; t in minutes; the values of k agree with those above.

°C	20	25	35	40
Initial $p_{N_2O_5}$, mm	1.3–55	2.5–29	2.9	2.5
10^3k	1.03	2.19	8.37	14.8

Decomposition in solvents; gas-volumetric method; t in seconds (346).

°C	CCl_4			$CHCl_3$			Gas*
	10^4k	Q_{10}	E	10^4k	Q_{10}	E	10^4k
55	21.2						15.0
50	11.6	3.47	25 292	12.8			
45	6.11	3.60	26 070				5.0
40	3.22	3.77	25 242	3.81	3.33	24 252	
35	1.62	3.83	26 218				1.35
30	0.8415	3.96	24 222	1.025	3.73	24 648	
25	0.409		25 770				0.34
	Mean: 25 469			Mean: 24 450			

* (132, 133).

Higher-Order Gas Reactions

DECOMPOSITION OF NITRIC OXIDE

$$2NO \longrightarrow N_2 + O_2$$

Analysis with nitrometer; units: seconds and M/cm^3; second-order k (278, 515); *cf.* (379).

T,° K	k	Q_{10}	A	T, °K	k	Q_{10}	A
1 620	191 800			1 201	624.6	1.11	15 970
1 525	47 059	1.16	36 440	1 108	228.3	1.12	14 400
1 355	3 843	1.16	30 390	962	39.82	1.13	12 740
1 252	1 073.6	1.13	21 000				

DECOMPOSITION OF NITROUS OXIDE

$$2N_2O \longrightarrow 2N_2 + O_2$$

Gas-density method; units: seconds and M/cm^3; second-order k (276).

T, °K	k	A
986	6.72	32 800
1 078	110.9	30 800
1 168	977.0	31 900
		Mean: 31 800

Manometric method; units: seconds and M/l (255).

T, °K	Values of k, second-order				
1125	12.5	10.6			
1085	3.70	3.27	3.93	4.05	(4.47)
1053	1.38	1.59	1.82	1.91	
1030	0.84	0.85	0.77	0.98	1.14
1001	0.38	0.51			
967	0.135				
838	0.011				

The reaction is homogeneous since neither quartz powder nor Pt or Rh foil influences its rate.

DECOMPOSITION AND FORMATION OF HYDROIODIC ACID

$$2HI \underset{k_1}{\overset{k}{\rightleftarrows}} H_2 + I_2$$

$$\frac{d[I_2]}{dt} = k[HI]^2 - k_1[H_2][I_2] \qquad \text{(I)}$$

$$\frac{[H_2][I_2]}{[HI]^2} = \frac{k}{k_1} = K_E \qquad \text{(II)}$$

Titrimetric method; k_1 (obs.)—4th column—by the gas-current method; k_1 (calc.) from Equation II above, and the relation $\log_e K_E = -90.48/T - 1.5959 \log_e T + 0.0055454T + 2.6981$; units: minutes and M/22.4l (49).

T, °K	k(obs.)	k_1(obs.)	k_1(obs.)	k_1(calc.)
556	0.0_6942	0.0_3119		0.0_4796
575	0.0_5326	0.0_3353		0.0_3239
599		0.00146		
629	0.0_4809	0.00676		0.00546
647	0.0_3230	0.0140		0.0146
666	0.0_3588	0.0379		0.0350
679		0.0568	0.0535	
683	0.00137	0.0659		0.0784
700	0.00310	0.172		0.164
703		0.250	0.225	
713		0.362	0.336	
716	0.00670	0.375		0.337
781	0.1059	3.58		4.21

$$\log_e k = \frac{-21\,922.5}{T} - 14.468 \log_e T + 0.02305T + 104.185.$$

$$\log_e k_1 = \frac{-21\,832}{T} - 12.872 \log_e T + 0.0055454T + 2.6981.$$

For discussion of theory of the reaction, *v.* (160, 336).

FORMATION OF HYDROBROMIC ACID

$$\begin{array}{ccccc} H_2 & + & Br_2 & \xrightarrow{k} & 2HBr \\ a-x & & b-x & & x \end{array}$$

$$\frac{dx}{dt} = k\frac{(a-x)(b-x)^{1/2}}{5.00 + \dfrac{x}{b-x}}$$

Titrimetric method; units: minutes and M/22.4l (52); *cf.* (380, 411).

°C	k	Q_{10}	°C	k	Q_{10}
301.3	0.0856		251.4	0.00260	2.00
277.5	0.0159	2.03	224.7	0.00036	2.25

FORMATION OF NITROSYL BROMIDE

$$2NO + Br_2 \longrightarrow 2NOBr$$

Manometric method; units: seconds and M/cm^3; third-order k; homogeneous reaction plus some wall reaction (518, 518.5).

T, °K.....	258	265	273	279	286
$10^{-10}k$.....	1.4(?)	1.2	1.2	1.9	0.9(?)

FORMATION AND DECOMPOSITION OF NITROGEN DIOXIDE

$$\begin{array}{ccccc} O_2 & + & 2NO & \underset{k_1}{\overset{k}{\rightleftarrows}} & 2NO_2 \\ \uparrow & & \uparrow & & \uparrow \\ a-x & & b-x & & x \end{array}$$

$$\frac{dx}{dt} = k(a-x)(b-x)^2 - k_1x^2$$

Manometric method; units: minutes and M/l; smoothed values (50); formation of NO_2.

T, °K..............	273	308	333	363	414
$10^{-6}k$..............	2.09	1.59	1.31	1.12	0.925
Q_{10}..............		0.912	0.932	0.949	0.963

T, °K..............	470	514	564	613	662
$10^{-6}k$..............	0.791	0.724	0.681	0.659	0.649
Q_{10}..............	0.972	0.980	0.988	0.993	0.997

k and k_1 calculated from K_E.

T, °K	NO_2-decomposition			NO_2-formation	
	k_1	k_1(calc.)	Q_{10}	$10^{-6}k$(calc.)	Q_{10}
592.0	61.0	66.4		0.670	
603.5	90.6	98.4	1.50	0.667	0.996
627.0	204	222	1.50	0.647	0.987
651.0	485	489	1.53	0.693	1.029
656.0	568	561	1.51	0.705	1.039

From 0 to 354°C the reaction of formation of NO_2 has a negative temperature coefficient or a fractional value for Q_{10} (98, 559).

DECOMPOSITION OF PHOSGENE

$$COCl_2 \xrightarrow{k} CO + Cl_2$$

$$\frac{d[CO]}{dt} = k([COCl_2] - \kappa)[Cl_2]^{1/2}$$

$$\kappa = \frac{[CO][Cl_2]}{K_E} \text{ and } K_E = \frac{[CO][Cl_2]}{[COCl_2]}$$

[CO] and [$COCl_2$] are of the same order of magnitude (10^{-3} to 10^{-4}).

Manometric method; units: minutes and M/l; $\log_{10} k = \dfrac{-11\,420}{T} + 15.154$; $\log_{10} K_E = \dfrac{-5850}{T} + 5.50$; homogeneous gas reaction (110).

T, °K..............	655	685	715	745	782
$100k$(obs.)..........	0.53	2.95	15.1	67.6	354.0
$100k$(calc.)..........	0.52	3.03	15.2	66.8	354.0

SUMMARY OF GAS REACTION DATA ACCORDING TO TRAUTZ (516)

Units: seconds and M/cm³

$$\text{Second-order: } \log_{10} k = \frac{-A'}{T} + \frac{1}{2}\log_{10} T + J'$$

Reaction	A′	J′	Authority
$H_2 + O_2 \rightarrow H_2O$	10 141	12.7	Bodenstein
$H_2 + I_2 \rightarrow 2HI$	8 640	13.7	Bodenstein
$2HI \rightarrow H_2 + I_2$	9 630	13.4	Bodenstein
$HI + O_2 \rightarrow H_2O + I_2$	5 600	11.9	Trautz and Helmer
$N_2 + O_2 \rightarrow NO$	18 800	11.4	Nernst and Jellinek
$2NO \rightarrow N_2 + O_2$	13 700	10.3	Nernst and Jellinek
$2O_3 \rightarrow O_2$	5 760	14.1	Warburg
$NO + Cl_2 \rightarrow NOCl_2$	4 220	12	Trautz and Schlueter
$NOCl_2 + NO \rightarrow NOCl$	3 940	12	Trautz and Schlueter
$2NOCl \rightarrow NO + NOCl_2$	6 040	12	Trautz and Schlueter
$\text{Third-order: } \log_{10} k = \frac{-A'}{T} - \log_{10} T + J'$			
$2NO + Cl_2 \rightarrow NOCl$	1 220	14.6	Trautz, Wachenheim, Schlueter, Henglein
$2NO + Br_2 \rightarrow NOBr$	760	15.1	Trautz and Dalal

Additional references (86, 87, 88, 109, 116, 299, 440, 501, 502, 536).

Racemization

HYOSCYAMINE (HY.) $\rightleftarrows$ SCOPOLAMINE (SC.)

Polarimetric method; t in minutes; first-order reaction with reversal (194).

1 g Hy. with absolute alcohol to 15 cm³ + 1 cm³ N NaOH; $2k = 0.0148$ at 5°C.

1.048 g Hy. with absolute alcohol to 24.95 cm³ + 0.5238 g tropine; $2k = 4.97 \times 10^{-6}$ at room temperature.

4.0173 g Sc. with absolute alcohol to 70 cm³ + 8.51 cm³ absolute alcohol containing 0.004017 mole NaOH; $2k = 0.0295$ at 3°C.

15.519 g alcohol solution of Sc. (of which 1 cm³ ≈ 9.46 cm³ 0.01N H_2SO_4) + 0.3736 g tropine; $2k = 4.42 \times 10^{-6}$ at room temperature.

The reaction is useful for determining [OH^-].

POTASSIUM CHROMOOXALATE

$$K_3[Cr(C_2O_4)_3],\ l \underset{k}{\overset{k}{\rightleftarrows}} d$$

Polarimetric method; t in seconds (420); *cf.* (277, 513, 549)

In H_2O	°C	0	11	22	24	Q_{10}	E
	$2 \times 10^6 k$	149	239	542	598	1.77	9328

	% Acetone	H_2O, M/l	$2k$
In H_2O + Acetone, 22°C	0	55.55	0.000542
	40	33.33	0.000329
	60	22.22	0.000262

$$l\text{-MENTHONE} \underset{k_2}{\overset{k_1}{\rightleftarrows}} d\text{-MENTHONE};\ k = k_1 + k_2$$

According to Beckmann (33) the two menthones are not optical antipodes and hence $k_1 \neq k_2$.

Measurements in various solvents; k independent of direction. Catalyzed by alcoholates, quaternary ammonium bases, and strong acids but not proportionally to their concentration.

Slight catalysis by weak acids. Not influenced by neutral salts, by acetic esters, or by dimethylhydroresorcinols. The catalysis by alcoholates is not influenced by slowly saponifiable esters but rapidly saponifiable ones react with Na from the alcoholates and decrease the reaction velocity accordingly.

l-MENTHONE $\rightleftarrows$ d-MENTHONE.—(*Continued*)

Polarimetric method; t in minutes; catalyst, 0.02 (resp. 0.01)N alcoholate (resp. 0.01N HCl) (522, 523).

Alcoholate / Solvent: alcohol	0.02N k', 20°C	0.01N k', 25°C	0.01N HCl k', 20°C
Methyl	0.00317		0.0067
Ethyl	0.00826		0.0150
n-Propyl	0.0107		0.0215
n-Butyl	0.0130	0.0092	
n-Heptyl	0.0165		
n-Octyl	0.0191		0.0492
Isobutyl	0.0147	0.0105	0.0265
Isoamyl	0.0159		0.0277
Isopropyl	0.0171		
sec.-Butyl	0.0336	0.0244	
sec.-Octyl	0.0572		
tert.-Butyl		0.0504	
Allyl		0.00200	0.0104
Benzyl		0.00118	0.0335

Values of 1000k' at 20°C in various solvents with 0.01N HCl

Solvent	C_6H_6	$C_6H_4(CH_3)_2$	C_6H_5Cl	$(C_2H_5)_2O$
$10^3k'$	2.3	2.0	6.9	0.4

Solvent	C_2H_5Br	CH_2BrCH_2Br	CCl_4	$CHCl_3$
$10^3k'$	3.4	10.8	5.3	47.1

For all reactions $Q_{10} = 2.31$–3.19; A′ = 3250–4250.

For determination of the "alcoholytic constant" of the type [acetoacetic ester] [alcoholate]/[Na acetoacetic ester] = K, and for theory of the reaction, *v.* (225); *cf.* (10, 427).

Transformation of Geometric Isomers

syn-ALDOXIME $\xrightarrow{k}$ *anti*-ALDOXIME (398, 399)

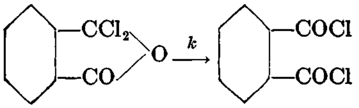
Method: change in rotation of the optically active solvent; t in minutes; θ = 20°C. 5 g oxime in 95 g solvent. Values of 1000k, (first-order):

syn-Anisaldoxime in dimethyl tartrate (3.0); in diethyl tartrate (1.8); in di-n-propyl tartrate (1.0); in dimethyl malate (5.0); in diethyl malate (6.7); in di-n-propyl malate (8.4) (398); *cf.* (399).

syn-m-Nitrobenzaldoxime in di-n-propyl tartrate (0.5) (398); *cf.* (399).

Intramolecular Transformation

PHTHALYL CHLORIDE



Reaction in liquid melt; method: initial freezing point; t in minutes; k (first-order) = 0.036 at 130°C; Q_{10} = 1.6 (90 – 170°) (130).

DIAZOAMINOBENZENE

$$C_6H_5NHN_2C_6H_5 \xrightarrow{k} C_6H_5N_2C_6H_4NH_2$$

Gas-volumetric method: t in hours; solvent, aniline; catalyzed by $C_6H_5NH_3Cl$; rate proportional to concn. of catalyst, $C_{\text{cat.}}$ (M/l); first-order k (216); *cf.* (204, 217).

°C	25			25	35	45	55	
$C_{\text{cat.}}$	0.1	0.2	0.3	0.1				
$10^3k'$	6.0	12.3	18.1	6.0	24.6	81.0	253	A′
Q_{10}					4.10	3.29	3.12	5355

TRIBROMOBENZENEDIAZONIUM CHLORIDE

$$Br_3C_6H_2N_2Cl \xrightarrow{k} ClBr_2C_6H_2N_2Br$$

Gravimetric method; t in minutes; solvent, methyl alcohol; first-order k (239); $10^3k' = 0.83$ at 0°C = 1.93 at 4°C; $Q_{10} = 8.2$. The solid salt decomposes rapidly, the aq. soln. slowly, the alcoholic soln. at measurable rate (239).

ACETOPHENOXIME

$$C_6H_5C(NOH)CH_3 \xrightarrow{k} C_6H_5NHCOCH_3$$

Beckmann rearrangement; titrimetric method; *t* in minutes; catalyst, H_2SO_4; first-order *k* (490).

% H_2SO_4		68.5	93.6	94.6	97.2	98.2
$10^3k'$	60°C		1.1	1.3	4	7
	65°C	0.6	1.9	2.1		

CINCHONINE OR CINCHONIDINE $\xrightarrow{k}$ CINCHOTOXINE

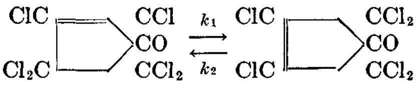
Gravimetric and polarimetric methods; *t* in hours; solvent, aqueous acids (39, 40, 41, 42, 44). Cinchonine at 99.7 ± 0.2°C; values of $1000k'$, (first-order); $C_{\text{cat.}}$ in M/l.

$C_{\text{cat.}}$ \ Cat.	$C_2H_5CO_2H$	CH_3CO_2H	HCO_2H	$(CO_2H)_2$	HCl
0.15		5.60			1.63
0.175		7.12			0.77
0.20	11.7	9.4	6.2		0.3
0.40	29.6	23.9	12.1	4.0	
0.80	61.1	49.9	16.5		
2.00		90.1		0.7	

The value of *k* varies also with the initial concn. of the alkaloid. For theory of the reaction, *v.* (38, 39).

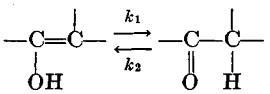
Tautomerism

HEXACHLORO-α-KETO-β-R-PENTENE IN THE LIQUID MELT



Gravimetric method; *t* in hours; first-order *k*, powerfully catalyzed by traces of H_2O or HCl. With material dried with P_2O_5, $k_1 = 0.049$, $k_2 = 0.078$. $K_E = 1.59$ at 210.5°C (321, 322).

ENOL⟶KETONE



First-order *k*; *t* in minutes:

I = Ethyl acetoacetate, $CH_3COCH_2CO_2C_2H_5$.

II = Methyl benzoylacetate, $C_6H_5COCH_2CO_2CH_3$.

III = Methyl mesityloxidoxalate, $(CH_3)_2C{:}CHCOCH_2COCO_2CH_3$.

Methods: (*a*) titration by Meyer's method; (*b*) bromine extraction; (331); *cf.* (138, 139, 141, 142); (*c*) viscosity; (*d*) refractometric; (*e*) $FeCl_3$ extraction; (*f*) $FeCl_3$, colorimetric.

Ester	Solvent	k_1	k_2	°C	Method	Lit.
I	Melt	0.0_355	0.0_446	15	(*a*)	(368)
I	H_2O	2.4	0.010	0	(*a*)	
I			0.013	0	(*b*)	
I			0.039	10	(*b*)	
I	0.1*N*HCl		0.018	0	(*b*)	
I	Alcohol	0.077	0.0105	0	(*a*)	
I	Hexane	0.0041	0.0035	0	(*a*)	
I	Melt	$k_1 + k_2 = 0.034$		25	(*c*)	(158)
I		0.0_3172	0.0_537	Rm	(*d*)	(306)
I		$k_1 + k_2 = 0.0178$		Rm	(*d*)	
I		$k_1 + k_2 = 0.613$		Rm	(*d*)	
I		0.0_397	0.0_42	Rm	(*d*)	
I		$k_1 + k_2 = 6.05$		Rm	(*d*)	
I	Petroleum ether	0.0192	0.0073	15	(*d*)	
I	H_2O		0.017	0	(*e*)	(266)
II	Melt	$k_1 + k_2 = 1.3$		Rm	(*d*)	(305)
II	Alcohol	0.10	0.04	0	(*a*)	(367)
III	Melt	0.0085	0.0_333	98	(*f*)	(307)
III	Alcohol	0.0_335	0.0_417	78	(*f*)	
III		0.0_455	0.0_52	Rm	(*f*)	

The reaction in the melt is very slow and depends on the nature of the walls, the presence of traces of impurities (*e.g.*, acids) and the previous history of the sample used. Acids are poor catalysts in H_2O and alcohol and good catalysts in non-ionizing solvents. The reaction in the gas phase is very slow even on the walls. For preparation of the pure tautomers, *v.* (370, 371).

HYDROXYTRIAZOLE ⟶ DIAZOMALONIC ESTER

$$\begin{array}{ccc} \text{Acid form} & \underset{k_2}{\overset{k_1}{\rightleftarrows}} & \text{Neutral form} \\ \text{A} & & \text{N} \end{array}$$

Method: iodine titration of the acid form; *t* in minutes; first-order *k*. Methyl 1-methyl-5-hydroxytriazole-4-carboxylate $\underset{k_2}{\overset{k_1}{\rightleftarrows}}$ Methyl methylaminodiazomalonate. Ionization constant of the acid form $= 2.8 \times 10^{-3}$.

Values for 50°C in various solvents (149)

	CH_3OH	$C_6H_5CH_2OH$	CH_3COCH_3
10^3k_1	0.120	0.278	1.36
10^6k_2	25.3	23.2	72.6
K_E	4.679	11.95	18.69

	$CH_3CO_2C_2H_5$	$C_6H_5NO_2$	$C_2H_5ONO_2$
10^3k_1	6.46	7.36	8.97
10^6k_2	117	73.6	98
K_E	54.25	100.0	98.9

$K_E = \frac{k_1}{k_2} = G\frac{S_N}{S_A}$ where S is the solubility (N- resp. A-form) in a given solvent and G is a universal constant independent of the nature of the solvent; *cf.* (260).

Values for 18°C in various solvents (149)

	CH_3OH	$C_6H_5CH_2OH$	CH_3COCH_3
K_E	3.27	8.62	14.15
S_N/S_A	6.29	13.28	20.82
G	0.52	0.65	0.68

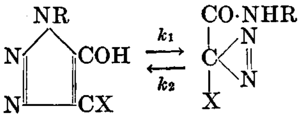
	$CH_3CO_2C_2H_5$	$C_6H_5NO_2$	$C_2H_5ONO_2$
K_E	51.63	99.0	89.91
S_N/S_A	84.61	157.7	171.3
G	0.61	0.63	0.53

Effect of solubility (g/l) on k_1 at 10°C. Methyl 1-phenyl-5-hydroxytriazole-4-carboxylate $\underset{k_2}{\overset{k_1}{\rightleftarrows}}$ Methyl anilinodiazomalonate (149).

Solvent	k_1	S_A	S_N	$k_1 \times S_A$
CH_3OH	0.00053	218	34.4	0.116
C_2H_5OH	0.00103	97.7	29.1	0.101
$C_6H_5CH_2OH$	0.0011	90	222	0.099
CH_3CN	0.0047	41.5	194	0.195
CH_3COCH_3	0.00527	56.5	206	0.298
$HCO_2C_2H_5$	0.00828	23.3	257	0.193
$CHCl_3$	0.0211	8.8	572	0.186
$CH_3CO_2C_2H_5$	0.0267	12	194	0.320
$C_6H_5NO_2$	0.046	6.5	346	0.299
$C_2H_5ONO_2$	0.055	3.2	317	0.176

Results obtained in water as the solvent indicate that the non-ionized acid form is the reacting molecular species, *v.* (149).

Effect of Chemical Constitution



k_1, measured; k_2, calculated from K_E; reaction in C_2H_5OH; values for very rapid or very slow reactions obtained by extrapolation to 25°C (149).

R	X	k_1	10^6k_2	K_E
H	$CONH_2$	0.0_53	1.3	2.26
H	CO_2CH_3	0.0_546	0.13	36
$C_6H_5CH_2$	CO_2CH_3	0.0_426	0.22	118
p-$C_6H_4CH_3$	$CO_2C_2H_5$	0.0094	78	120
C_6H_5	CO_2CH_3	0.01	34	300
p-C_6H_4Br	$CO_2C_2H_5$	0.046	83	555
p-$C_6H_4NO_2$	CO_2CH_3	0.6		Very large

Effect of Temperature
Values of 10^4k_1 for R = $C_6H_5CH_2$ and X = CO_2CH_3 (149)

Solvent	40°C	50°C	60°C	Q_{10}
CH_3OH		6.35	9.59	3.5
C_2H_5OH		10.0	42.3	4.2
CH_3COCH_3	15.2	65.1		4.3
$CHCl_3$	61.8	172		6.5

AMMONIUM THIOCYANATE

$$NH_4CNS \underset{k_2}{\overset{k_1}{\rightleftharpoons}} CS(NH_2)_2$$

Reaction in the melt; titrimetric method; first-order k; t in minutes; at 170°C, $k_1 = 0.015$, $k_2 = 0.044$, $K_E = 1/3$ (25, 415, 528).

Decomposition Reactions

NITRAMIDE

$$H_2N_2O_2 \xrightarrow{k} H_2O + N_2O$$

For preparation of nitramide, *v.* (512). First-order k; t in minutes; solvent, water; all values at 15°C (93).

$k = k_0 + k_cC_{cat.}$, where k_0 is the constant for the uncatalyzed reaction and k_c that with a catalyst of concn. $C_{cat.}$, M/l. All substances which decrease the [H⁺] of the solution act as catalyzers. $k_0' = 366$ to 398×10^{-6}, mean = 0.0_338.

Catalysis Constants for Anions of Acids

Values of k_c for the anions of weak monobasic acids, and their relation to the ionization constants, k_D

Acid	k_c'	$100k_D$	$10^5k_c' \times k_D{}^{0.83}$
Propionate	0.65	0.00134	5.9
Acetate	0.50	0.0018	5.8
Phenylacetate	0.23	0.0053	6.5
Benzoate	0.19	0.0065	6.3
Formate	0.082	0.021	7.2
Salicylate	0.021	0.1	6.2
Dichloroacetate	0.0007	5.0	5.8
			Mean: 6.2

In the case of polybasic acids the value of k_c for each anion was found to be similarly related to the corresponding ionization constant when the latter is corrected by a "statistical" factor, n, as illustrated below. The subscripts 1 and 2 refer to the first and second ionization stages, respectively.

Catalysis Constants for Anions of Acids.—(*Continued*)

Acid	$10^3k_{D_1}$	n	k_{c_1}'	$10^5k_{c_1}'(nk_{D_1})^{0.83}$	$10^5k_{D_2}$	n	k_{c_2}'	$10^5k_{c_2}'(nk_{D_2})^{0.83}$
Succinic	0.065	$\frac{1}{2}$	0.320	6.0	0.21	2	1.8	6.2
Malic	0.40	$\frac{1}{2}$	0.0765	6.4	0.69	2	0.72	6.8
Tartaric	0.97	$\frac{1}{2}$	0.0363	6.3	3.7	2	0.165	6.2
Phthalic	1.2	$\frac{1}{2}$	0.029	6.2				
Oxalic					4.5	2	0.104	4.8
Phosphoric	8.9	$\frac{1}{3}$	0.0079	6.3	0.0049	1	86	7.2
			Mean:	6.2			Mean:	6.2

Catalysis Constant for Bases

The "acid" equilibrium constant of the base, RNH_2, is $k_B = [RNH_2][H^+]/[RNH_3^+]$

	Aniline	Quinoline	Dimethylaniline	Pyridine
10^5k_B	2.0	1.2	0.63	0.44
k_c'	0.531	1.9	2.7	4.6

For applications of the nitramide method to the determination of the ionization constants of (*a*) weak acids, (*b*) unsymmetrical dibasic acids, (*c*) H_2CO_3 (true constant), and (*d*) pseudo acids, *v.* (93).

HYDROGEN PEROXIDE

$$H_2O_2 \xrightarrow{k} H_2O + \tfrac{1}{2}O_2 \text{ (aqueous solution)}$$

Homogeneous Catalysis

Catalysis by Alkalies

First-order k; t in minutes; θ = 40°C (100)

[NaOH]	0.0004	0.0016	0.008	0.04	0.16
10^3k	0.896	1.67	3.06	4.51	7.90

Base, 0.04N	NaOH	KOH	NH_4OH	$Ba(OH)_2$
10^3k	4.51	4.68	3.98	2.26

Effect of temperature in 0.04N NaOH

°C	20	30	35	40	45	50	60	70
10^3k	1.06	3.08	5.16	7.90	13.4	17.3	38.9	58.8
Q_{10}		2.9	2.6		2.2		2.2	1.5

Catalysis by Iodide Ion

According to Abel (3), the reactions are $H_2O_2 + I_2 \longrightarrow 2H^+ + 2I^- + O_2$ [for kinetics, *v.* (5)] and $H_2O_2 + 2H^+ + 2I^- \longrightarrow 2H_2O + I_2$. For t in minutes; first-order $k_{cat.} = k[I^-]$. At 25°C, k = 1.33 (84, 534); *cf.* (89); = 1.4 (3); = 1.38 (241).

Neutral salts alone have slight influence. In the presence of iodide their pronounced catalytic effects increase in the order K⁺, Na⁺, Li⁺ (241, 537, 538, 540).

In cases where the H_2O activity is constant, this catalysis by a neutral chloride is related to the Cl⁻-activity, a, by the simple rule, $k_{cat.}/a$ = constant, for the same salt concentration (240).

Catalysis by $K_2Cr_2O_7$

$$-\frac{d[H_2O_2]}{dt} = k[K_2Cr_2O_7][H_2O_2]$$

t in minutes; θ = 25°C; k = 20.9 to 34.5 in the interval $[K_2Cr_2O_7]$ = 0.009 to 0.0_43 (494); *cf.* (421, 495).

Heterogeneous Catalysis

By Colloidal Platinum

First-order k; t in minutes; θ = 25°C; Pt, 1 to 31 500 (76, 79), effect of age of Pt soln.

Pt-soln., days old	0	1	5
k'	0.023	0.025	0.022
k' (with Na_2HPO_4, 1 to 2000)	0.015	0.016	0.012

Effect of concentration of Pt soln.; $k = \text{constant} \times [\text{Pt}]^n$ where n is a constant dependent upon the nature of the Pt preparation.

1.13×10^6 [Pt]		32	24	16	12	6	4	3
n = 1.58	$10^3k'$(obs.)	115	72	40	24	8.4	4.6	2.7
	$10^3k'$(calc.)	115	74	39	24	8.2	4.3	2.7

Effect of Poisons

The catalytic action of colloidal Pt is diminished by various "poisons" most of which are likewise physiological poisons. With certain of these poisons the catalyst, toward the end of the reaction, partially "recovers" from the effects. This is illustrated by the following table for HCN on [Pt] = 1.03×10^{-5}.

10^6[HCN]	0	0.05	0.1	0.2	0.5	1	2
$10^2k'$, (begin)	4.1	1.6	1.3	0.75	0.33	0.20	0.15
$10^2k'$ (end)	4.1	2.4	1.5	0.86	0.36	0.29	0.35

List of "Poisons" (* = Partial Recovery)

Powerful "poisons:" HCN*, ICN, I_2, $HgCl_2$, H_2S, $Na_2S_2O_3$, CO*, P, PH_3, AsH_3, $Hg(CN)_2$, CS_2.

Moderate "poisons:" aniline, hydroxylamine,* Br_2, HCl, oxalic acid, amyl nitrite, As_2O_3, Na_2SO_3,* NH_4Cl.

Weak "poisons:" H_3PO_3, $NaNO_3$, HNO_2, pyrogallol, nitrobenzene, HF, NH_4F.

Inactive substances: dilute $KClO_3$, ethyl and amyl alcohols, ether, glycerol, turpentine, chloroform.

Positive catalysts, ("tonics"): formic acid, hydrazine, dilute HNO_3.

By Colloidal Palladium

First-order k; t in minutes; $\theta = 25°C$ (75)

[Pd]	[NaOH]	k	[Pd]	[NaOH]	k
0	1:33 000	0	1:13 200*	1:6 000	0.0073
1:100 000	1:33 000	0.003	1: 6 600	1:3 000	0.0045
1: 13 000	1: 6 000	0.014	1: 6 600†	1:3 000	0.001
1: 4 400	1: 3 000	0.016	1:16 800	1:6 000	0.013
1: 13 200	1: 6 000	0.0103	1:16 800‡	1:6 000	0.0010

Poisoned by: *$[I_2] = 0.5 \times 10^{-7}$; †$[HgCl_2] = 10^{-3}$; ‡$AsH_3$ saturated.

By Colloidal Gold Catalysis in Alkaline Solution, *v.* (80)

In all of the preceding cases, the H_2O_2 reacts according to a first-order heterogeneous reaction [*v.* (95, 378)] if the reaction at the boundary is rapid in comparison with the rate of diffusion.

By Platinized Platinum

$$k' = \frac{1}{t}\log_{10}\frac{a}{a-x} = 0.4343\frac{SD}{\delta v}$$

D = diffusion coefficient; S = active surface; δ = thickness of diffusion layer; v = total volume, cm³; RPM = stirring rate, revolutions per min.; t in minutes; $\theta = 25°C$ (83).

v	450	450	450	450	675	900	900	900	1350
RPM	235	255	275	285	245	240	266	272	250
$10^4k'$	60	67	74	80	46	39	42	39	20

Temp. interval, °C	25–35	35–45	45–55
Q_{10}	1.28	1.28	1.28

By Mercury

For pulsating catalysis on Hg surface, *v.* (19, 68)

The thinnest Hg layer on gold which exhibits catalytic action is *ca.* 3×10^{-8} cm thick (85).

Dianthracene ⟶ Anthracene

$$C_{28}H_{20} \xrightarrow{k} 2C_{14}H_{10}$$

Gravimetric method; first-order k; t in minutes (349)

Solvent	°C	10^4k	Q_{10}
Phenetole	170	39.0	
	167	28.6	2.8
	160	13.9	2.8
Anisole	154	6.7	

The reaction is complete in the dark.

Na Isonitrosoacetophenone $\xrightarrow{k}$ Na Benzoate + HCN

$$C_6H_5COCH{:}NONa \xrightarrow{k} C_6H_5COONa + HCN$$

Colorimetric method; first-order k; t in minutes (489)

In H_2O	°C	35.6	60.1	69.0	70.0	Q_{10}
	$10^3k'$	0.62	2.3	4.5	4.8	3.5

Effect of solvent at 60.1°C

Aqueous	$10^3k'$	Solvent	$10^3k'$
0.1*N* NaOH	1.4	50% C_2H_5OH	1.3
N NaOH	1.5	97% C_2H_5OH	1.0
N NaCl	1.5	97% CH_3OH	1.8
10*N* NaOH	2.2	100% CH_3OH	1.7

Hydrazobenzene ⟶ Aniline + Azobenzene

$$2C_6H_5NHNHC_6H_5 \xrightarrow{k} 2C_6H_5NH_2 + C_6H_5N{:}NC_6H_5$$

Titrimetric method; first-order k; t in minutes (499)

In C_2H_5OH dried with Na, $k = 0.00156$ at 140.3°C. Authors conclude that free radicals are formed as intermediate step.

Xanthogenic Acid

$$CS(SH)(OC_2H_5) \longrightarrow CS_2 + C_2H_5OH$$

Autocatalyzed by the alcohol. $\frac{dx}{dt} = (k + k_0x)(a - x)$. At the beginning of the reaction and in media where the reaction is rapid k_0x is negligible in comparison with k and the reaction is of first order.

Titrimetric method; t in minutes (233)

Solvent	k', 0°C	k', 25°C	A′
CS_2		0.0_5132	
Ligroin	0.0_6190	0.0_5198	2500
Chloroform	0.0_654	0.0_5480	2972
Benzene	0.0_680	0.0_568	3060
Nitrobenzene	0.0_4644	0.0_3415	3548
Ether	0.0_474	0.0_364	3080
Acetone	0.00324	0.0343	3199
Alcohol	0.143		

Reaction in benzene-alcohol mixture of normality *N* with respect to alcohol; $\theta = 25°C$ (233)

N	0	0.01	0.02	0.174	0.5	1.0
k'	0.0_568	0.0_4274	0.0_458	0.0_3294	0.0251	0.0423

For reaction in aqueous solution, *v.* (232).

Diacetone Alcohol ⟶ Acetone

$$CH_3COCH_2C(CH_3)_2OH \xrightarrow{k} 2CH_3COCH_3$$

In aqueous solution, the reaction is reversible, but for concentrations less than 10% it may be treated as complete. Dilatometric method; first-order k proportional to $[OH^-]$; t in minutes; $[OH^-]$ from conductivity; *N* = normality; $\theta = 25.2°C$ (308).

N	NaOH		
	k'/N	$10^2[OH^-]$	$k'/[OH^-]$
0.0942	0.2316	8.762	0.2490
0.0471	0.2357	4.503	0.2465
0.01884	0.2320	1.841	0.2375
0.00942	0.2358	0.929	0.2392
0.00471	0.2236	0.468	0.2250
0.002355	(0.1890)	0.235	(0.1894)

Diacetone Alcohol $\longrightarrow$ Acetone.—(*Continued*)

N	$Ba(OH)_2$		
	k'/N	$10^2[OH^-]$	$k'/[OH^-]$
0.0942	(0.2161)	8.006	0.2544
0.0471	0.2300	4.192	0.2584
0.01884	0.2243	1.771	0.2386
0.00942	0.2301	0.918	0.2362
0.00471	0.2252	0.466	0.2276

The average of $k'/N = 0.2298$, and hence on the assumption of complete ionization, $dx/dt = 0.5292[OH^-]$ (a − x) at 25.2°C.

Effect of neutral salts

M/l	[NaCl]	0	0.471	0.942	1.413
[NaOH] = 0.0942..	$10^3k'$	21.81	18.90	16.93	15.67
[NaOH] = 0.0942..	Salt	NaCl	$NaNO_3$	Na_2SO_4	$Na_2S_2O_3$
[Salt] = 0.942......	$10^3k'$	16.93	15.59	22.87	20.79

Method used to determine hydrolysis of Na_2CO_3 and ionization of ammonia and amine bases.

Nitrosotriacetoneamine $\xrightarrow{k}$ Phorone + N_2 + H_2O

In aqueous solution with catalysis by OH^-. Gas-volumetric and (more accurate) manometric method; first-order k, t in minutes (117, 184, 185, 186, 386). $k/[OH^-] = 1.92$ at 30°C; mean of 12 measurements between 0.016 and 0.020N OH^-.

°C	18	30	40	50	60
$k/[OH^-]$, (obs.).........	0.612	1.92	4.51	10.15	22.0
$k/[OH^-]$, (calc. A = 8101)	0.637	1.92	4.51	10.06	21.3
Q_{10}....................		2.58	2.35	2.25	2.17

For application to determination of $[OH^-]$, *v.* (26); effect of neutral salts (21, 308); hydrolysis of soap solutions (350); acidity of $Sn(OH)_4$ solutions (123).

CO_2-Dissociation of Carboxylic Acids

Malonic Acid $\longrightarrow$ Acetic Acid + CO_2

$$CH_2(CO_2H)_2 \xrightarrow{k} CH_3CO_2H + CO_2$$

Manometric method; first-order k; t in minutes; medium: the melt, stable and undercooled (254)

°C*.................	153.6	153.2	143.5	142.3	136.4
10^3k.................	65.0	62.7	24.6	22.0	12.5

°C*.....................	134.2	133.6	129.4	125.9
10^3k.....................	10.15	9.58	6.39	4.58

* Q_{10} = 2.6 over the whole range.

For the solid acid, k is not constant, but a value k_s can be obtained by extrapolation to $t = 0$. In the following table this value is compared with the value, k, for the undercooled melt.

°C...........	126.3	125.3	121.2	117.3	110.8
10^3k_s.........	0.58	0.51	0.113	0.094	0.028
10^3k.........	4.77	4.42	2.91	2.00	1.08
k/k_s.........	8	9	26	21	39

Solvent: acetic acid (340)

°C*.........	98.5	99.1	99.4	100.0	102.5	104.5
10^6k..........	650	708	739	830	1150	1460

* Q_{10} = 3.85 over the whole range.

Values of 10^3k at 110.8°C in different media are: the solid acid, 0.028; the undercooled melt, 1.08 (254); acetic acid, 3.41 (340); H_2O, 3.62 (35, 36).

$$CRR'(CO_2H)_2 \xrightarrow{k} CRR'HCO_2H + CO_2$$

Titrimetric method; first-order k; t in hours; solvent, H_2O (35, 36)

Malonic acid, $CH_2(CO_2H)_2$

°C................	66.0	68.5	78.0	87.5	91.6	95.2	99.5
10^3k................	0.27	0.9	4.4	16.4	28.8	47.3	75.5
°C................	75.0	88.5	99.35	103.6	107.0	110.0	
10^3k................	3.36	18.9	75.5	108.4	154.4	201.9	

Ethylmalonic acid, $C_2H_5CH(CO_2H)_2$

°C.............	80.0	86.0	95.0	102.0	105.0	110.0
10^3k.............	4.4	11.5	33.6	63.5	75.4	116.2

Benzylmalonic acid, $C_6H_5CH_2CH(CO_2H)_2$

°C.............	76.0	85.5	89.5	95.0	106.3	110.0
10^3k.............	14.3	48.6	83.3	116.1	259.0	476.5

Diethylmalonic acid, $(C_2H_5)_2C(CO_2H)_2$

°C.....................	95.0	99.7	102.0	105.0	110.0
10^3k.....................	9.1	35.5	55.5	73.0	122.5

Acid	Formula	k, 99.5°C
Phenylmalonic..........	$C_6H_5CH(CO_2H)_2$	1.9
Benzylmalonic..........	$C_6H_5CH_2CH(CO_2H)_2$	0.197
Chloromalonic..........	$CHCl(CO_2H)_2$	0.18
Allylmalonic............	$CH_2{:}\,CHCH_2CH(CO_2H)_2$	0.132
Tartronic...............	$CH(OH)(CO_2H)_2$	0.080
Malonic.................	$CH_2(CO_2H)_2$	0.0757
Diallylmalonic..........	$(CH_2{:}\,CHCH_2)_2C(CO_2H)_2$	0.07
Methylmalonic..........	$CH_3CH(CO_2H)_2$	0.06
Ethylmalonic...........	$C_2H_5CH(CO_2H)_2$	0.051
Dichloromalonic.........	$CCl_2(CO_2H)_2$	0.05
Di-*n*-propylmalonic......	$(C_3H_7)_2C(CO_2H)_2$	0.05
Methylethylmalonic......	$(CH_3)(C_2H_5)C(CO_2H)_2$	0.035
Dimethylmalonic........	$(CH_3)_2C(CO_2H)_2$	0.029
Diethylmalonic..........	$(C_2H_5)_2C(CO_2H)_2$	0.028
Dibromomalonic.........	$CBr_2(CO_2H)_2$	0.02

Acetoacetic Acid $\longrightarrow$ Acetone + CO_2

$CH_3COCH_2CO_2H \longrightarrow CH_3COCH_3 + CO_2$; solvent, H_2O

Both the undissociated acid (HA) and its anion (A^-) undergo the reaction:

$$\frac{d[CO_2]}{dt} = k_1[HA] + k_2[A^-]$$

Let k_D = the ionization constant and α the degree of ionization of the aceto-acid, then

$$\frac{dx}{dt} = k_1[(1 - \alpha) + k_2\alpha](a - x)$$

$$\frac{dx}{dt} = [k_1[H^+] + k_2k_D]\frac{(a - x)}{[H^+] + k_D}$$

k_1 is measured in strongly acid and k_2 in strongly alkaline solution. k_1 and k_2 together with a velocity measurement in an acetic acid-acetate solution give k_D. t in minutes (551); *cf.* (343). For preparation of the aceto-acid, *v.* (344).

°C	10^3k_1	10^3k_2	10^3k_D	Q_{10}
25	0.99	0.02	0.316	3.53(k_1)
37	4.5	0.08	0.24	3.16(k_2)

Catalysis by Aniline

This reaction is of interest because, as in the case of many biochemical reactions, there is a maximum catalytic effect at a given $[H^+]$. For details, *v.* (552).

Trichloroacetic Acid $\longrightarrow$ Chloroform + CO_2

$$CCl_3CO_2H \xrightarrow{k} CHCl_3 + CO_2$$

First-order k; t in minutes; solvent, aniline (207). 10^3k = 0.040 at 25°C; = 0.80 at 45°C; Q_{10} = 4.47. Addition of picric acid does not influence the velocity.

Aminobenzoic Acid $\longrightarrow$ Aniline + CO_2

$$C_6H_4(NH_2)CO_2H \xrightarrow{k} C_6H_5NH_2 + CO_2$$

Titrimetric method; first-order k; t in hours; solvent, H_2O; Temp. = B. P. of the solution (351)

Solution	10^3k
2 g Anthranilic acid in 150 cm³ H_2O...............	27
3 g Anthranilic acid in 200 cm³ H_2O...............	30
2 g *p*-Aminobenzoic acid* in 200 cm³ H_2O...........	15

* *m*-Aminobenzoic acid does not react.

d-Camphorcarboxylic acid $\longrightarrow$ Camphor + CO_2

First-order k; t in minutes (30, 69); reaction in aqueous solution; no catalytic effect by H^+ or OH^-

°C	78	88	98	Q_{10}
10^3k for the undissociated acid	0.214	0.669	2.12	3.14
10^3k for the anion of the acid			0.063	

In C_6H_6, A = 14 040	°C	68	78	88	98
	10^3k	0.305	0.958	2.91	8.48
	Q_{10}		3.14	3.04	2.91

At 98°C	In	$C_6H_5NH_2$	C_2H_5OH	C_6H_6
	10^3k	32.50	10.40	8.48

At 98°C	In	$C_6H_5OC_2H_5$	$(C_2H_5)_2O$	H_2O
	10^3k	7.36	3.02	2.12

In alcohol, esterification takes place also with a first-order $k = 0.0102$. Bases act as catalyzers; optically inactive bases act the same on the d- and the l-acids, but active bases act more powerfully on the d-acid (73, 75).

°C	Solvent	10^3k	
		d-	l-
80	Aniline	6.76	6.63
80	Acetophenone	1.14	1.15
90		3.57	3.55
70	Nitrobenzene	0.333	
70	Nicotine	4.88	4.34
70	20 cm³ Nitrobenzene + 1.02 cm³ Nicotine	3.02	2.79
70	10 cm³ Acetophenone + 1.00 cm³ Nicotine	2.77	2.33
75	10 cm³ Acetophenone + 1.65 g Quinidine	6.46	4.42

The dl-acid is made optically active by catalysis with an optically active base. The optical activity attains a maximum at the time,

$$t = \frac{1}{k_l + k_d} \log_e \frac{k_l}{k_d},$$

where k_l (resp. k_d), are the constants of the two isomers. For asymmetric synthesis, v. (74).

The catalytic action of bases in general can be interpreted in terms of two velocity constants, one for the free acid and one for its salt. For details, v. (77, 285).

Bromocamphorcarboxylic acid $\longrightarrow$ Bromocamphor + CO_2

First-order k; t in minutes (128, 128.5)

d- or l- acid in Acetophenone	°C	60	70	80
	10^3k	2.16	5.03	12.1
	Q_{10}		2.37	2.40

In ethyl benzoate as solvent the acid is polymerized (2x), and the decomposition is a second-order reaction. It is catalyzed by bases. Quinine catalyzes the l-acid; quinidine, the d-acid, more rapidly.

Dissociation of Carboxylic Acids with the Production of CO or HCO_2H

OXALIC ACID $\longrightarrow$ $CO + CO_2 + H_2O$

$$(CO_2H)_2 \longrightarrow CO + CO_2 + H_2O$$

First-order k; t in minutes; solvent, H_2SO_4 + various % H_2O. Even at 0°C the reaction is too rapid to be measured in H_2SO_4 containing 1% SO_3 (78, 338).

%H_2O	0.60	0.70	0.80	1.00	1.20	1.50	2.00	3.00
10^3k, 70°C	18.1	13.1	10.2	6.8	4.9	3.15	1.93	0.94
%H_2O	3.0	4.0	6.0	8.0	10.0	15.0	20.0	Q_{10}
10^3k, 98°C	23.7	14.6	6.9	4.0	2.22	0.73	0.294	3–4

FORMIC ACID $\longrightarrow$ $H_2O + CO$

$$HCO_2H \longrightarrow H_2O + CO$$

First-order k; t in minutes; solvent, 90% H_2SO_4 (365)

Reaction mixture; 0.610 g HCO_2H + v cm³ H_2SO_4				Reaction mixture: m grams HCO_2Na + v cm³ H_2SO_4				
v	°C	10^3k	Q_{10}	m	v	°C	10^3k	Q_{10}
25	18	3.09	4.17	0.483	40	18	3.49	3.61
40	18	2.85		0.807	25	18	3.47	
40	25	8.44		0.512	40	25	8.68	
25	25	8.90		0.738	25	25	8.95	

Measurements by Schierz; same units (434)

%H_2SO_4	98.9	97.6	94.5	91.8	89.2	85.0
$10^3k'$, 25°C	320.0	106.0	31.5	10.5	2.38	0.751
$10^3k'$, 15°C		32.6	9.9	3.29		
E		18 520	19 670	19 720		

In acetic anhydride as solvent the mixed anhydride CH_3CO_2OCH is formed. For details of the reaction with various catalyzers, v. (535). For application of this reaction to the determination of acetic acid in acetic anhydride, v. (434).

CHLORAL HYDRATE

$$CCl_3CH(OH)_2 + NaOH \longrightarrow CHCl_3 + HCO_2Na + H_2O$$

The equilibrium:

$$CCl_3CH(OH)_2 + OH^- \rightleftharpoons CCl_3CH(OH)O^- + H_2O \qquad (I)$$

is rapidly established in alkaline solution and is followed by the slower reaction:

$$CCl_3CH(OH)O^- \xrightarrow{k} CCl_3H + HCOO^- \qquad (II)$$

At low temperatures in strongly alkaline solutions the equilibrium (I) is displaced to the right and the net reaction is (II) with first-order k.

Titrimetric method; first-order k; t in minutes; reaction mixture: 1 liter, composed of a moles chloral hydrate and b equivalents of base, the titer being T, hence

$$k' = \frac{1}{t} \log_{10} \frac{b - T_\infty}{T - T_\infty} \cdot [OH^-] = b - a$$

Measurements at 0°C, with KOH and with a = 0.01 (164)

b	b − a	k'	$k'/(b - a)$
0.012	0.002	0.0062	3.10
0.014	0.004	0.0134	3.35
0.016	0.006	0.0204	3.40

For the first solution ($k' = 0.0062$) we have therefore

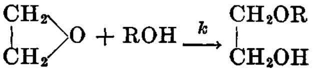
$$\frac{d[HCOO^-]}{dt} = 7.1[OH^-][CCl_3CH(OH)O^-] \text{ at } 0°C$$

Neutral salts catalyze the reaction as in the case of sugar inversion by acids.

With increasing temperature ($Q_{10} = 5$), hydrolysis of the chloral salt increases and the constant k' exhibits a progressive decrease; *cf*. (57, 412, 548).

Addition Reactions

ADDITION OF PHENOLS TO OLEFIN OXIDES IN 98% ALCOHOL



$$\begin{matrix} CH_2 \\ | \\ CH_2 \end{matrix}\!\!>O + ROH \xrightarrow{k} \begin{matrix} CH_2OR \\ | \\ CH_2OH \end{matrix}$$

With pure phenol the reaction proceeds slowly, catalyzed by the phenolate (59, 60):

$$\begin{array}{ll} (CH_2)_2O + RO^- \longrightarrow CH_2(OR)CH_2O^- & \text{(measurable)} \\ CH_2(OR)CH_2O^- + ROH \longrightarrow & \\ \quad CH_2(OR)CH_2(OH) + RO^- & \text{(rapid)} \\ \hline (CH_2)_2O + ROH \longrightarrow CH_2(OR)CH_2(OH) & \text{(net reaction)} \end{array}$$

At *constant* concentration of phenol, k for olefin oxides is of first-order. Gravimetric method; t in hours; [ROH] = 1; [RONa] = 0.05; θ = 70.4°C (59, 60). (I) k' for ethylene oxide = $0.4343k$; (II) k' for propylene oxide = $0.4343k$.

Phenol	(I)	(II)
Mesitol	0.375	
ψ-Cumenol	0.338	0.125
Thymol	0.311	0.107
o-4-Xylenol	0.305	
m-6-Xylenol	0.301	
m-Dimethylaminophenol		0.105
p-Cresol	0.279	0.101
Carvacrol	0.257	0.101
m-Cresol	0.256	0.083
2, 5-Dimethylphenol	0.244	0.092
Eugenol	0.226	0.080
o-Cresol	0.225	0.078
Phenol	0.205	0.075
α-Naphthol	0.173	0.083
Guaiacol	0.171	0.064
β-Naphthol	0.144	0.053
p-Chlorophenol	0.108	0.042
o-Chlorophenol	0.104	0.050
m-Chlorophenol	0.101	0.043
2, 4, 6-Tribromophenol	0.099	0.065
2, 4, 6-Trichlorophenol	0.075	0.045
p-Benzeneazophenol	0.050	0.023
m-Hydroxybenzonitrile	0.044	0.0224
Salicylic nitrile	0.033	0.0193
m-Nitrophenol	0.032	0.0152
p-Hydroxybenzonitrile	0.026	0.0150
p-Nitrophenol	0.013	0.0075
o-Nitrophenol	0.0073	0.0035

REVERSIBLE ADDITION OF PCl_3 TO BENZALDEHYDE (125)

$$\underset{(a - x)}{PCl_3} + \underset{(b - x)}{C_6H_5CHO} \underset{k_2}{\overset{k_1}{\rightleftharpoons}} \underset{x}{C_6H_5CHO.PCl_3}$$

$$\frac{dx}{dt} = k_1(a - x)(b - x) - k_2x$$

$$k_1 = \frac{K}{t\sqrt{q}} \log_e \frac{2Kx + m - \sqrt{q}}{2Kx + m + \sqrt{q}} \times \frac{m + \sqrt{q}}{m - \sqrt{q}}$$

$$m = -(Ka + Kb + 1)$$

$$q = (Ka + Kb + 1)^2 - 4K^2ab$$

$$k_1 = k_2K$$

Concn. in M/l; t in hours; θ = 25°C; solvent: *nil* or benzene (125)

Benzene, cm³	a = mole PCl_3	b = mole C_6H_5CHO	10^3k_1	K
0	0.0573	0.0573	(0.56)	0.126
0	0.0573	0.1146	(4.60)	0.216
0	0.1146	0.0573	(0.71)	0.533
25	0.0226	0.0226	5.1	0.416
25	0.0226	0.0452	4.8	0.424
25	0.0452	0.0226	2.5	0.182
25	0.0452	0.0452	4.0	0.266

Average values in the benzene solution: $k_1 = 4 \times 10^{-3}$; $k_2 = 13.3 \times 10^{-3}$; $K = 0.3$.

POLYMERIZATION OF CYANAMIDE TO DICYANDIAMIDE BY AQUEOUS ALKALIES

$$2CNNH_2 \xrightarrow{k} (CNNH_2)_2$$

The velocity in 0.125N NaOH is a maximum (223, 224) which accords with the relation:

$$\frac{d[(CNNH_2)_2]}{dt} = k[CNNH^-][CNNH_2]$$

ADDITION OF BROMINE TO DOUBLE BONDS

$$CHCl{:}CHCl + Br_2 \xrightarrow{k} CHClBrCHClBr$$

First-order k if the concn. of olefin as solvent is constant; t in hours; θ = 25°C (249); *cf.* (31, 248).

Olefin	Formula	$k' = 0.4343k$
cis-Dichloroethylene	CHCl: CHCl	0.024
trans-Dichloroethylene	CHCl: CHCl	0.012
Tetrachloroethylene	$CCl_2{:}CCl_2$	0.077

ADDITION OF OLEFINS TO ORGANIC ACIDS TO FORM ESTERS

Acetic acid scarcely reacts with amylene. The equilibrium is toward the side of the dissociation product. In general, ester formation is more nearly complete the stronger the acid.

$$CH(CH_3){:}\,C(CH_3)_2 + CHCl_2CO_2H \rightleftharpoons CHCl_2CO_2C(CH_2CH_3)(CH_3)_2$$

$$CH(CH_3){:}\,C(CH_3)_2 + CCl_3CO_2H \rightleftharpoons CCl_3CO_2C(CH_2CH_3)(CH_3)_2$$

Reaction with Excess of Amylene

The reaction is of the third-order with respect to the acid and runs to completion at low temperatures:

$$\frac{1}{V}\frac{dx}{dt} = k\left(\frac{1 - x}{V}\right)^3$$

$$k' = \frac{1}{t - t_0}\left(\frac{1}{(1 - x)^2} - \frac{1}{(1 - x_0)^2}\right) = \frac{\text{constant}}{V^2}$$

Trichloroacetic Acid (382)

Titrimetric method; V = dilution per mole; t in minutes

Mole		V in cm³	°C	k'	$10^4k'V^2$
Acid	Amylene				
1	6.8	915	28.7	0.037	3.10
1	15.75	1986	28.7	0.0079	3.12
1	4.124	595.6	31.2	0.127	4.50
1	7.663	1018	31.2	0.041	4.25

$Q_{10} = 3.93$

The acid which combines acts therefore simultaneously as a catalyst according to its second power.

Equilibrium Reaction

$$\underset{(a - x)}{\text{Amylene}} + \underset{(b - x)}{\text{Acid}} \underset{k_1}{\overset{k}{\rightleftharpoons}} \underset{x}{\text{Amyl Ester}}$$

Both reactions are catalyzed by the acid according to the second power, hence

$$\frac{1}{V}\frac{dx}{dt} = \frac{k}{V^4}(a - x)(b - x)^3 - \frac{k'}{V^3}[x(b - x)^2]$$

Integration for b = 1 gives approximately

$$C = \frac{k(1 - \xi_1)^2\xi_2^2}{V^3(\xi_1 + \xi_2)} = \frac{1}{t}\left[\log_e \frac{\xi_1(1 - x)}{\xi_1 - x} - (1 - \xi_1)\left(1 + \frac{1 - \xi_1}{\xi_1 + \xi_2}\right)\left(\frac{1}{1 - x} - 1\right)\right]$$

where

$$\xi_1 = x \text{ for } t = \infty$$

$$\xi_2 = \frac{a}{\xi_1} \text{ for } t \text{ in minutes.}$$

Dichloroacetic Acid and Amylene at 100°C (382)

Mole		ξ_1	ξ_2	C, average
Acid	Amylene			
1	5.9	0.650	9.035	0.00234
1	8.03	0.682	11.77	0.00139
1	8.03	0.682	11.77	0.00138
Trichloroacetic Acid and Amylene at 100°C				
1	9.51	0.86	11.06	0.0087

The formation of *isomeric* esters does not affect the calculation.

FORMATION OF AMMONIUM SALTS FROM ALKYL HALIDES AND AMINES

$$RX + NR'R''R''' \xrightarrow{k} NRR'R''R'''X$$

Second-order reaction: titrimetric method; units: minutes and M/l.

Addition of Amines to Ethyl Bromoacetate in Absolute Alcohol Soln. at 0°C (115); *cf.* (114)

$$NR\,(CH_3)_2 + CH_2BrCO_2C_2H_5 \xrightarrow{k} BrNR(CH_3)_2CH_2CO_2C_2H_5$$

n / Base	Values of 10^3k 2	3	4	5	6	7
$C_2H_5(CH_3)_nN(CH_3)_2$	11.4	10.7	10.3	11.2	10.9	
$(CH_3)_2CH(CH_2)_nN(CH_3)_2$	9.7	9.9	10.6	10.6		
$(CH_3)_2N(CH_2)_nN(CH_3)_2$	9.5	16.8	24.9	20.8	24.5	27.5
$CH_3O(CH_2)_nN(CH_3)_2$	6.7	9.3	10.6	10.5	11.5	

Addition of Aniline to ω-Bromoacetophenone in Various Solvents at Various Temperatures (127); *cf.* (126)

$$C_6H_5NH_2 + BrCH_2COC_6H_5 \xrightarrow{k} BrNH_2(C_6H_5)(CH_2COC_6H_5)$$

Solvent	10^2k, 27.8°	Q_{10}	10^2k, 37.8°	Q_{10}	10^2k, 47.8°	E*
Ethyl ether	0.0607					
Benzene	0.0644	1.53	0.0985	1.52	0.150	8 088
Chloroform	0.0970	1.92	0.186	1.61	0.299	10 760
Nitrobenzene	0.617	2.19	1.35	1.87	2.52	13 470
Acetone	1.39	1.93	2.69	1.64	4.40	11 080
Benzyl alcohol	2.08	2.12	4.40	2.10	9.24	14 290
n-Butyl alcohol	2.67	2.06	5.50	2.10	11.6	14 060
Ethyl alcohol	2.90	2.16	6.26	1.98	12.4	13 910
Methyl alcohol	3.89	1.92	7.48	1.91	14.3	12 440

* Computed on the basis of R = 1.985.

Addition of Pyridine to Allyl Bromide in Various Solvents at Various Temperatures (244)

$$C_5H_5N + CH_2{:}CHCH_2Br \longrightarrow CH_2{:}CHCH_2N(C_5H_5)Br$$

Solvent	10^3k, 28.3°	Q_{10}	10^3k, 38.3°	Q_{10}	10^3k, 56.5°	E
Toluene	0.231	2.25	0.517	1.97	1.86	15 100
Benzene	0.305	2.11	0.642	1.90	2.23	14 400
Ethyl alcohol	2.51	2.22	5.57	1.98	20.2	15 100
Acetone	5.05	2.02	10.2	1.82	33.8	13 600
p-Nitrotoluene	6.57	1.92	12.6	1.63	37.6	12 600
Acetophenone	10.4	1.95	20.3	1.42	52.6	12 100
Nitrobenzene	12.9	1.94	25.1	1.85	84.8	13 300

Mixed solvents; bimolecular k at 56.5°C

Mole Acetone	Toluene	k	Mole Acetophenone	Benzene	k
1	0	0.0338	1	0	0.0526
0.88	0.12	0.0244	0.68	0.32	0.0340
0.75	0.25	0.0177	0.43	0.57	0.0203
0.59	0.41	0.0124	0.19	0.81	0.00913
0.40	0.60	0.00945	0	1	0.00227
0.23	0.77	0.00687			
0	1	0.00193			

Addition of Primary and Secondary Amines to Aromatic Halides

$$\underset{(a\,-\,2x)}{2C_6H_5NH_2} + \underset{(b\,-\,x)}{C_6H_2Br(NO_2)_3} \xrightarrow{k} C_6H_5NHC_6H_2(NO_2)_3 + C_6H_5NH_3Br$$

The effect of the $C_6H_5NH_3Br$ formed upon the bromide is 100 times slower than that of the free aniline so that only the above reaction is significant.

Calculation of bimolecular k (416)

$$k = \frac{1}{2t} \times \frac{x}{b(b-x)} \text{ for } a = 2b$$

$$k = \frac{1}{(a-2b)t} \log_e \frac{b(a-2x)}{a(b-x)} \text{ for } a \sim 2b$$

Solvent: absolute alcohol; units: hours and M/l; θ = 50°C; values of 10^2k (416)

Halide	Amine $C_6H_5NH_2$	$C_6H_5NHCH_3$
C_6H_3Cl (1) $(NO_2)_2$ (2, 4)	0.275	0.0295
C_6H_3Br (1) $(NO_2)_2$ (2, 4)	0.421*	0.0869
C_6H_3I (1) $(NO_2)_2$ (2, 4)	0.123	0.0212
C_6H_2Cl (1) $(NO_2)_3$ (2, 4, 6)	1.90	0.0493
C_6H_2Br (1) $(NO_2)_3$ (2, 4, 6)	3.31	0.269
C_6H_2I (1) $(NO_2)_3$ (2, 4, 6)	1.72	0.668

* Mean of 7 determinations with the following extremes:

a	b	10^2k
0.025	0.025	0.383
0.4	0.2	0.466

REVERSIBLE DECOMPOSITION AND FORMATION OF AMMONIUM AND SULFONIUM SALTS IN DIFFERENT SOLVENTS (229); *cf.* (230)

k_1 = first-order constant of decomposition.
k_2 = second-order constant of formation.
Titrimetric method; units: minutes and M/l; k_1' = 0.4343 k_1.

Reversible Decomposition of *p*-Bromophenyldimethylallylammonium Bromide

$$BrC_6H_4NBr(CH_3)_2C_3H_5 \underset{k_2}{\overset{k_1}{\leftrightarrows}} BrC_6H_4N(CH_3)_2 + C_3H_5Br$$

Solvent	$10^4k_1'$ 25°	35°	Q_{10}	10^4k_2 25°	35°	Q_{10}
Tetrachloroethane	0.78	3.8	4.8	17	29	1.7
Chloroform	0.27	1.42	5.3	5.5	10.2	1.9
Nitrobenzene	0.80					
Tetrabromoethane	1.6					
Acetone		5.0				

Reversible Decomposition of Triethylsulfonium Bromide

$$(C_2H_5)_3SBr \underset{k_2}{\overset{k_1}{\leftrightarrows}} (C_2H_5)_2S + C_2H_5Br$$

Measurement at 25°C; the constant of formation, k_2, is corrected for the velocity of decomposition

Solvent	$10^4k_1'$	10^4k_2
Acetone	0.42	0.023
Acetone + 3.46% H_2O	0.04	0.035
Acetone + 7.11% H_2O	0	0.058

Decomposition of $(C_2H_5)_3SBr$, values of $10^4k_1'$

Solvent	A′	18°C	30°C	40°C	50°C	60°C	70°C	80°C	86°C	88°C	90°C	92°C	98°C
Tetrachloroethane	6680	0.072	0.59	2.89	13.4	55	230						
Nitrobenzene	6240	0.109	0.78	3.52	14.5	55	180						
Nitromethane	5990							47.0	90.0			171.0	
Ethyl acetoacetate	6460				12.8	49	194						
Amyl alcohol	7260				0.218	1.03	4.6	17.3			66		179
Propyl alcohol	7380					0.399	1.77	7.10			27.0		74.0
Benzyl alcohol	7459							3.9			15.9		47.0
Acetic acid	6087							3.5		8.0			26.5
Ethyl alcohol													26.5
Tetrabromoethane				3.8									

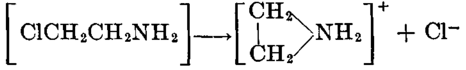
For the velocity of formation of $(C_2H_5)_3SI$, *v.* (106).

Coordination Reactions

By this is understood reactions of the type:

$$[Co(NH_3)_5Cl]^{++} + H_2O \longrightarrow [Co(NH_3)_5(H_2O)]^{+++} + Cl^-$$

and the analogous reaction of alkyl halogen amines in forming heterocyclic compounds:



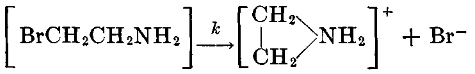
$$\left[ClCH_2CH_2NH_2\right] \longrightarrow \left[\begin{matrix}CH_2\\ |\\ CH_2\end{matrix}\!\!>NH_2\right]^+ + Cl^-$$

ALKYL HALOGEN AMINES (188, 189, 190, 192)

In alkaline media the first-order reaction runs to completion with the formation of a heterocyclic compound; in acid media the reverse reaction runs to completion; in neutral media the reaction reaches a measurable equilibrium but is accompanied by a side reaction.

Method: volumetric and coagulation of As_2S_3 sol; k, first-order; t in minutes.

Conversion of β-Bromoethylamine into Ethyleneimine in aqueous alkaline solution:

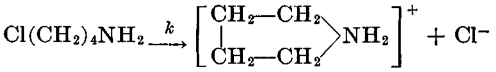


$$\left[BrCH_2CH_2NH_2\right] \xrightarrow{k} \left[\begin{matrix}CH_2\\ |\\ CH_2\end{matrix}\!\!>NH_2\right]^+ + Br^-$$

°C	0	16.65	25
10^2k	0.068	0.89	2.9

$$\log_e k = -\frac{12579}{T} + 38.770$$

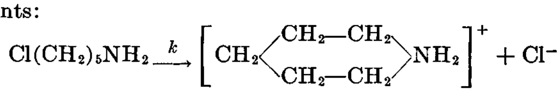
Conversion of δ-Chlorobutylamine into Pyrrolidine in aqueous alkaline solution:



$$Cl(CH_2)_4NH_2 \xrightarrow{k} \left[\begin{matrix}CH_2{-}CH_2\\ |\qquad\\ CH_2{-}CH_2\end{matrix}\!\!>NH_2\right]^+ + Cl^-$$

°C	0	25	Q_{10}
k	0.021	0.45	3.6

Conversion of ε-Chloroamylamine into Piperidine in various solvents:



$$Cl(CH_2)_5NH_2 \xrightarrow{k} \left[CH_2\!\!<\begin{matrix}CH_2{-}CH_2\\ CH_2{-}CH_2\end{matrix}\!\!>NH_2\right]^+ + Cl^-$$

The solvents immiscible with water were saturated with H_2O.

Solvent	10^2k, °C		
Aqueous alkali	0.029 (0°)	0.71 (25°)	2.98 (37°)
Ethyl alcohol, 91.2 Vol. %		0.10 (25°)	
Tetrachloroethane	0.019 (0°)	0.17 (24.8°)	0.45 (36.7°)
Nitrobenzene		0.13 (25°)	
Benzene		0.0049 (25°)	0.012 (36.1°)

$$\log_e k = -A/T + B$$

H_2O	Tetrachloroethane	Benzene
A = 10 440, B = 30.088	A = 7 231, B = 17.94	A = 7 575, B = 15.84

For the analogous reaction of $Br(CH_2)_5NH_2$ (resp. $I(CH_2)_5NH_2$) at 0°C in aqueous alkalies k = *ca.* 0.02 (resp. *ca.* 2).

KINETICS OF MONOMOLECULAR REACTIONS IN WATER

$$[Co(NH_3)_5X]^{++} + H_2O \xrightarrow{k} [Co(NH_3)_5(H_2O)]^{+++} + X^- \quad (1)$$

$$[Cr(NH_3)_5X]^{++} + H_2O \xrightarrow{k} [Cr(NH_3)_5(H_2O)]^{+++} + X^- \quad (2)$$

$$cis[Cr\,en_2Cl_2]^+ + 4H_2O \xrightarrow{k} cis[Cr\,en_2(O_2H_4)_2]^{+++} + 2Cl^- \quad (3)$$

en = $NH_2(CH_2)_2NH_2$.

$$[Cr(CNS)_6]^{---} + H_2O \xrightarrow{k} [Cr(CNS)_5(H_2O)]^{--} + CNS^- \quad (4)$$

First-order k; t in minutes

Reaction	X	k	°C	Lit.	Method
1	Cl	0.000132	25	(329)	(*a*)
1	Br	0.00039	25		
1	NO_3	0.00175	25		
2	Cl	0.00058	25	(188)	(*b*)
2	Br	0.003	25		
2	Cl	0.00002	0		
2	Br	0.00010	0		
2	I	0.01	0		
3		0.0032	25	(191)	(*b*)
3		0.00013	0		
4		0.00050	17	(47)	(*c*)

Reaction 1.—X = Cl: $\log_e k = -\frac{11067}{T} + 31.330$; $Q_{10} = 4.2$.

Reaction 2.—X = Cl: $\log_e k = -\frac{10890}{T} + 29.093$; $Q_{10} = 4.2$.

Reaction 3.— $\log_e k = -\frac{10430}{T} + 29.264$; $Q_{10} = 3.6$.

Methods: (*a*) = conductivity; (*b*) = coagulation; (*c*) colorimetric.

REVERSIBLE COORDINATION REACTIONS

$$[Cr(H_2O)_5(CNS)]^{++} + H_2O \underset{k_2}{\overset{k_1}{\rightleftarrows}} [Cr(H_2O)_6]^{+++} + CNS^-$$

$$\frac{dCNS^-}{dt} = k_1[Cr(H_2O)_5(CNS)]^{++} - k_2[CNS^-][Cr(H_2O)_6]^{+++}$$

Colorimetric method; units: minutes and M/l; solvent, H_2O (47)

	25°C	50°C
k_1	0.0000054	0.00040
k_2	0.0018	0.13

$$[Ir(NH_3)_5X]^{++} + H_2O \underset{k_2}{\overset{k_1}{\rightleftarrows}} [Ir(NH_3)_5(H_2O)]^{+++} + X^-$$

$$\frac{d[X^-]}{dt} = k_1[Ir(NH_3)_5X]^{++} - k_2[X^-][Ir(NH_3)_5(H_2O)]^{+++}$$

Conductivity method; units: hours and M/l; aqueous medium (327)

X	95°C		80°C	
	k_1	k_2	k_1	k_2
Cl..........	0.00231	0.118	0.0028	0.0151
Br..........	0.0081	0.076		
I............	0.0081	0.054		
NO_3.........	1.564	0.0475		

Coordination Reactions in Stages

The complete conversion of green dichlorotetraaquochromic chloride $[CrCl_2(H_2O)_4]Cl$ into blue hexaaquochromic chloride $[Cr(H_2O)_6]Cl_3$ takes place in dilute aqueous solution:

$$[CrCl_2(H_2O)_4]^+ \xrightarrow{k_1} [CrCl(H_2O)_5]^{++} \xrightarrow{k_2} [Cr(H_2O)_6]^{+++}$$

k_1 and k_2 are first-order constants.

Conductivity method; t in minutes; $\theta = 0°C$ (46, 328). s = Concn. of HCl added, M/l. a = Initial concn. of green dichlorochloride, M/l; k_1 refers to the beginning ($t = 0$) and k_2 to the end of the reaction.

10^3s	10^3a	k_1(obs.)	k_1(calc.)	k_2	Lit.
0	3.22	0.187		0.008	(46)
0	10.74	0.107		0.0035	
0.415	9.99	0.0362	0.0365	0.00465	
1.015	3.56	0.0180	0.0183	0.0031	
1.015	10.81	0.0182	0.0180	0.00231	
2.050	10.07	0.0104	0.0105	0.00131	
10.22	3.22	0.0042	0.0043	0.00031	
10.22	8.52	0.0044	0.0043	0.00032	
10.20	9.65	0.0044	0.0043	0.00032	
10.34	9.98	0.0044	0.0043	0.00032	
0	7.930	0.143	(0.133)		(328)
0	7.987	0.144	(0.134)		
0	7.948	0.131	(0.134)		
0.0824	8.072	0.098	0.0967		
0.2000	7.978	0.066	0.0644		
0.844	8.045	0.0204	0.0211	0.0038	
0.878	8.033	0.0205	0.0205	0.0038	
0.999	8.016	0.0179	0.0187	0.0033	
1.005	7.935	0.0179	0.0185		
1.005	7.815	0.0186	0.0185		
1.005	7.950	0.0190	0.0185		
4.196	8.133	0.0064	0.00642	0.00080	
8.000	7.933	0.0047	0.00463	0.00050	
9.815	8.050	0.0042	0.00419	0.00032	
10.09	7.565	0.0042	0.00418		

Neutral salts have no significant influence. The influence of temperature is great. For k_1, $Q_{10} = 4.80$ between 1 and 25°, = 3.80 between 20 and 25°; for k_2, $Q_{10} = 4.00$ between 20 and 25° (46).

At 25°C, k_1 and k_2 are expressed by the equations:

$$k_1 = 0.00272 + \frac{0.0000162}{[H^+]} \quad (46)$$

$$k_1 = 0.00265 + \frac{0.0000142}{[H^+]} \quad (328)$$

$$k_2 = \frac{3.1 \times 10^{-6}}{[H^+]} + \frac{5 \times 10^{-10}}{[H^+]^2} \quad (46)$$

k_1 and k_2 are aggregates of the velocity of conversion of the separate forms in which the reacting salts may appear. The hydrolytic forms act more rapidly than the ions. The first-order constants of the following forms have the values indicated (46):

$$[CrCl_2(H_2O)_4]^+ = 0.00272$$
$$[CrCl_2(H_2O)_3(OH)] = 4.26$$
$$[CrCl(H_2O)_4(OH)]^+ = 0.36$$

According to Lamb and Fonda (328) the hydrolysis constants are:

$$[CrCl_2(H_2O)_3(OH)][H^+] = 2.05 \times 10^{-6}[CrCl_2(H_2O)_4]^+$$
$$[Cr(H_2O)_5(OH)]^{++}[H^+] = 1.6 \times 10^{-4}[Cr(H_2O)_6]^{+++}$$

The large temperature coefficients of k_1 and k_2 are caused by the great increase of hydrolysis with increasing temperature. The reaction: green chromic salt ⟶ blue chromic salt is an example of the negative catalysis of hydrogen ion. For other work on negative catalysis, *see* (45, 514, 563).

Rearrangement of Dyestuffs and Indicators

Carbinol Form ⇄ Quinoid Form

Colorimetric method; t in minutes; aqueous solution with 7% alcohol; first-order $k' = 0.0434\ k$ (43); *cf.* (15, 38, 197, 236, 237, 374, 433).

Crystal violet: carbinol ⟶ quinone; $Q_{10} = 2.75$

HCl, N	k', 25°C	k', 30°C	k', 35°C	k', 40°C
0.0026	0.1001	0.1688	0.2751	
0.0051	0.0249	0.0412	0.0726	0.1209
0.0068	0.0160	0.0261	0.0440	0.0730
0.0151	0.0096	0.0153	0.0255	0.0430
0.0234	0.0090	0.0150	0.0243	0.0399

Crystal violet: quinone ⟶ carbinol: $Q_{10} = 2.04$

KOH, N	k', 25°C	k', 30°C	k', 35°C	k', 40°C
0.0033	0.0189	0.0263	0.0377	0.0535
0.0050	0.0290	0.0399	0.0570	0.0828
0.0083	0.0474	0.0651	0.0931	0.1334

Crystal violet: carbinol ⟶ quinone, at 25°C

HCl, N......	0.0432	0.0234	0.0151	0.0068	0.0051	0.0026
k'...........	0.01170	0.00899*	0.00969	0.01628	0.02482	0.10009

* Minimum at *ca.* 0.0234N HCl.

Malachite green at 25°C

HCl, N.......	0.065	0.023	0.015	0.007*	0.005	0.003
k'............	0.1224	0.1092	0.0645	0.0480	0.0559	0.0628

* Minimum at *ca.* 0.007N HCl.

Phenolphthalein at 25°C

KOH, N.................	0.11	0.15	0.22	0.33
k'......................	0.0280	0.0420	0.0707	0.1048

The velocity of decolorization of triphenylmethane dyes increases with the concentration of alkali; with basic dyes it is proportional to the $[OH^-]$; with acid dyes (*e.g.*, phenolphthalein) it increases with increasing $[OH^-]$ more rapidly than with the basic.

Retardation by neutral salts
Crystal violet in 0.013N KOH

Salt, N.............	0	0.1	0.2	0.3	0.4	0.5
k' (KNO_3)..........	0.0712	0.0520	0.0411	0.0350	0.0309	0.0259
k' (KCl)............	0.0712	0.0540	0.0440	0.0380	0.0328	0.0290

Crystal violet in 0.004N HCl

Salt, N..................	0.004	0.092	0.183	0.362
k' (KCl).................	0.0337	0.0163	0.0125	0.0105
k' (NaCl)................	0.0334	0.0186	0.0133	0.0105

Phenolphthalein in 0.31N KOH

NaCl, N......	0	0.116	0.194	0.388	0.966	1.940
k'...........	0.1048	0.1204	0.1306	0.1451	0.1555	0.1625

Reactions of Sugars

Inversion of Cane Sugar

Sucrose + H_2O ⟶ Dextrose + Levulose

Earlier investigations showed that the reaction with respect to sucrose is of the first order and that its velocity is proportional to $[H^+]$ (23, 119, 396, 497).

Polarimetric method: t in hours; concn. in M/l; $\theta = 27°C$; catalyst, 57.50 g HCO_2H/l (428, 429).

$$\frac{dx}{dt} = kW(S - x) \text{ where } W = [H_2O] \text{ and } S = [C_{12}H_{22}O_{11}]$$

g $C_{12}H_{22}O_{11}$/l	g H_2O/l	W	$10^4k'$W	$10^4k'$(obs.)	$10^4k'$(calc.)
400	705.4	39.15	58.1	1.484	1.485
300	768.52	42.65	57.0	1.337	1.335
200	829.60	46.04	54.4	1.182	1.203
160	855.52	47.48	54.8	1.156	1.152
140	887.60	48.15	53.8	1.117	1.128
100	892.82	49.54	53.9	1.088	1.081
60	916.86	50.88	53.1	1.044	1.039

k' (calc.) from $k' = 0.000490e^{-0.03049}$W.

If C_1, C_2 . . . equal the concentration of the substances which determine the nature of the medium, and k_1, k_2 . . . equal the catalysis coefficients of these substances, the velocity coefficient, $k = k_0e^{k_1C_1+k_2C_2+k_3C_3+\cdots}$

Sugar inversion in $0.1N$ H_2SO_4; t in sec (284)

g $C_{12}H_{22}O_{11}$/l	MH_2O/l	10^6k				Q_{10}		
		20°C	30°C	40°C	50°C	30/20	40/30	50/40
100	51.95	4.43	18.3	67.3	229	4.13	3.68	3.40
200	48.45	4.79	19.7	73.7	255	4.11	3.74	3.46
300	44.99	5.21	21.2	80.4	281	4.07	3.79	3.49
400	41.62	5.54	22.9	88.0	308	4.13	3.84	3.50
500	38.09	5.95	24.5	95.3		4.12	3.89	
600	34.59	6.22	25.8	102.2		4.15	3.96	
700	30.94	6.29	26.6	109.2	394	4.23	4.11	3.64

For formulation in terms of activities, *see* (372). Definition of activities according to (335); *cf.* (90, 243, 401, 433). For sugar inversion with subsequent mutarotation of glucose and fructose, *see* (362).

Effect of Pressure

Polarimetric method; p in atm.; $\theta = 25°C$; catalyst, $\frac{1}{16}N$ HCl (121)

p	1	250	500	750	1000	1250	1500
$10^6k'$(obs.)	243	231	220	210	197.5	190	181
$10^6k'$(calc.)	(243)	233	222	212	202	191	(181)

k' (calc.) from $k' = a + bp$.

Sugar inversion in $0.5N$ HCl in aqueous alcohol with 10% $C_{12}H_{22}O_{11}$ (101).

First-order $k'_1 = 0.4343k_1$, and second-order $k'_2 = 0.4343k_2$, the latter calculated under the assumption that H_2O acts according to the first power of its concentration. Polarimetric method; t in minutes; $\theta = 25°C$.

Vol. % alcohol	0	16.7	25.0	40.0	50.0	60.0	75.0
$10^3k'_1$	2.19	2.13	2.04	1.92	1.76	1.85	2.08
$10^5k'_2$	4.27	4.91	5.19	6.07	6.67	8.77	16.03

For the use of sugar inversion to determine the hydrolysis of salts of weak bases, *see* (532, 533). For autocatalytic inversion by boric acid and its causes, *see* (55).

MUTAROTATION OR BIROTATION OF SUGARS

Mutarotation of Glucose in Aqueous Solution

$$\alpha\text{-Glucose} \underset{k_2}{\overset{k_1}{\rightleftarrows}} \beta\text{-Glucose}$$

$$k = k_1 + k_2 = \frac{1}{t}\log_e\frac{\xi}{\xi - x} = \frac{1}{t}\log_e\frac{\alpha_\infty}{\alpha_\infty - \alpha}$$

Polarimetric method; t in minutes; $\theta = 25°C$.

$$k = k_w + k_s[H^+] + k_a[OH^-]$$

k_w	k_s	k_a	Lit.
0.0221	0.594	22 450	(272, 273, 274, 275, 394)
0.0239	0.769	21 520	(323, 324)

For further references on mutarotation of sugars, *see* (29, 170, 172, 334, 362, 377, 400, 422, 521, 524).

Decomposition of Pine Shavings by Caustic Soda in Autoclave under Pressure of 6–9 atm. at 140–170°C (24)

The velocity of decomposition of the shavings (52 % cellulose, 48 % non-cellulose) is proportional to the concn. of NaOH and to those of the dissolved portions of cellulose and non-cellulose.

k_i = first-order constant for the non-cellulose; t in hours
k_c = first-order constant for the cellulose

°C	k_i	k_c	$k_i : k_c$
140	1.94	0.069	28
160	5.34	0.430	12.4
170	8.47	0.976	8.7
270			1*
A	9 004	16 120	

* The value, $k_i : k_c = 1$ for 270°C is extrapolated from A.

Ureide Formation of Sugars in Aqueous Solution

Polarimetric method: units: M/l and hours; $\theta = 25°C$; catalyst, N H_2SO_4 (435); *cf.* (526).

Glucose and Galactose

$$C_6H_{12}O_6 + CO(NH_2)_2 \underset{k_2}{\overset{k_1}{\rightleftarrows}} C_6H_{12}O_5NCONH_2 + H_2O$$

$$\frac{d[\text{Ureide}]}{dt} = k_1[\text{Sugar}]\,[\text{Urea}] - k_2[\text{Ureide}]$$

Sugar	k_1	k_2
Glucose	0.00260	0.00153
Galactose	0.02435	0.00645

Mannose

$$2C_6H_{12}O_6 + CO(NH_2)_2 \underset{k_2}{\overset{k_1}{\rightleftarrows}} (C_6H_{12}O_5N)_2CO + H_2O$$

Substance	Concentration		
	$t = 0$	$t = t$	$t = \infty$
Mannose	C_0	C	C_∞
Urea	C'_0	$C'_0 - \frac{1}{2}(C_0 - C)$	
Ureide	0	$\frac{1}{2}(C_0 - C)$	

$$\frac{-dC}{dt} = k_1C^2\left\{C'_0 - \frac{1}{2}(C_0 - C)\right\} - \frac{1}{2}k_2(C_0 - C)$$

$$\delta = \frac{1}{t}\left[\log_e\frac{(\beta - C_0)^2(\alpha + \gamma C + C^2)}{(\beta - C_0)^2(\alpha + \gamma C + C_0)^2} + \frac{2\beta + \gamma}{\sqrt{\alpha - \frac{1}{4}\gamma^2}}\right.$$
$$\left.\operatorname{arctg}\frac{(C - C_0)\sqrt{\alpha - \frac{1}{4}\gamma^2}}{(\alpha - \frac{1}{4}\gamma^2) + (C + \frac{1}{2}\gamma)(C_0 + \frac{1}{2}\gamma)}\right]$$

$$\delta = k_1(\alpha + \beta\gamma + \beta^2),\ \alpha - \beta\gamma = \frac{k_2}{k_1}$$

$$\gamma - \beta = 2C_0 - C_0,\ \alpha\beta = \frac{k_2}{k_1}C_0,\ \beta = C_\infty$$

C_0	C'_0	C_∞	k_1	k_2	Lit.
0.4386	0.5	0.2074	0.0368	0.00527	(435)
0.4386	0.2412	0.2977	0.0367	0.00788	(526)

Hydrolysis or Saponification of Esters, Ethers and Acid Anhydrides

$CH_3CO_2CH_3 + H_2O \longrightarrow CH_3CO_2H + CH_3OH$ IN AQUEOUS SOLUTION

Influence of the concentration of the catalyst, HCl, on first-order k (in minutes), titrimetric method (330)

HCl, N	10^3k		Q_{10}
	25°C	35°C	
0.1005	0.653	1.663	2.547
0.5024	3.510	8.836	2.520
0.8275	6.001	15.26	2.542
1.800	16.09	37.84	2.353
2.429	20.78	63.47	3.054

+ Cl_2. QQ. Uviol lamp. Bimolecular. TC.) (175) Varahalu, Ram and Rao, *194*, **1**: 107; 24. (Phototropy of Hg compounds.) (176) Volmar, *34*, **178**: 697; 24. (Calculations of effective λ.) (177) Volmer and Riggert, *7*, **100**: 502; 22. (Anthracene dissolved in hexane. Splitting off of an electron. QQ. Equation for RV.) (178) Warburg, *76*, **1918**: 1228. (KNO_3. UV. Quantum sensitivity. Criticism by Anderson, *1*, **46**: 797; 24. *cf.* Robinson, *1*, **46**: 1834; 24.) (179) Weigert, *8*, **24**: 55; 07. ($COCl_2 \rightleftharpoons CO + Cl_2$. UV. Equilibrium at high temperature.)

(180) Weigert, *8*, **24**: 243; 07. (Sensitizing gas reactions with Cl_2. UV.) (181) Weigert, *9*, **14**: 591; 08. ($2O_3[+Cl_2] \rightarrow 3O_2$. QQ. Glass filter. Equation for RV.) (182) Weigert, *7*, **63**: 458; 08. (Anthracene → dianthracene. Calculations from earlier researches.) (183) Weigert, *7*, **80**: 78; 12. *9*, **18**: 654; 12. ($2O_3 \rightarrow 3O_2$. UV. Kinetics.) (184) Weigert, *99*, **11**: 381; 12. (Efficiency factor of absorbed energy.) (185) Weigert, *Nernst Festschrift*, 464; 12. (O_2 retardation. Calculations by Winther, *7*, **108**: 271; 24.) (186) Weigert, *25*, **46**: 815; 13. ($O_3 + H_2$. UV. Kinetics.) (187) Weigert and Bohm, *7*, **90**: 189; 15. ($O_3 + H_2$. UV. RV in relation to *C*. TC. Spectral effect not additive.) (188) Weigert and Kellermann, *7*, **107**: 1; 23. *76*, **1922**: 315; *9*, **28**: 456; 22. ($H_2 + Cl_2$. Draper effect.) (189) Weigert and Kummerer, *25*, **46**: 1207, 1884; 13. *See also* Kummerer, *Diss.*, Berlin, 1914. (*o*-Nitrobenzaldehyde → *o*-nitrosobenzoic acid. $\lambda =$ 405 and 366. Constant velocity at total absorption. RV proportional to *I*. TC *ca.* 1.)

(190) Wigand, *7*, **65**: 442; 09. ($S\lambda \rightleftharpoons S\mu$. Arc lamp.) (191) Wigand, *7*, **77**: 423; 11. ($S\lambda \rightleftharpoons S\mu$. QQ. Glass filter. Solution and fusion.) (192) Wildermann, *7*, **42**: 257; 03. ($CO + Cl_2$. Acetylene lamp. Kinetics.) (193) Winther, *99*, **7**: 409; 09. **8**: 197, 237; 10. **9**: 205; 11. (Eder's solution. Catalysis. Color sensitivity. Mechanics.) (194) Winther, *99*, **8**: 135; 10. (Ferric oxalate. UV. Inversion.) (195) Winther, *99*, **11**: 60; 12. *9*, **18**: 138; 12. ($Hg^{++} + Fe^{++} \rightleftharpoons Hg^{+} + Fe^{+++}$. UV. Light accumulator.) (196) Winther, *137*, **2**: No. 1; 20. ($H_2O_2 + K_4Fe(CN)_6$. UV. Constant velocity.) (197) Winther, *137*, **2**: No. 2; 20. ($HI + O_2$. $\lambda = 436 - 313$. Autocatalysis.) (198) Winther and Oxholt-Howe, *99*, **13**: 89; 13. (Eder's solution, eosin. False equilibrium.) (199) Winther and Oxholt-Howe, *99*, **14**: 196; 14. (Organic Fe salts. $\lambda = 436 - 313$. Kinetics.)

(200) Wittwer, *8*, **94**: 597; 55. **97**: 304; 56. **106**: 266; 59. ($Cl_2 + H_2O$. Daylight. Monomolecular. Criticism by Bunsen and Roscoe, *8*, **96**: 373; 55.) (201) Wurmser, *34*, **171**: 820; 20. (CO_2 assimilation. Daylight. Color sensitivity.)

THE ABSORPTION SPECTRA OF DYES

WALTER C. HOLMES

ARRANGEMENT, SYMBOLS, UNITS AND CONVENTIONS

The following tables are designed to supplement the tables of spectroscopic data on technical synthetic dyes supplied by Formánek and Grandmougin in their "Untersuchung und Nachweis organischer Farbstoffe auf spektroskopischem Wege" and the review of the spectroscopy of natural coloring matters found in Kayser's "Handbuch der Spektroskopie."

The primary aim has been that of affording a ready means of ascertaining what data are available for any given coloring matter. With this end in view the selection of dyes has been made as comprehensive and the literature references as complete as possible. There have also been recorded numerous data on the spectral location of the maxima of absorption bands, under various conditions, in the ultra-violet, visible and infra-red, which will usually prove adequate to those interested in the identification of dyes or in the correlation of color and constitution. If a more complete qualitative or quantitative definition of the absorption is desired it may, in numerous instances, be obtained readily by consulting the references recorded.

Synthetic dyes have been arranged by classes in twelve tables and listed in the order of their constitutional formulae. Natural coloring matters have been listed in alphabetical sequence in Table 13. The dye formulae are followed by the scientific names of the coloring matters, supplemented, in some instances, by names of more common usage and by C. I. (Colour Index of the Society of Dyers and Colourists) numbers.

All absorption maxima in the ultra-violet and visible spectrum are recorded in terms of wave length in millimicrons. Italicized values refer to the principal bands and bracketed values to relatively insignificant bands. (The common bracketing of several values signifies multiple maxima in a single band.) The absorption data are followed by reference numbers to the source from which they were taken, together with further reference numbers to other literature on the dye in question which may prove of further interest. References followed by (q) contain data on the more definitely quantitative aspect of the absorption.

In instances in which various data of independent origin have been available the recorded values are those which have appeared the more reliable to the writer. The question of the dependence which may be placed upon the greater portion of the material presented is left to the discrimination of the reader. Since data

Les tables suivantes ont pour objet de compléter les tables des données spectroscopiques concernant les colorants synthétiques techniques présentées par Formánek et Grandmougin dans leur ouvrage "Untersuchung und Nachweis organischer Farbstoffe auf spektroskopischem Wege" et la revue de la spectroscopie des matières colorantes naturelles, qui se trouve dans l'ouvrage de Kayser "Handbuch der Spektroskopie."

L'objectif principal a été celui de procurer un moyen rapide de s'assurer quelles données sont disponibles pour une matière colorante donnée. À cette fin la sélection des colorants a été faite aussi étendue et les références bibliographiques aussi complètes que possible. Il a aussi été mentionné un très grand nombre de données sur la position spectrale des maxima des bandes d'absorption, pour des conditions variées, dans l'ultra-violet, le visible et l'infra-rouge, qui se révèleront ordinairement suffisantes pour ceux qui s'occupent de l'identification des colorants ou de la corrélation entre la couleur et la constitution. Si une définition qualitative ou quantitative plus complète de l'absorption est désirée, celle-ci pourra être obtenue promptement dans bien des cas en consultant les références mentionnées.

Les colorants synthétiques ont été arrangés par classes en douze tables et sont inscrits en listes suivant l'ordre de leurs formules de constitution. Les matières colorantes naturelles ont été disposées dans l'ordre alphabétique dans la Table 13.

Les formules des colorants sont suivies des noms scientifiques des matières colorantes, complétés dans certains cas par les noms d'un usage plus courant, et les nombres C. I. (Colour Index of the Society of Dyers and Colourists). Tous les maxima d'absorption dans les spectres ultra-violet et visible sont exprimés en millimicrons. Les valeurs en italique concernent les bandes principales, et les valeurs entre crochets ont rapport à des bandes relativement insignifiantes. (Plusieurs valeurs comprises entre deux crochets signifient des maxima multiples dans une seule bande.) Les données d'absorption sont suivies de nombres de référence indiquant la source dont elles proviennent; d'autres nombres de référence mentionnés à la suite se rapportent à d'autres sources bibliographiques relatives aux colorants en question qui peuvent présenter par surcroit un certain intérêt. Les références suivies de (q) signifient la disponibilité de données au point de vue plus défini de l'aspect quantitatif de l'absorption.

available for a given dye are meager and difficult to locate, in general, and since any information may be of service, it has not been considered advisable to exclude any material of definite character.

Die folgenden Tafeln bilden eine Ergänzung (1) zu den Tafeln spektroskopischer Werte technischer synthetischer Farbstoffe, die von Formánek und Grandmougin in ihrem Werke "Untersuchung und Nachweis organischer Farbstoffe auf spektroskopischem Wege" beigegeben sind. Sie ergänzen (2) die Zusammenstellung über die Spektroskopie natürlicher Farbstoffe, die Kayser in seinem "Handbuch der Spektroskopie" gegeben hat.

Das Hauptziel war, ein bequemes Mittel für die Feststellung zu schaffen, welche Werte für einen bestimmten färbenden Stoff zu Gebote stehen. Unter diesem Gesichtspunkte geschah die Auswahle der Farbstoffe so umfassend wie möglich und der Nachweis der Literatur möglichst vollständig. Dort wurden zahlreiche Angaben über die spektrale Lage der Maxima von Absorptionsbanden zusammengetragen und zwar für verschiedene Bedingungen: im sichtbaren, Ultraviolett und Infrarot. In der Regel werden sie sich als ausreichend erweisen für diejenigen Forscher, denen an der Identifizierung von Farbstoffen oder an der Beziehung von Farbe und Konstitution gelegen ist. Braucht man eine vollständigere qualitative oder quantitative Definition der Absorption, so ist sie in zahlreichen Fällen bequem zu erhalten, wenn man die gesammelten Literaturangaben einsieht.

Synthetische Farbstoffe sind nach Klassen in zwölf Tafeln angeordnet und in der Reihenfolge ihrer Konstitutionsformeln aufgeführt. Natürliche Farbstoffe sind in alphabetischer Folge in Tafel 13 gesammelt.

Den Formeln der Farbstoffe folgen die wissenschaftlichen Namen der färbenden Stoffe. Zur Ergänzung dienen in einigen Fällen mehr allgemein gebräuchliche Bezeichnungen und die C. I. Nummern (des "Colour Index of the Society of Dyers and Colourists"). Alle Absorptions-Maxima im Ultraviolett und in sichtbaren Spektren sind in Millimikron angegeben. Kursiv (in Schrägschrift) gesetzte Werte beziehen sich auf die Hauptbanden, eingeklammerte Werte beziehen sich auf verhältnismässig unbedeutende Banden. (Das Zusammenklammern verschiedener Werte bedeutet mehrere Maxima in einer einzelnen Bande.) Auf die Absorptionswerte folgen die Nummern-Angaben anderer Literaturstellen für die in Rede stehenden Farbstoffe, die von weiterem Interesse sein können. Angaben, die mit einem (q) versehen sind, kennzeichnen die Brauchbarkeit von Werten für die mehr quantitative Betrachtung der Absorption.

In Fällen, in denen verschiedene Werte aus von einander unabhängigen Quellen zur Verfügung standen, hat der Herausgeber die ihm zuverlässiger erscheinenden Werte aufgenommen. Die Frage der Verlässlichkeit, die für einen grossen Teil des Stoffes gestellt werden kann, ist der Entscheidung des Lesers überlassen. Im allgemeinen sind die für einen bestimmten Farbstoff verfügbaren Werte so dürftig und auch so schwierig festzustellen—während auch der geringste Nachweis schon von Nutzen sein kann—dass es nicht ratsam erschien, irgendwelche Unterlagen bestimmten Charakters fortzulassen.

Dans le cas où des données diverses d'origines différentes ont été disponibles, les valeurs mentionnées sont celles qui ont paru les plus dignes de confiance au rédacteur. La question de la confiance, qui peut être placée dans la plus grande portion de la matière présentée, est laissée à la discrimination du lecteur. Comme les données disponibles pour un colorant donné sont en général peu abondantes et difficiles à trouver et comme chaque information peut être utile, il a été considéré comme judicieux de n'exclure aucune matière présentant un caractère défini.

Le seguenti tabelle sono compilate come complemento delle tabelle di dati spettroscopici sulle sostanze coloranti sintetiche di uso industriale dati da Formánek e Grandmougin nella loro "Untersuchung und Nachweis organischer Farbstoffe auf spektroskopischem Wege" e sulle sostanze coloranti naturali contenute nel "Handbuch der Spektroskopie" di Kayser.

Il principale nostro scopo è stato quello di fornire un modo rapido per stabilire quali sono i dati dei quali si dispone per qualsiasi sostanza colorante. Tenendo presente questo fine si è tenuto conto del maggior numero possibile di sostanze coloranti, e si è riportato nel modo più completo la bibliografia. Abbiamo pure riportato un considerevole numero di dati sopra la posizione dei massimi nelle bande di assorbimento in diverse condizioni, nell'ultra-violetto, nel visibile e nell'infra-rosso, i quali dati potranno bastare per chi si interessa della identificazione dei coloranti o dei rapporti tra colore e costituzione. Se si vuole un quadro più completo, dal punto di vista qualitativo o quantitativo, dell'assorbimento, lo si può ottenere subito in molti casi consultando le citazioni riportate.

I coloranti sintetici sono stati disposti per classi in dodici tavole e ordinati in base alle loro formule di costituzione. Le sostanze coloranti naturali sono state messe in ordine alfabetico nella Tavola 13.

Le formule dei coloranti sono seguite dai nomi scientifici della sostanza colorante completati in alcuni casi con i nomi di uso più comune e con i numeri del C. I. (Colour Index of the Society of Dyers and Colourists). Tutti i massimi di assorbimento nell'ultravioletto e nello spettro visibile sono riportati in millimicron. I valori in italici si riferiscono alle principali bande e i valori fra parentesi alle bande relativamente insignificanti. (Le parentesi comuni che racchiudono vari valori significano massimi multipli in una stessa banda.) I dati degli assorbimenti sono seguiti da numeri che si riferiscono alla memoria dalle quali sono stati presi insieme con altri numeri di riferimento ad altra letteratura sul colorante in questione, che può essere di ulteriore interesse. Quando una citazione è seguita da (q) significa che si hanno a disposizione dati quantitativi sull'assorbimento.

Nei casi nei quali si sono potuti avere dati di origine indipendente, i valori riportati sono quelli che sono sembrati i più attendibili al compilatore. La questione della fiducia che si può avere nella maggior parte dei dati riprodotti è lasciata al criterio del lettore. Siccome i valori ottenibili per un dato colorante sono in genere rari e difficili a rintracciare e siccome qualsiasi informazione può essere utile, non abbiamo creduto opportuno di escludere nessun dato di carattere definito.

ABBREVIATIONS

AcO = CH_3COO^-
HOAc = CH_3COOH
AmOH = $C_5H_{11}OH$
B. A. A. = Boric acid—acetic anhydride
EtOH = C_2H_5OH
S. B. A. = Sulfuric—boric acid

TABLES

Table 1.—Monoazo Dyes

$C_{10}H_8N_4O_2$.—*o*-Nitrobenzeneazopyrrole: 639 in EtOH (76).

m-Nitrobenzeneazopyrrole: 560 in EtOH (76).

p-Nitrobenzeneazopyrrole: 600 in EtOH (76).

$C_{10}H_9N_3$.—Benzeneazopyrrole: 612 in EtOH (76).

$C_{11}H_{10}N_4O_2$.—*p*-Nitrobenzeneazo-*N*-methylpyrrole: 635 in EtOH (76).

$C_{12}H_6Br_4N_2O_2$.—Tetrabromo-*p*-azophenol: 476, 360 in EtOH (with both α- and β-isomers) (543).

$C_{12}H_6N_8O_{12}$.—Hexanitrohydrazobenzene: 314 in $CHCl_3$; 493 in MeOH; 337 with HCl; 500 with NaOEt (224).

$C_{12}H_7Br_2N_3O_3$.—*p*-Nitrobenzeneazo-*m*-dibromophenol: alkali salt, 555 in Me_2CO; 511 in EtOH; 493 in H_2O (643).

$C_{12}H_7Br_3N_2O$.—*sym.*-Tribromobenzeneazophenol: 430, 384 in alk. H_2O (468).

$C_{12}H_8BrN_3O_3$.—*p*-Nitrobenzeneazo-*p*-bromophenol: alkali salt, 550 in Me_2CO; 504 in EtOH; 498 in H_2O (643).

p-Nitrobenzeneazo-*o*-bromophenol: alkali salt, 559 in Me_2CO; 502 in EtOH; 480 in H_2O (643).

$C_{12}H_8ClN_3O_3$.—*p*-Nitrobenzeneazo-*m*-chlorophenol: alkali salt, 556 in Me_2CO; 501 in EtOH; 470 in H_2O (643).

$C_{12}H_8N_4O_4$.—*p*-Dinitroazobenzene: 494 in H_2O (463).

$C_{12}H_9BrN_2O$.—Benzeneazo-*o*-bromophenol: 436, 390 in alk. H_2O (468).

p-Bromobenzeneazophenol: 445, 395 in alk. H_2O (468); *cf.* (595).

$C_{12}H_9ClN_2O$.—Chlorobenzeneazophenol: data on *o*-, *m*- and *p*-isomers (596).

$C_{12}H_9ClN_4$.—Azobenzenediazonium chloride: 340 in EtOH (260).

$C_{12}H_9IN_2$.—*p*-Iodoazobenzene: 340 in EtOH (476, *294* with HCl) (260).

$C_{12}H_9N_3O_3$.—*o*-Nitrobenzeneazophenol: 362, 235 in EtOH; *437*, 240 in alk. H_2O (62); 356 in EtOH (465 with NaOEt) (31); 487, 440 in alk. H_2O (468); *cf.* (596q, 622).

m-Nitrobenzeneazophenol: 350 in EtOH (459 with NaOEt) (31); *358*, 245 in EtOH; *436*, 262 in alk. H_2O (62); 480 in alk. H_2O (471); *cf.* (596q, 622).

p-Nitrobenzeneazophenol; *380*, 257 in EtOH; *478*, 273, (237) in alk. H_2O (62); alkali salt, 556 in Me_2CO; 505 in EtOH; 475 in H_2O (643); *cf.* (31, 468, 501, 521, 595, 596q, 624).

$C_{12}H_9N_3O_4$.—*o*-Nitrobenzeneazoresorcinol: abs. in visible and ultra-violet in neutral and alk. solns. (622).

m-Nitrobenzeneazoresorcinol; abs. in visible and ultra-violet in neutral and alk. solns. (624).

p-Nitrobenzeneazocatechol: abs. in visible and ultra-violet for neutral and alk. solns. (622).

p-Nitrobenzeneazoresorcinol: alkali salt, 605 in Me_2CO; 570 in EtOH; 550 in H_2O (643); *cf.* (501, 624).

p-Nitrobenzeneazohydroquinol: abs. in visible and ultra-violet for neutral and alk. solns. (622).

$C_{12}H_9N_3O_5$.—*p*-Nitrobenzeneazopyrogallol: alkali salt, 528 in Me_2CO (643); *cf.* (623).

p-Nitrobenzeneazophloroglucinol: abs. in visible and ultra-violet for neutral and alk. solns. (623).

$C_{12}H_9N_3O_6S$.—*p*-Nitrobenzeneazosulfocarbolate: alkali salt, 575 in Me_2CO; 514 in EtOH (643); data given in (501) are incorrect.

$C_{12}H_{10}N_2$.—Azobenzene: 463, 312 in H_2O (suspension) (471); 444, (345), *317* in EtOH; *417*, 280 in concd. HCl (59); 440 in H_2SO_4; 589 in fuming acid (diacid salt) (310). In EtOH, 455, 313 (84); (third band at 229) (393). Similar abs. in $CHCl_3$ (210) and in vapor form (532); *cf.* (26, 29, 111, 185q, 201q, 214, 220q, 231q, 385, 413, 516, 534q, 618).

$C_{12}H_{10}N_2O$.—Azoxybenzene: 323 in EtOH and in vapor form (532). Metallic salts (225); *cf.* (533).

o-Hydroxyazobenzene: 441, 390 in alk. H_2O; 480 in acid H_2O (468).

m-Hydroxyazobenzene: 415, 380 in alk. H_2O (468).

p-Hydroxyazobenzene (benzeneazophenol): 340, 315 in H_2O; 433, 395 with alkali; 490, 463 with acid (468); *429*, 268 in alk. H_2O (62); 331 in HCl (618); 465, 248 in H_2SO_4 (210); 360 in EtOH (*456*, 320 with NaOEt); 348 in Et_2O (211); (470), *355*, 235 in EtOH (62). Abs. in 30 organic solvents (12q). Abs. of various derivs. (185q, 220q); *cf.* (26, 111, 225, 469, 471, 475, 544, 595, 596q, 613q, 624).

$C_{12}H_{10}N_2O_2$.—2, 2′-Dihydroxyazobenzene: 490 in alk. H_2O (471).

2, 4-Dihydroxyazobenzene (benzeneazoresorcinol): 483 in alk. H_2O (471); *488*, 450 in H_2SO_4 (196); 408 in EtOH (352); *cf.* (624).

3, 3′-Dihydroxyazobenzene: 500, 475 in alk. H_2O (471).

3, 4-Dihydroxyazobenzene (benzeneazocatechol): 480, 430 in alk. H_2O (468); *cf.* (622).

2, 5-Dihydroxyazobenzene (benzeneazoquinol): abs. of neutral and alk. solns. in visible and ultra-violet (622).

2, 4′-Dihydroxyazobenzene: 490 in alk. H_2O (471).

3, 4′-Dihydroxyazobenzene: 480 in alk. H_2O (471).

4, 4′-Dihydroxyazobenzene: 473 in alk. H_2O, 360 in EtOH (463 with NaOEt) (619).

$C_{12}H_{10}N_2O_3$.—2, 3, 4-Trihydroxyazobenzene: abs. in visible and ultra-violet in neutral and alk. solns. (623).

2, 4, 2′-Trihydroxyazobenzene: 540, 492 in alk. H_2O (471).

2, 4, 4′-Trihydroxyazobenzene: 528, 490 in alk. H_2O (471).

2, 4, 5-Trihydroxyazobenzene: 505, 440, 345 in alk. H_2O (471).

2, 4, 6-Trihydroxyazobenzene: 460, 410 in alk. H_2O (471); *490*, 405 in H_2SO_4 (196); *cf.* (623).

3, 4, 4′-Trihydroxyazobenzene: 470, 535 in H_2O with Na_2CO_3; 470, 440 with $NaHCO_3$ (471).

3, 4, 5-Trihydroxyazobenzene: 515, 495, 420 in alk. H_2O (471).

$C_{12}H_{10}N_2O_3S$.—Azobenzene-*p*-sulfonic acid: 432 in H_2O over pH range 1–12 (613q).

$C_{12}H_{10}N_2O_4$.—2, 2′, 4, 4′-Tetrahydroxyazobenzene: 575, 540, 462 in H_2O with $NaHCO_3$ (471).

2, 4, 3′, 4′-Tetrahydroxyazobenzene: 585 in alk. H_2O (471).

3, 3′, 4, 4′-Tetrahydroxyazobenzene: 680 in alk. H_2O (471).

$C_{12}H_{10}N_2O_4S$.—*m*-Sulfobenzeneazophenol: 460, 410 in alk. H_2O (471).

p-Sulfobenzeneazophenol: 440, 400 in alk. H_2O (471); *cf.* (595, 613).

Benzeneazosulfocarbolate: 455 in alk. H_2O (468).

$C_{12}H_{10}N_2O_5S$.—*p*-Sulfobenzeneazocatechol: 520 with NaOH; 485 with Na_2CO_3 (471).

p-Sulfobenzeneazoresorcinol (C. I. 148): Na salt, 430 in H_2O (271); *cf.* (231q, 420q, 525q).

$C_{12}H_{10}N_2O_6S$.—*p*-Sulfobenzeneazophloroglucinol: 490 in H_2SO_4 (196).

$C_{12}H_{10}N_4O_2$.—3′-Nitro-4-aminoazobenzene: 518, 490 in acid H_2O (471).

$C_{12}H_{11}N_3$.—*m*-Aminoazobenzene: 430 in H_2O (pH 1) (613); (495 in acid H_2O (471)).

p-Aminoazobenzene: 490 in acid H_2O (pH 1) (613); 420 in H_2SO_4 (diacid salt); 556 in fuming acid (triacid salt); *395*, 250 in EtOH (300 with HCl) (310). Abs. of vapor (532); *cf.* (26, 260, 385, 463, 468, 469, 619).

Diazoaminobenzene: 361, 235 in EtOH; abs. of vapor (532).

$C_{12}H_{11}N_3O$.—Aminoazoxybenzene: 527 in acid H_2O (468).

3-Hydroxy-4′-aminoazobenzene: 490, 470 in acid H_2O; 485, 430 in alk. H_2O (471).

p-Aminobenzeneazophenol: 385 in EtOH; *546*, 354 in dil. HCl; 467 in conc. HCl (diacid salt) (261).

$C_{12}H_{11}N_3O_2$.—2-Amino-3′, 4-dihydroxyazobenzene: 478 in alk. H_2O; 490, 460 in acid H_2O (471).

5-Amino-2, 4′-dihydroxyazobenzene: 460 in alk. soln. (473).

$C_{12}H_{11}N_3O_3S$.—4-Sulfo-4′-aminoazobenzene (Aniline Orange): 485 in acid H_2O (pH 1) (613q); 448, (280) in dil. NaOH; 496 in dil. HCl (216).

$C_{12}H_{12}N_2$.—Hydrazobenzene: 290, *245* in EtOH (413); 310 in $CHCl_3$ (534).

$C_{12}H_{12}N_4$.—*p*-Diaminoazobenzene: 499 in acid H_2O (463); 603 in very dil. HOAc (monacid salt); 497, 310 in EtOH + 3% HCl (diacid salt); 410 in H_2SO_4 (triacid salt) (261).

Benzeneazo-*m*-phenylenediamine (hydrochloride, C. I. 20): Infra-red abs. (296). Acid salts (497); *cf.* (231q).

$C_{13}H_9N_3O_4$.—*p*-Nitrobenzeneazosalicylaldehyde: alkali salt, 564 in Me_2CO; 500 in EtOH; 478 in H_2O (643).

p-Nitrobenzeneazo-*p*-hydroxybenzaldehyde: alkali salt, 547 in Me_2CO; 494 in EtOH; 470 in H_2O (643).

$C_{13}H_9N_3O_5$.—*p*-Nitrobenzeneazosalicylic acid (C. I. 40): 609 in alk. Me_2CO; 555 in alk. EtOH; 514 in alk. H_2O (643); *cf.* (501, 525q, 595).

p-Nitrobenzeneazo-*m*-hydroxybenzoic acid: alkali salt, 583 in Me_2CO; 508 in EtOH; 474 in H_2O (643).

p-Nitrobenzeneazo-*p*-hydroxybenzoic acid: alkali salt, 566 in Me_2CO; 505 in EtOH; 475 in H_2O (643).

$C_{13}H_{10}ClN_3O_2$.—*p*-Nitrobenzeneazo-2-chloro-5-hydroxytoluene: alkali salt, 580 in Me_2CO; 524 in EtOH; 505 in H_2O (643).

$C_{13}H_{10}N_2O$.—Benzoylazobenzene: 294 in EtOH (?) (434).

$C_{13}H_{10}N_2O_3$.—4-Hydroxy-2-carboxyazobenzene: 445, 395 in alk. H_2O (471).

4-Hydroxy-2′-carboxyazobenzene: 435, 385 in alk. H_2O (471).

$C_{13}H_{10}N_2O_3$.—4-Hydroxy-3-carboxyazobenzene: 452, 402 in alk. H_2O (471).

4-Hydroxy-3′-carboxyazobenzene: 438, 388 in alk. H_2O (471).

4-Hydroxy-4′-carboxyazobenzene: 452, 402 in alk. H_2O (471).

$C_{13}H_{10}N_2O_4$.—2, 4′-Dihydroxy-5-carboxyazobenzene: 475 in alk. soln. (473).

$C_{13}H_{10}N_4O_4$.—*p*-Nitrobenzeneazosalicylamide: alkali salt, 525 in Me_2CO; 480 in EtOH (643).

$C_{13}H_{11}N_3O_3$.—*o*-Nitrobenzeneazo-*o*-cresol: *380*, 238 in EtOH; *457*, 273 in alk. H_2O (62).

o-Nitrobenzeneazo-*m*-cresol: *375*, 240 in EtOH; *445*, 278 in alk. H_2O (62).

o-Nitrobenzeneazo-*p*-cresol: abs. in visible and ultra-violet in neutral and alk. solns. (621).

m-Nitrobenzeneazo-*m*-cresol: *375*, 257 in EtOH; *436*, 273 in alk. H_2O (62).

m-Nitrobenzeneazo-*o*-cresol: *370*, 255 in EtOH; *465*, 276 in alk. H_2O (62).

m-Nitrobenzeneazo-*p*-cresol: abs. in visible and ultra-violet in neutral and alk. solns. (621).

p-Nitrobenzeneazo-*o*-cresol: *391*, 273 in EtOH; *493*, 287 in alk. H_2O (62); alkali salt, 590 in Me_2CO; 530 in EtOH; 490 in H_2O (643); *cf.* (621).

p-Nitrobenzeneazo-*m*-cresol: *398*, 266 in EtOH; *486*, 286 in alk. H_2O (62); 585 in alk. Me_2CO; 520 in alk. EtOH (643); *cf.* (501, 621).

p-Nitrobenzeneazo-*p*-cresol: alkali salt, 590 in Me_2CO: 542 in EtOH; 499 in H_2O (643); *cf.* (94, 501).

$C_{13}H_{11}N_3O_4$.—*p*-Nitrobenzeneazoguaiacol: alkali salt, 600 in Me_2CO; 540 in EtOH; 510 in H_2O (643); *cf.* (501, 622).

p-Nitrobenzeneazosaligenin: alkali salt, 565 in Me_2CO; 509 in EtOH; 483 in H_2O (643); *cf.* (501).

p-Nitrobenzeneazoorcinol: 539 in alk. Me_2CO (643).

p-Nitrobenzeneazoresorcinol methyl ether; alkali salt, 574 in Me_2CO; 520 in EtOH; 493 in H_2O (643).

p-Nitrobenzeneazohydroquinol methyl ether: abs. in visible and ultra-violet in neutral and alk. solns. (622).

$C_{13}H_{11}N_3O_7S$.—*p*-Nitrobenzeneazothiocol: alkali salt, 555 in Me_2CO; 536 in EtOH; 510 in H_2O (643); *cf.* (501).

$C_{13}H_{12}N_2O$.—Benzeneazo-*o*-cresol: (470), *358*, 238 in EtOH; *450*, 273 in alk. H_2O (62); *cf.* (621).

Benzeneazo-*m*-cresol: 352 in EtOH (431 with NaOEt); 481, 328 in HCl (618); (450), *358*, 238 in EtOH; *412*, 270 in alk. H_2O (62); *cf.* (621).

Benzeneazo-*p*-cresol: 316 in EtOH (488, 330 with NaOEt); 492, 406 in HCl (618); *cf.* (624).

Tolueneazophenol: abs. of isomers in visible and ultra-violet in neutral and alk. solns. (621).; abs. of derivs. (220q).

$C_{13}H_{12}N_2O_2$.—Benzeneazoguaiacol: 460 in alk. H_2O (468).

o-Tolueneazoresorcinol: 435 in EtOH (352); *cf.* (621).

m-Tolueneazoresorcinol: abs. in visible and ultra-violet in neutral and alk. solns. (621).

p-Tolueneazoresorcinol: 427 in EtOH (352); *cf.* (621).

p-Methoxybenzeneazophenol: 360 in EtOH (619).

p-Azoxyanisole: 355 in EtOH (533).

$C_{13}H_{12}N_2O_4S$.—*p*-Sulfobenzeneazo-*o*-cresol: 463 in alk. H_2O (468).

p-Sulfobenzeneazo-*m*-cresol: 475 in alk. H_2O (468).

$C_{13}H_{12}N_2S$.—Benzeneazothioanisole: 365 in EtOH (160).

$C_{13}H_{12}N_4O_3$.—*p*-Nitrobenzeneazo-*o*-methylaminophenol: alkali salt, 635 in Me_2CO; 573 in EtOH; 550 in H_2O (643).

$C_{13}H_{13}N_3$.—Benzeneazo-*o*-toluidine: *505*, 308 in 2*N* HCl; 392 in EtOH (216).

$C_{13}H_{13}N_3O_3S$.—*p*-Sulfobenzeneazo-*o*-toluidine (*o*-Toluidine Orange): 491 in dil. HCl (613q); 414, (280) in dil. NaOH; 488, (319) in dil. HCl (216).

m-Sulfobenzeneazo-*m*-toluidine (*m*-Toluidine Orange): 483 in dil. acid (613q); 414, (280) in dil. NaOH; 501, (320) in dil. HCl (216).

4-Sulfo-4′-methylaminoazobenzene (Monomethyl Orange): 500 in acid soln. (pH 1); 454 in alk. soln. (pH 12) (613q); 453, (280) in dil. NaOH; 506 in dil. HCl (216).

$C_{13}H_{11}N_3O_5$.—*p*-Nitrobenzeneazovanillin: alkali salt, 572 in Me_2CO; 525 in EtOH; 509 in H_2O (643).

$C_{14}H_{11}N_3O_4$.—*p*-Nitrobenzeneazohomosalicylaldehyde: alkali salt, 595 in Me_2CO; 546 in EtOH; 525 in H_2O (643).

$C_{14}H_{11}N_3O_5$.—*p*-Nitrobenzeneazomethylsalicylate: alkali salt, 530 in Me_2CO; 485 in EtOH; 467 in H_2O (643).

p-Nitrobenzeneazo-*o*-cresotic acid: alkali salt, 535 in Me_2CO; 530 in EtOH; 512 in H_2O (643).

$C_{14}H_{11}N_3O_5$.—*p*-Nitrobenzeneazo-*m*-cresotic acid: alkali salt, 544 in Me_2CO; 525 in EtOH; 508 in H_2O (643).

p-Nitrobenzeneazo-*p*-cresotic acid: alkali salt, 579 in Me_2CO; 535 in EtOH; 515 in H_2O (643).

$C_{14}H_{12}N_2O_2$.—*p*-Acetylbenzeneazophenol: 370 in EtOH; 476 in NaOH soln. (258).

$C_{14}H_{13}N_3O$.—*p*-Acetylaminoazobenzene: 345 in EtOH (619); *cf.* (385).

$C_{14}H_{13}N_3O_2$.—*m*-Acetylamino-*o*-hydroxyazobenzene (385).

$C_{14}H_{13}N_3O_4$.—*p*-Nitrobenzeneazocreosol: alkali salt, 602 in Me_2CO; 545 in EtOH; 512 in H_2O (643).

$C_{14}H_{14}N_2O$.—Benzeneazophenetole: 340 in EtOH; *474*, 331 in HCl (618).

o-Tolueneazocresol: abs. of cresol isomers in visible and ultraviolet in neutral and alk. solns. (620).

m-Tolueneazocresol: abs. of cresol isomers in visible and ultraviolet in neutral and alk. solns. (620).

p-Tolueneazocresol: abs. of cresol isomers in visible and ultraviolet in neutral and alk. solns. (620). *p*-Cresol isomer: 327 in EtOH (481, 334 with NaOEt); *505*, 427 in HCl (618).

$C_{14}H_{14}N_2O_2$.—*o*, *o*′-Azoanisole: 490 in HOAc-HCl soln. (54q).

p, *p*′-Azoanisole: 500 in HOAc-HCl soln. (54q).

p-Ethoxybenzeneazophenol: 447, 390 in alk. H_2O (468).

$C_{14}H_{14}N_2O_4S$.—2, 6-Dimethyl-4-hydroxy-4′-sulfoazobenzene: influence of pH (613q).

$C_{14}H_{14}N_2S_2$.—*o*, *o*′-Azophenylmethylsulfide: 620 in HOAc-HCl soln. (54q).

p, *p*′-Azophenylmethylsulfide: 577 in HOAc-HCl soln. (54q).

$C_{14}H_{14}N_3O_3$.—*p*-Nitrobenzeneazo-2-hydroxy-1, 3-dimethylbenzene: alkali salt, 610 in Me_2CO; 558 in EtOH; 517 in H_2O (643).

p-Nitrobenzeneazo-2-hydroxy-1, 4-dimethylbenzene: alkali salt, 599 in Me_2CO; 544 in EtOH; 510 in H_2O (643).

p-Nitrobenzeneazo-4-hydroxy-1, 2-dimethylbenzene: alkali salt, 600 in Me_2CO; 540 in EtOH; 510 in H_2O (643).

p-Nitrobenzeneazo-4-hydroxy-1, 3-dimethylbenzene: alkali salt, 605 in Me_2CO; 553 in EtOH; 513 in H_2O (643).

$C_{14}H_{14}N_4O_2$.—*m*-Nitrobenzeneazodimethylaniline: 467 in EtOH (31).

p-Nitrobenzeneazodimethylaniline: 483, 277 in EtOH (31).

$C_{14}H_{14}N_4O_3$.—*p*-Nitrobenzeneazo-*m*-dimethylaminophenol: alkali salt, 596 in Me_2CO; 564 in EtOH; 530 in H_2O (643).

$C_{14}H_{15}N_3$.—*p*-Dimethylaminoazobenzene (C. I. 19): 508 in acid soln. (pH 1); 450 in alk. soln. (pH 13) (613q); 545, 507 in 3% HCl; 420 in H_2SO_4 (diacid salt); 607 in fuming acid (triacid salt); 410 in EtOH; 550, 511, 300 in EtOH + 3% HCl (310); 405, 375 in H_2O; 490, 460 with alkali; 543, 508 with acid (469); *cf.* (26, 111, 210, 214, 218, 423q, 468, 475, 619).

$C_{14}H_{15}N_3O$.—*p*-Dimethylaminobenzeneazophenol: 413 in EtOH; *550*, 341 in dil. HCl; *477*, 314 in HCl (diacid salt) (261).

p-Dimethylaminoazoxybenzene: 545 in acid H_2O (471).

2-Dimethylamino-4-hydroxyazobenzene: 486, 463 in alk. H_2O (471).

4-Dimethylamino-2-hydroxyazobenzene: 492, 463 in alk. H_2O; 503, 473 in acid H_2O (471).

$C_{14}H_{15}N_3O_3S$.—*p*-Sulfobenzeneazodimethylaniline (Na salt, C. I. 142, Methyl Orange): 506 in acid soln. (pH 1), 472 in alk. soln. (pH 13) (613q); 442 in EtOH; *481*, 281 in H_2O; *465*, 280 in *N* NaOH; 508, (333), 283 in dil. HCl (469); *cf.* (208, 231, 269, 473, 525, 583q, 612, 647).

m-Sulfobenzeneazodimethylaniline: 535, 490 in acid H_2O (471).

o-Sulfobenzeneazodimethylaniline: 510 in acid soln. (pH 1); 435 in alk. soln. (pH 13); 516 in 6*N* HCl (613q).

p-Sulfobenzeneazoethylaniline: 498 in acid soln. (pH 1); 442 in alk. soln. (pH 12) (613q); 493 in dil. HCl; 453, (280) in dil. NaOH (216).

2, 5-Dimethyl-4-amino-4′-sulfoazobenzene: 490 in acid H_2O (613q).

3, 5-Dimethyl-4-amino-4′-sulfoazobenzene: 500 in acid H_2O (613q).

$C_{14}H_{16}N_2O_2$.—Benzeneazodimethyldihydroresorcinol: 394, 246 in EtOH (472, *349*, 283 with NaOEt) (380).

$C_{14}H_{16}N_4$.—Anilineazodimethylaniline: *513*, 306, 256 in EtOH with 0.1*N* HCl (214); *cf.* (473).

$C_{15}H_{10}N_2O_3$.—Benzeneazocarbonylcoumaranone: *417*, 250 in EtOH (*368*, 286 with NaOEt) (abs. of acetyl deriv. also described) (434).

$C_{15}H_{11}N_3O$.—Quinolineazophenol: 380 in EtOH (159).

5-Benzeneazo-8-hydroxyquinoline: 376 in EtOH; 518, 256 in HCl (159).

$C_{15}H_{12}N_4O$.—5-*p*-Aminobenzeneazo-8-hydroxyquinoline: 412 in EtOH (159).

$C_{15}H_{13}N_3O_5$.—*p*-Nitrobenzeneazoethylsalicylate: alkali salt, 531 in Me_2CO; 490 in EtOH; 465 in H_2O (643).

$C_{15}H_{15}N_3O_2$.—2-Carboxy-4-dimethylaminoazobenzene: 549, 503 (471).

3-Carboxy-4-dimethylaminoazobenzene: 531, 497 (471).

2′-Carboxy-4-dimethylaminoazobenzene (Methyl Red, C. I. 211): 517 in pH 1 soln.; 530 in pH 4.5 soln.; 447 in pH 13 soln. (613q); 530 in alk. soln. (58q) (double band, 548, 514 (469)); *cf.* (433, 471, 612q).

3′-Carboxy-4-dimethylaminoazobenzene: 538, 503 (471).

4′-Carboxy-4-dimethylaminoazobenzene: 512 in acid soln. (pH 1); 463 in alk. soln. (pH 13) (613q); 539, 495 (471).

$C_{15}H_{16}N_2O$.—Benzeneazo-*m*-cresetole: 348 in EtOH (*479*, 331 with NaOEt) (618).

Benzeneazo-*p*-cresetole: 313 in EtOH; 500, 410 in HCl (618).

$C_{15}H_{17}N_3$.—Benzeneazodimethyl-*o*-toluidine: 347 in EtOH; 493, 250 in 2*N* HCl (216).

$C_{15}H_{17}N_3O$.—2-Methoxy-4-dimethylaminoazobenzene: 575, 532 in acid H_2O (471).

4′-Methoxy-4-dimethylaminoazobenzene: 412 in EtOH; *510*, 351 in dil. HCl; *473*, 323 in HCl (diacid salt) (261); 549, 350, 200 in 0.1*N* HCl (214).

$C_{15}H_{17}N_3O_3S$.—*p*-Sulfobenzeneazodimethyl-*o*-toluidine: 374 in EtOH; 447, *311* in HCl (216).

$C_{15}H_{17}N_3O_4S$.—*m*-Methoxymethyl orange: 510, 480 (473).

$C_{15}H_{18}N_2O_2$.—Benzeneazodimethyldihydroresorcinol methyl ether: *379*, 244 in EtOH (380).

$C_{15}H_{18}ClN_3$.—Azobenzenetrimethylammonium chloride: 448, *312* (216).

$C_{15}H_{18}IN_3$.—Azobenzenetrimethylammonium iodide: 437, *314* in EtOH; 498, (314) in EtOH + 1% HCl; 428 in H_2SO_4; (500), 435 in HCl (26); *cf.* (210, 260).

$C_{16}H_{10}BrN_3O_3$.—4′-Nitrobenzeneazo-2-bromo-1-naphthol: 608 in alk. EtOH (473).

$C_{16}H_{11}BrN_2O$.—*p*-Bromobenzeneazo-*α*-naphthol: 470 in EtOH; K salt, 476 in EtOH (595).

$C_{16}H_{11}N_3O_3$.—*o*-Nitrobenzeneazo-*α*-naphthol: 476 in EtOH (540 with NaOEt) (31).

m-Nitrobenzeneazo-*β*-naphthol (*m*-Nitroaniline Orange, C. I. 38): 557.6, 524.1 in H_2SO_4 (190).

p-Nitrobenzeneazo-*α*-naphthol: alkali salt, 630 in Me_2CO; 590 in EtOH; 568 in H_2O (643); (602), 576, (552) in H_2O; (623), 598, (572) in EtOH (468); *cf.* (501).

p-Nitrobenzeneazo-*β*-naphthol (*p*-Nitroaniline Red, C. I. 44): 578.3, 541.3 in H_2SO_4 (352); alkali salt, 587 in Me_2CO; 555 in EtOH (643); *cf.* (501).

$C_{16}H_{12}N_2O$.—Benzeneazo-*α*-naphthol: 496 in alk. H_2O, (468); 469, 405 in EtOH (29); 490, 406, 275 in EtOH (352); 585 in H_2SO_4 (196); *cf.* (595).

$C_{16}H_{12}N_2O$.—Benzeneazo-β-naphthol (Sudan I, C. I. 24): 514, 311 in EtOH; 311 in H_2SO_4 (352); *563*, 517 in H_2SO_4 (196); *cf.* (423q, 619).

$C_{16}H_{12}N_2O_2$.—Benzeneazo-1, 5-dihydroxynaphthalene: 540 in alk. EtOH (174).

Benzeneazo-2, 7-dihydroxynaphthalene: *545*, 498 in H_2SO_4 (196).

p-Hydroxybenzeneazo-α-naphthol: 490 in alk. EtOH (174).

p-Hydroxybenzeneazo-β-naphthol: 610, *490* in alk. EtOH (174).

$C_{16}H_{12}N_2O_3$.—*p*-Hydroxybenzeneazo-1, 3-dihydroxynaphthalene: 490 in alk. EtOH (174).

p-Hydroxybenzeneazo-1, 5-dihydroxynaphthalene: 550 in alk. EtOH (174).

p-Tolueneazocarbonylcoumaranone: 431, 253 in EtOH (369, 288 with NaOEt) (434).

$C_{16}H_{12}N_2O_4S$.—Benzeneazo-α-naphthol-2-sulfonic acid: Na salt, (424q).

Benzeneazo-α-naphthol-4-sulfonic acid: *547*, 500 in H_2SO_4 (196).

Benzeneazo-β-naphthol-5-sulfonic acid: 525, 493 in H_2SO_4 (196).

Benzeneazo-β-naphthol-6-sulfonic acid: 526.5, *495* in H_2SO_4 (196); Na salt, *493*, 315 in H_2O (352).

Benzeneazo-β-naphthol-7-sulfonic acid: 534 in H_2SO_4 (196).

Benzeneazo-β-naphthol-8-sulfonic acid: 522, *495* in H_2SO_4 (196).

p-Sulfobenzeneazo-α-naphthol (Orange I, C. I. 150): *476*, 267, 232 in H_2O (179q); *cf.* (231q, 420q, 422q, 468, 519q, 595).

p-Sulfobenzeneazo-β-naphthol (Orange II, C. I. 151): 490 in H_2O (271); *cf.* (231q).

$C_{16}H_{12}N_2O_5S$.—*m*-Sulfo-*o*-hydroxybenzeneazo-β-naphthol (Na salt, C. I. 169), Pontachrome Violet S. W.: 548 in H_2O (concd.), 515 (dil.) (269).

$C_{16}H_{12}N_2O_7S_2$.—Benzeneazo-α-naphthol-4, 8-disulfonic acid: *557*, 500 in H_2SO_4 (196).

Benzeneazo-β-naphthol-3, 6-disulfonic acid (Na salt, Orange R, C. I. 28): 528, 496 in H_2SO_4 (196); *500*, 321 in H_2O (352); *cf.* (231q).

Benzeneazo-β-naphthol-6, 8-disulfonic acid (Na salt, Orange G, C. I. 27): 503, 487 in H_2SO_4 (196); *491*, 320 in H_2O (352); *cf.* (162, 271).

p-Sulfobenzeneazo-α-naphthol-2-sulfonic acid: Na salt (424q).

$C_{16}H_{12}N_2O_8S_2$.—Benzeneazo-1, 8-dihydroxynaphthalene-3, 6-disulfonic acid (Na salt, C. I. 29, Chromotrop 2R): 510 in H_2O (271).

$C_{16}H_{12}N_2O_8S_2$.—*p*-Hydroxybenzeneazo-α-naphthol-3, 6-disulfonic acid: 560, 494 (473).

$C_{16}H_{12}N_2O_9S_2$.—1-Hydroxy-3, 6-sulfonaphthaleneazoresorcinol: 491 in alk. soln.; 545, 491 in acid soln. (473).

$C_{16}H_{12}N_4O_2$.—2-(4′-Nitrobenzeneazomethylene)-1, 2-dihydroquinoline: 545 in EtOH; 527 in H_2SO_4; hydrochloride, 460 in EtOH; data given for isomeric phenylhydrazone (341).

$C_{16}H_{12}N_4O_9S_2$.—2-*p*-Nitrobenzeneazo-1-amino-8-naphthol-3, 6-disulfonic acid: 522 in 1% HCl; 556 in 1% NaOH; 584 in 10% NaOH; 535 in H_2O (60q).

$C_{16}H_{13}N_3$.—Benzeneazo-α-naphthylamine: 293 in H_2SO_4 (352).

Benzeneazo-β-naphthylamine (Oil Yellow A. B., C. I. 22): 585 in H_2SO_4 (196); 453, *322* in H_2SO_4; 474, 306 in EtOH (352); *cf.* (423q).

$C_{16}H_{13}N_3O$.—*p*-Hydroxybenzeneazo-β-naphthylamine: 565 in alk. EtOH (174).

$C_{16}H_{13}N_3O_3S$.—Benzeneazo-β-naphthylamine-5-sulfonic acid: 543, 498 in H_2SO_4 (196).

Benzeneazo-β-naphthylamine-6-sulfonic acid: *545*, 495 in H_2SO_4 (196).

Benzeneazo-β-naphthylamine-7-sulfonic acid: 545, 495 in H_2SO_4 (196).

$C_{16}H_{13}N_3O_4S$.—*o*-Aminosulfobenzeneazo-β-naphthol: 567.5, 537 (123).

m-Aminosulfobenzeneazo-β-naphthol: 556.3, 526 (123).

p-Aminosulfobenzeneazo-β-naphthol: 563, 533.3 (123).

$C_{16}H_{13}N_3O_6S$.—1-Amino-4-sulfo-2-naphtholazoresorcinol: 640, 590.5, 550 in alk. soln.; 583.5, 543, 513.5 in acid soln. (123).

1-Amino-6-sulfo-2-naphtholazoresorcinol: 560, 510, 472 in H_2O; 625, 582, 540 with NH_4OH (123).

1-Amino-7-sulfo-2-naphtholazoresorcinol: 566, 520, 481 in H_2O; 633, 588, 546 with NH_4OH (123).

1-Amino-8-sulfo-2-naphtholazoresorcinol: 547, 514 in H_2O; 610. 568, 530 with NH_4OH (123).

2-Amino-3-sulfo-1-naphtholazoresorcinol: 560, 483 in H_2O; 630. 541.5, 502.5 with NH_4OH (123).

2-Amino-4-sulfo-1-naphtholazoresorcinol: 561, 518, 478 in H_2O; 528 with NH_4OH (123).

2-Amino-5-sulfo-1-naphtholazoresorcinol: 574, 529, 476 in H_2O; 586, 541 with NH_4OH (123).

$C_{16}H_{13}N_3O_6S_2$.—Benzeneazo-β-naphthylamine-3, 6-disulfonic acid: 539, 495 in H_2SO_4 (196).

$C_{16}H_{13}N_3O_7S$.—2-Amino-4-sulfo-1, 8-dihydroxynaphthaleneazoresorcinol: 518 in alk. soln. (123).

$C_{16}H_{13}N_3O_7S_2$.—Benzeneazo-1, 8-aminonaphthol-3, 6-disulfonic acid: 541 in NaOH; 529, 494 in HCl; 545, 502 in HOAc (473); 495 in 10% NaOH; 530 in H_2O (60).

2, 4-Disulfo-1-aminobenzeneazo-β-naphthol: 507.5, *483* in H_2O; *560*, 528.5 in H_2SO_4; 505, *479.5* in EtOH (123).

2, 5-Disulfo-1-aminobenzeneazo-β-naphthol: 509.5, *478* in H_2O; *562*, 538 in H_2SO_4; 502, 479.5 in EtOH (123).

$C_{16}H_{13}N_3O_9S_2$.—1-Amino-3, 6-disulfo-2-naphtholazoresorcinol: 566.5, 526, 486.5 in H_2O; 635, 586.5, 550 with NH_4OH (123).

1-Amino-6, 8-disulfo-2-naphtholazoresorcinol: 543, 508.2 in H_2O; 611.5, 536, 497 with NH_4OH (123).

2-Amino-3, 6-disulfo-1-naphtholazoresorcinol: 569, 537.5, 502 in H_2O; 635, 582.5 with NH_4OH (123).

2-Amino-3, 8-disulfo-1-naphtholazoresorcinol: 564, 480.5 in H_2O; 637.5, 588 with NH_4OH (123).

2-Amino-4, 8-disulfo-1-naphtholazoresorcinol: 560, 523, 483 in H_2O; 629, 560 with NH_4OH (123).

$C_{16}H_{13}N_3O_{10}S_2$.—2-Amino-3, 6-disulfo-1, 8-dihydroxynaphthaleneazoresorcinol: 564.5, 537 in alk. soln.; 591.5, 549.5 in acid soln. (123).

$C_{16}H_{13}N_3O_{12}S_3$.—1-Amino-3, 6, 8-trisulfo-2-naphtholazoresorcinol: 555, 521 in H_2O; 626.5, 578, 541.5 with NH_4OH (123).

$C_{16}H_{15}BrN_2O$.—*p*-Bromobenzene-1-azo-1′, 2′, 3′, 4′-tetrahydro-4-naphthol: K salt, 476 in EtOH (595).

$C_{16}H_{15}N_3O_3$.—*p*-Nitrobenzene-1-azo-1′, 2′, 3′, 4′-tetrahydro-4-naphthol: K salt, 581 in EtOH (595).

$C_{16}H_{15}N_3O_4$.—*p*-Nitrobenzeneazoeugenol: alkali salt, 610 in Me_2CO; 556 in EtOH; 535 in H_2O (643); *cf.* (501).

$C_{16}H_{16}N_2O$.—Benzeneazotetrahydro-α-naphthol: 470, 430 in alk. H_2O; 471 in EtOH (595).

$C_{16}H_{17}N_3O_3$.—*p*-Nitrobenzeneazocarvacrol: alkali salt, 606 in Me_2CO; 545 in EtOH; 511 in H_2O (643); *cf.* (501).

p-Nitrobenzeneazothymol: alkali salt, 610 in Me_2CO; 559 in EtOH; 515 in H_2O (643); *cf.* (501).

$C_{16}H_{18}ClN_3O_3S$.—2-Chloro-4-diethylamino-4′-sulfoazobenzene: 510 in acid soln. (pH 1); 470 in alk. soln. (pH 12) (613q).

$C_{16}H_{18}N_2O$.—Benzeneazothymol: 455, 410 in alk. H_2O (468).

p-Tolueneazo-*p*-cresetole: 325 in EtOH; *495*, 420 in HCl (618).

$C_{16}H_{18}N_2O_2$.—Azophenetole: 384 in EtOH (431 with NaOEt) (619).

$C_{16}H_{18}N_2O_3$.—*p*-Azoxyphenetole: 360 in EtOH(533).

$C_{16}H_{18}N_2O_5S$.—*o*-Methyl-*m*-isopropyl-*p*-sulfobenzeneazoresorcinol: Na salt, 440 in H_2O (271).

$C_{16}H_{18}N_4O$.—4-Acetylamino-4′-dimethylaminoazobenzene: 540 (473).

$C_{16}H_{19}N_3O$.—4-Ethoxy-4′-dimethylaminoazobenzene: 548 (473).

$C_{16}H_{19}N_3O_3S$.—4-Diethylamino-4′-sulfoazobenzene (Ethyl Orange): 510 in acid soln. (pH 1); 470 in alk. soln. (pH 13) (613q).

$C_{16}H_{19}N_3O_5S$.—2, 2′-Dimethoxy methyl orange: 537, 495 (473).

$C_{16}H_{20}N_4$.—Tetramethyl-*p*-diaminoazobenzene: 450 in EtOH; 692, (514), 450 in dil. HOAc; 530, 497 in 3% HCl (diacid salt); (498), 410 in H_2SO_4 (triacid salt) (310); *cf.* (475).

$C_{17}H_{11}N_3O_5$.—*p*-Nitrobenzeneazo-*n*-butylsalicylate: alkali salt, 556 in Me_2CO; 496 in EtOH; 480 in H_2O (643).

p-Nitro-*α*-naphthaleneazosalicylic acid: K salt, 541 in EtOH (595).

$C_{17}H_{12}N_2O_6S$.—*o*-Carboxybenzeneazo-*α*-naphthol-2-sulfonic acid: Na salt (424q).

$C_{17}H_{13}N_3O_3$.—*o*-Nitro-*p*-tolueneazo-*β*-naphthol (Toluidine Red, C. I. 69): 569.4, 533.2 in H_2SO_4 (190); 561 in gelatin (114).

$C_{17}H_{14}N_2O$.—*o*-Tolueneazo-*α*-naphthol: *406*, 275 in EtOH (352).

o-Tolueneazo-*β*-naphthol: *515*, 313 in EtOH; 313 in H_2SO_4 (352).

p-Tolueneazo-*α*-naphthol: 402 in EtOH; 300 in H_2SO_4 (352).

p-Tolueneazo-*β*-naphthol: *495*, 312 in EtOH (352).

$C_{17}H_{14}N_2O_4S$.—*o*-Tolueneazo-*β*-naphthol-6-sulfonic acid: Na salt, *496*, 316 in H_2O; 311 in H_2SO_4 (352).

p-Tolueneazo-*β*-naphthol-6-sulfonic acid: Na salt, *498*, 316 in H_2O (352).

o-Tolueneazo-*α*-naphthol-2-sulfonic acid: Na salt (424q).

p-Tolueneazo-*α*-naphthol-2-sulfonic acid: Na salt (424q).

$C_{17}H_{14}N_2O_5S$.—2-Anisoleazo-*α*-naphthol-6-sulfonic acid (Na salt, Anisole Red): 522 in gelatin (114).

$C_{17}H_{14}N_2O_7S_2$.—*o*-Tolueneazo-*β*-naphthol-3, 6-disulfonic acid: Na salt, *503*, 323 in H_2O (352).

o-Tolueneazo-*β*-naphthol-6, 8-disulfonic acid: Na salt, *491*, 324 in H_2O; 320 in H_2SO_4 (352).

p-Tolueneazo-*β*-naphthol-3, 6-disulfonic acid: Na salt, *500*, 322 in H_2O (352).

p-Tolueneazo-*β*-naphthol-6, 8-disulfonic acid: Na salt, *497*, 323 in H_2O (352).

$C_{17}H_{14}N_4O_2$.—1-Methyl-2-(4′-nitrobenzeneazomethylene)-1, 2-dihydroquinoline: hydrochloride, 527 in H_2SO_4 (343).

$C_{17}H_{15}N_3$.—*o*-Tolueneazo-*α*-naphthylamine: 298 in H_2SO_4 (352).

o-Tolueneazo-*β*-naphthylamine (Oil Yellow OB, C. I. 61): 474, 306 in EtOH; 455, 323 in H_2SO_4 (352); *cf.* (220q).

p-Tolueneazo-*β*-naphthylamine: 473, 305 in EtOH; 323 in H_2SO_4 (352).

$C_{17}H_{16}N_4O_2$.—2-(4′-Nitrobenzeneazomethylene)-3, 3-dimethylindoline: hydrochloride, 469 in HOAc (347).

$C_{17}H_{17}N_3$.—2-(Benzeneazomethylene)-3, 3-dimethylindoline: hydrochloride, 465; base, 435 (347).

$C_{17}H_{19}N_3O_2$.—2-Carboxy-4′-diethylaminoazobenzene: 512 in pH 1 soln.; 522 in pH 4 soln.; 499 in pH 12 soln. (613q).

4-Dimethylamino-4′-ethylcarboxyazobenzene: *444*, 275 in EtOH (214).

$C_{18}H_{12}N_4O$.—Quinolineazo-8-hydroxyquinoline: 403 in EtOH (159).

$C_{18}H_{14}N_2O$.—Diphenylazophenol: 451 in alk. H_2O (468).

$C_{18}H_{14}N_2O_2$.—*p*-Hydroxydiphenylazophenol; monobasic salt, 492 ($NaHCO_3$); dibasic salt, 470 (NaOH) (463).

Benzeneazo-*α*-naphthyl acetate: 376 in EtOH (619).

Benzeneazo-*β*-naphthyl acetate: 472, 282 in EtOH (619).

p-Acetylbenzeneazo-*α*-naphthol: 467, 315 in EtOH; 526, 300 in NaOH (258).

p-Acetylbenzeneazo-*β*-naphthol: 476, 318 in EtOH; 513, 286 in NaOH (258).

$C_{18}H_{14}N_2O_6S$.—*o*-Methylcarboxybenzeneazo-*α*-naphthol-2-sulfonic acid: Na salt (424q).

$C_{18}H_{15}N_3O_3S$.—4-Phenylamino-4′-sulfoazobenzene (Na salt, C. I. 143): 527 in pH 1 soln.; 456 in pH 12 soln. (613q).

$C_{18}H_{15}N_3O_8S_2$.—Benzeneazo-8-acetylamino-1-naphthol-3, 6-disulfonic acid (Na salt, C. I. 31): Kiton Red G (22).

$C_{18}H_{16}N_2O$.—Benzeneazo-*α*-naphthol ethyl ether: 400 in EtOH (619).

$C_{18}H_{17}N_3$.—Benzeneazodimethyl-*α*-naphthylamine: 570, 525 in acid H_2O (471).

$C_{18}H_{17}N_3O_3S$.—4-Sulfonaphthaleneazodimethylaniline: (473).

$C_{18}H_{18}N_4O_3$.—2-(4′-Nitro-2′-methoxybenzeneazomethylene)-3, 3-dimethylindoline: hydrochloride, 484 in HOAc (347).

$C_{19}H_{14}N_2O_2$.—*p*-Benzoylbenzeneazophenol: 481, 333 in EtOH (?) (471); 370 in EtOH; 476 in NaOH (258).

$C_{19}H_{14}N_4O_2$.—*p*-Nitrobenzylideneaminoazobenzene: 383 in EtOH (521).

$C_{19}H_{15}N_3$.—Benzylidineaminoazobenzene: 383 in EtOH (521).

$C_{19}H_{15}N_3O$.—*p*-Hydroxybenzylidineaminoazobenzene: 375 in EtOH (521).

$C_{19}H_{17}N_3O_3S$.—*p*-Sulfobenzeneazobenzylaminobenzene: 448, (280) in dil. NaOH; 496 in dil. HCl (216); 560 in pH 1 soln. (613q).

$C_{19}H_{18}N_2O_7S_2$.—Pseudocumeneazo-*β*-naphthol-3, 6-disulfonic acid (Na salt, C. I. 80): *504*, 330 in H_2O (179q); *cf.* (422q).

$C_{19}H_{19}N_3O$.—2-(4′-Acetylbenzeneazomethylene)-3, 3-dimethylindoline: hydrobromide, 456 in EtOH (347).

$C_{19}H_{19}N_3O_4S$.—*p*-Sulfo-*o*-methoxybenzeneazodimethyl-*α*-napthylamine: 580, 525, 500 in acid H_2O (595).

$C_{19}H_{20}N_4O_2$.—2-(4′-Nitrobenzeneazomethylene)-3, 3-diethylindoline: hydrochloride, 472 in HOAc (347).

$C_{20}H_{13}BrN_2O$.—*p*-Bromobenzene-1-azo-4-anthrol: 503 in EtOH; K salt, 588 in EtOH (595).

$C_{20}H_{13}N_3O_3$.—*p*-Nitrobenzeneazoanthrol: 460 in EtOH (595).

p-Nitrobenzene-1-azo-4-anthrol: 482 in EtOH; K salt, 650 in EtOH (595).

3′-Nitro-4-hydroxyazonaphthalene: 557 in H_2O (471).

$C_{20}H_{14}N_2O$.—Benzeneazoanthrol: 466 in EtOH; K salt, 580 in EtOH (595).

Benzene-1-azo-4-anthrol: 499 in EtOH; K salt, 549 in EtOH (595).

α-Naphthaleneazo-*β*-naphthol (Autol Red RL, C. I. 82): 628, 585.8 in H_2SO_4 (190).

β-Naphthaleneazo-*β*-naphthol: 483 in EtOH (85).

β, *β*′-Azoxynaphthalene: 337, 282, 266 in EtOH (?) [550 after exposure to light] (85).

$C_{20}H_{14}N_2O_4S$.—*p*-Sulfobenzene-1-azo-4-anthrol: 503 in EtOH; K salt, 571 in EtOH (595).

α-Naphthaleneazo-*α*-naphthol-2-sulfonic acid: Na salt (424q).

β-Naphthaleneazo-*α*-naphthol-2-sulfonic acid: Na salt (424q).

4-Sulfo-*α*-naphthaleneazo-*α*-naphthol (Na salt, C. I. 175): (231).

4-Sulfo-*α*-naphthaleneazo-*β*-naphthol (Na salt, Fast Red A.S., C. I. 176): 500 in H_2O (concd.); 505 (dil.) (269); *cf.* (231, 390, 391, 516).

$C_{20}H_{14}N_2O_7S_2$.—*α*-Naphthaleneazo-*β*-naphthol-3, 6-disulfonic acid (Na salt, Bordeaux B, C. I. 88): 510 in H_2O (concd.); 515 (dil.) (269); *cf.* (421q, 516q, 588).

α-Naphthaleneazo-*β*-naphthol-6, 8-disulfonic acid (Na salt, Crystal Scarlet, C. I. 89); *508*, 329.5 in H_2O (391q); *cf.* (388q, 518q).

4-Sulfo-*α*-naphthaleneazo-*α*-naphthol-2-sulfonic acid: Na salt (424q).

4-Sulfo-*α*-naphthaleneazo-*α*-naphthol-4-sulfonic acid (Na salt, C. I. 179): "Azorubin," infra-red abs. (511); Pontacyl Ruby G, 505 in H_2O (concd.); 512 (dil.) (269); Chromotrope FB, 555.9, *519.5* in dil. HOAc; 569.5 in H_2SO_4; Chrome Lake, *620.7*, 575.7, 537.5 in 90% HOAc + HCl; *614.7*, 568.2, 530.3 in H_2SO_4 (190).

$C_{20}H_{14}N_2O_8S_2$.—α-Naphthaleneazo-1, 8-dihydroxynaphthalene-3, 6-disulfonic acid (Na salt, C. I. 90): 533 in 0.1*N* HCl; 519 in 0.1*N* NaOH; 535 in H_2O (pH 6.75) (11q).

$C_{20}H_{14}N_2O_{10}S_3$.—α-Naphthaleneazo-α-naphthol-3, 6, 8-trisulfonic acid: Na salt, 534 in 0.1*N* HCl; 514 in 0.1*N* NaOH; 535 in pH 6.75 soln. (11q).

4-Sulfo-α-naphthaleneazo-β-naphthol-3, 6-disulfonic acid (Na salt, Amaranth, C. I. 184): *522*, 331 in H_2O (179q); *cf.* (422q).

4-Sulfo-α-naphthaleneazo-β-naphthol-6, 8-disulfonic acid (Na salt, C. I. 185): Cochineal Red A, *515*, 500 on wool (522).

$C_{20}H_{15}N_3$.—α-naphthaleneazo-α-naphthylamine: (231q).

β-Naphthaleneazo-β-naphthylamine: (231q).

$C_{20}H_{15}N_3O_4S$.—4-Sulfo-1-naphthylamineazo-β-naphthol: Na salt, 500 in H_2O; 629, 587.5 in H_2SO_4 (123).

5-Sulfo-1-naphthylamineazo-β-naphthol: Na salt, 499 in H_2O; 608.5, 568 in H_2SO_4 (123).

6-Sulfo-1-naphthylamineazo-β-naphthol: Na salt, 499 in H_2O; 607.5, 568.5 in H_2SO_4 (123).

7-Sulfo-1-naphthylamineazo-β-naphthol: Na salt, 500 in H_2O; 572 in H_2SO_4 (123).

1-Sulfo-2-naphthylamineazo-β-naphthol; Na salt, 505.5 in H_2O; 589.5, 552.5 in H_2SO_4 (123).

5-Sulfo-2-naphthylamineazo-β-naphthol: Na salt, 492.5 in H_2O; 576, 541.5 in H_2SO_4 (123).

6-Sulfo-2-naphthylamineazo-β-naphthol: Na salt, 494 in H_2O; 579.5, 543.5 in H_2SO_4 (123).

7-Sulfo-2-naphthylamineazo-β-naphthol: Na salt, 493 in H_2O; 580, 543 in H_2SO_4 (123).

8-Sulfo-2-naphthylamineazo-β-naphthol: Na salt, 494.5 in H_2O; 581, 544.5 in H_2SO_4 (123).

$C_{20}H_{15}N_3O_7S_2$.—α-Naphthaleneazo-8-amino-α-naphthol-3, 6 disulfonic acid: Na salt, 544 in 0.1*N* HCl; 545 in 0.1*N* NaOH; 548 in pH 6.75 soln. (11).

3, 6-Disulfo-1-naphthylamineazo-β-naphthol: Na salt, 498.5 in H_2O; 604.5, 568 in H_2SO_4 (123).

3, 8-Disulfo-1-naphthylamineazo-β-naphthol: Na salt, 492 in H_2O; 578.5, 542 in H_2SO_4 (123).

4, 7-Disulfo-1-naphthylamineazo-β-naphthol: Na salt, 498.5 in H_2O; 617, 575 in H_2SO_4 (123).

4, 8-Disulfo-1-naphthylamineazo-β-naphthol: Na salt, 491 in H_2O; 540 in H_2SO_4 (123).

3, 6-Disulfo-2-naphthylamineazo-β-naphthol: Na salt, 493.5 in H_2O (123).

4, 7-Disulfo-2-naphthylamineazo-β-naphthol: Na salt, 495.5 in H_2O; 582, 542.5 in H_2SO_4 (123).

4, 8-Disulfo-2-naphthylamineazo-β-naphthol: Na salt, 492 in H_2O; 581.5, 544.5 in H_2SO_4 (123).

5, 7-Disulfo-2-naphthylamineazo-β-naphthol: Na salt, 490.5 in H_2O; 580, 543 in H_2SO_4 (123).

6, 8-Disulfo-2-naphthylamineazo-β-naphthol: Na salt, 494.5 in H_2O; 583.5, 546 in H_2SO_4 (123).

$C_{20}H_{15}N_3O_{10}S_3$.—5-Sulfo-1-naphthylamineazo-β-naphthol-3, 6-disulfonic acid: Na salt, 594.5, 555 in H_2SO_4 (123).

6-Sulfo-1-naphthylamineazo-β-naphthol-3, 6-disulfonic acid: Na salt, 572, 537.5 in H_2SO_4 (123).

$C_{20}H_{15}N_3O_{13}S_4$.—3, 6-Disulfo-2-naphthylamineazo-β-naphthol-3, 6-disulfonic acid: Na salt, 495 in H_2O; 583, 547 in H_2SO_4 (123).

$C_{20}H_{16}N_2O_2$.—*p*-Benzoylbenzeneazo-*p*-cresol: 327 in EtOH; 513, 341 in NaOH (258); *cf.* (618).

$C_{20}H_{16}N_4O_5S$.—4-Sulfo-1, 5-diamino-2-naphtholazo-α-naphthol: Na salt, 521.5 in alk. soln.; 518 in acid soln. (123).

$C_{20}H_{16}N_4O_{11}S_3$.—3-Sulfo-2, 5-diamino-1-naphtholazo-β-naphthol-3, 6-disulfonic acid: Na salt, 496.5 in H_2SO_4 (123).

$C_{20}H_{17}N_3O$.—*p*-Methoxybenzylideneaminoazobenzene: 327 in EtOH; 513, 341 in NaOH (521).

$C_{20}H_{18}N_4O_9S_2$.—*p*-Acetylaminobenzeneazo-8-acetylamino-α-naphthol-3, 6-disulfonic acid (Na salt, C. I. 57): Pontacyl Carmine 6B, 514 in H_2O (concd.); 525 (dil.) (269).

$C_{20}H_{20}N_2O$.—*p*-Cymeneazo-β-naphthol: 532 in H_2SO_4 (677).

$C_{20}H_{20}N_2O_3S$.—*p*-Cymeneazo-α-naphthalene-4-sulfonic acid: Na salt, 460 in H_2O (677).

$C_{20}H_{20}N_2O_4S$.—*o*-Methyl-*m*-isopropyl-*p*-sulfobenzeneazo-β-naphthol: Na salt, 495 in H_2O (271).

$C_{20}H_{20}N_2O_7S_2$.—*o*-Methyl-*m*-isopropylbenzeneazo-β-naphthol-6, 8-disulfonic acid: Na salt, 492 in H_2O (271).

$C_{20}H_{20}N_2O_8S_2$.—*o*-Methyl-*m*-isopropylbenzeneazo-1, 8-dihydroxynaphthalene-3, 6-disulfonic acid: Na salt, 520 in H_2O (271).

$C_{20}H_{20}N_2O_{10}S_3$.—*o*-Methyl-*m*-isopropyl-*p*-sulfobenzeneazo-β-naphthol-3, 6-disulfonic acid: Na salt, 498 in H_2O (677). (The 6, 8-disulfo isomer in H_2O, 485 (677).)

$C_{20}H_{20}N_2O_{11}S_3$.—*o*-Methyl-*m*-isopropyl-*p*-sulfobenzeneazo-1, 8-dihydroxynaphthalene-3, 6-disulfonic acid: Na salt, 525 in H_2O (271).

$C_{20}H_{21}N_3$.—*p*-Cymeneazo-β-naphthylamine: 570 in H_2SO_4 (677).

$C_{20}H_{26}N_2$.—Azocymene: 465 in H_2SO_4 (677).

$C_{21}H_{13}N_3O_5$.—*p*-Nitronaphthalene-1-azo-4-naphthol-3-carboxylic acid: 470 in EtOH; K salt, 606 in EtOH (595).

$C_{22}H_{17}N_3O_3S$.—4-Diphenylazo-α-naphthylamine-4-sulfonic acid: 575 in dil. HCl (468).

$C_{22}H_{18}N_4O_5S$.—8-Sulfo-4-amino-1-phenylnaphthylamineazoresorcinol: 561.5 with excess H_2SO_4 (123).

$C_{22}H_{19}N_3O_7S_2$.—3, 6-Disulfo-8-hydroxy-α-naphthaleneazoethyl-α-naphthylamine (Na salt, C. I. 307): Pontacyl Sulfon Violet R, 530 in H_2O (concd.); 550 (dil.) (269).

$C_{22}H_{20}N_2O_2$.—*p*-Benzoylbenzeneazo-*p*-cresetole: 326 in EtOH (618).

$C_{23}H_{16}N_2O_2$.—*p*-Benzoylbenzeneazo-α-naphthol: 461, 330 in EtOH; 535, 300 in NaOH (258).

p-Benzoylbenzeneazo-β-naphthol: 486, 320 in EtOH; 513, 283 in NaOH (258).

$C_{23}H_{16}N_4O_4$.—*p*-Nitrobenzeneazo-β-hydroxynaphthoic acid anilide (Fast Red GG): 570 in H_2SO_4 (677).

$C_{23}H_{22}N_4O_3$.—Phenyl-(*p*-dimethylaminobenzeneazobenzoylamino)-acetic acid: *461*, 375 (306), 274 in EtOH (abs. of *d*, *l*, and *dl* forms identical) (64q).

$C_{24}H_{16}ClN_3O_7S_3$.—Benzenylaminothiocresolazo-8-chloro-α-naphthol-3, 6-disulfonic acid (Na salt, C. I. 128): Diamine Rose BD on cotton and silk (627).

$C_{25}H_{19}N_3O_4$.—β-Naphthol deriv. of diazotized phenyl- (*p*-aminobenzoylamino)- acetic acid: *486*, (381), 314, (271) in H_2O; 516, *443* with excess alkali; 553, *522* with excess acid (abs. of *d*, *l* and *dl* forms identical) (63q).

$C_{26}H_{17}N_3O_6$.—*p*-Nitrobenzeneazophenolphthalein: alkali salt, 568 in Me_2CO; 508 in EtOH; 495 in H_2O (643); *cf.* (501).

$C_{26}H_{21}N_5O_8S_2$.—3-Sulfo-2, 5-diamino-α-naphtholazophenyl-β-naphthylamine-5-hydroxy-7-sulfonic acid: 493.8 in dil. H_2SO_4 (123).

$C_{27}H_{20}N_4O_9S_2$.—8-Benzoylamino-2-amino-3, 5-disulfo-α-naphtholazo-β-naphthol: 525, 493 in H_2SO_4 (123).

Aminobenzoyl-H-acid-azo-β-naphthol: 608, 578 in H_2SO_4 (123).

Azo dyes derived from substituted pyrroles: (33, 378, 399, 408, 409).

p-Nitrobenzeneazocephaeline: 610 in alk. Me_2CO; 550 in alk. EtOH; 525 in alk. H_2O (502).

p-Nitrobenzeneazoemetamine: 627.5 in alk. Me_2CO; 590 in alk. EtOH; 570 in alk. H_2O (502).

Table 2.—Polyazo Dyes

$C_{18}H_{13}N_5O_3$.—*p*-Nitrobenzeneazobenzeneazophenol: 395 in EtOH; Na salt, 546 in EtOH (521).

$C_{18}H_{14}N_4O$.—Benzeneazobenzeneazophenol: 435 (111); 497 in alk. H_2O (463).

$C_{18}H_{14}N_4O_2$.—Phenolazobenzeneazophenol: disodium salt, 515 in H_2O (463).

$C_{18}H_{18}N_8$.—Benzene-*m*-disazo-*bis*-*m*-phenylenediamine (hydrochloride, Bismarck Brown Y, C. I. 331): infra-red abs. (296); 460 on cotton (627); *cf.* (231).

$C_{20}H_{19}N_5$.—Benzeneazobenzeneazodimethylaniline: 509 (111).

$C_{22}H_{15}N_7O_{11}S_2$.—2-*p*-Nitrobenzeneazo-1-amino-8-naphthol-3, 6-disulfo-7-azo-*p*-nitrobenzene: Na salt, 612 in H_2O (609).

$C_{22}H_{16}N_4O$.—Benzeneazobenzeneazo-*α*-naphthol: *655*, 625 in H_2SO_4 (196).

Benzeneazobenzeneazo-*β*-naphthol (Sudan III, C. I. 248): *640.9*, 589.8 in H_2SO_4 (190); *cf.* (196).

$C_{22}H_{16}N_4O_3S$.—*p*-Sulfobenzeneazobenzeneazo-*α*-naphthalene: Na salt, 507 in H_2O; 516 in 0.02*N* HCl; 663 in H_2SO_4 (436).

$C_{22}H_{16}N_4O_4S$.—Benzeneazobenzeneazo-*α*-naphthol-4-sulfonic acid (Na salt, C. I. 249): *627*, 575 in H_2SO_4 (196).

Benzeneazobenzeneazo-*β*-naphthol-6-sulfonic acid: *610*, 580 in H_2SO_4 (196).

Benzeneazobenzeneazo-*β*-naphthol-8-sulfonic acid: 598, 572 in H_2SO_4 (196).

$C_{22}H_{16}N_4O_6S_2$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-*α*-naphthalene: Na salt, 524 in H_2O; 542 in alk. H_2O; 519 in 0.02*N* HCl; 643 in H_2SO_4 (436).

p-Sulfobenzeneazobenzeneazo-*α*-naphthalene-7-sulfonic acid: Na salt, 532 in H_2O (520 with alkali); 496 in 0.02*N* HCl; 657 in H_2SO_4 (436).

$C_{22}H_{16}N_4O_7S_2$.—Benzeneazobenzeneazo-*α*-naphthol-4, 8-disulfonic acid (Na salt, C. I. 251): *630*, 575 in H_2SO_4 (196).

Benzeneazobenzeneazo-*β*-naphthol-3, 6-disulfonic acid (Na salt, C. I. 253): *616*, 573 in H_2SO_4 (196).

Benzeneazobenzeneazo-*β*-naphthol-6, 8-disulfonic acid (Na salt, C. I. 252): *592*, 550 in H_2SO_4 (196). Brilliant Croceine M, 545 on silk (627).

p-Sulfobenzeneazo-*o*-sulfobenzeneazo-*β*-naphthol (Na salt, Biebrich Scarlet, C. I. 280): (231).

$C_{22}H_{16}N_4O_9S_3$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-*α*-naphthalene-7-sulfonic acid: Na salt, 539 in H_2O; 530 in 0.02*N* HCl; 638 in H_2SO_4 (436).

$C_{22}H_{16}N_4O_{10}S_3$.—Benzeneazobenzeneazo-*α*-naphthol-3, 6, 8-trisulfonic acid: *620*, 573 in H_2SO_4 (196).

Benzeneazobenzeneazo-*β*-naphthol-3, 6, 8-trisulfonic acid: 600, 555 in H_2SO_4 (196).

p-Sulfobenzeneazobenzeneazo-*α*-naphthol-4, 8-disulfonic acid: 642 in H_2SO_4 (196).

p-Sulfobenzeneazobenzeneazo-*β*-naphthol-3, 6-disulfonic acid: *607*, 575 in H_2SO_4 (196).

p-Sulfobenzeneazobenzeneazo-*β*-naphthol-6, 8-disulfonic acid: 587 in H_2SO_4 (196).

p-Sulfobenzeneazo-*o*-sulfobenzeneazo-*α*-naphthol-4-sulfonic acid: *688*, 596 in H_2SO_4 (196).

p-Sulfobenzeneazo-*o*-sulfobenzeneazo-*β*-naphthol-8-sulfonic acid: 620 in H_2SO_4 (196).

$C_{22}H_{16}N_4O_{13}S_4$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-*α*-naphthol-4, 8-disulfonic acid: *631*, 584 in H_2SO_4 (196).

p-Sulfobenzeneazo-*o*-sulfobenzeneazo-*β*-naphthol-3, 6-disulfonic acid: *630*, 575 in H_2SO_4 (196).

p-Sulfobenzeneazo-*o*-sulfobenzeneazo-*β*-naphthol-6, 8-disulfonic acid: 589 in H_2SO_4 (196).

$C_{22}H_{16}N_4O_{16}S_5$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-*α*-naphthol-3, 6, 8-trisulfonic acid: *629*, 582 in H_2SO_4 (196).

p-Sulfobenzeneazo-*o*-sulfobenzeneazo-*β*-naphthol-3, 6, 8-trisulfonic acid: *607*, 580 in H_2SO_4 (196).

$C_{22}H_{16}N_6O_9S_2$.—*p*-Nitrobenzeneazo-3, 6-disulfo-8-amino-*α*-naphtholazobenzene (Na salt, C. I. 246): Agalma Black 10B, 620 in H_2O (129); *cf.* (609); 600 in H_2O (concd.); 620 (dil.) (269).

$C_{22}H_{24}N_6$.—4, 4′-Benzenedisazodimethylaniline: (570), 544, 510 (473).

$C_{24}H_{18}N_4O_2$.—Diphenyldisazo-*bis*-phenol: monosodium salt, 496 ($NaHCO_3$); disodium salt, 370 (NaOH) (463).

5, 5′-*Bis*-benzeneazo-2, 2′-diphenol: 344 in EtOH (?) (544).

$C_{24}H_{18}N_4O_8S_2$.—Diphenyldisazo-*bis*-*p*-sulfophenol: 475 in alk. H_2O (468).

$C_{24}H_{18}N_6O$.—Benzeneazobenzeneazobenzeneazophenol: 436 (111).

$C_{24}H_{20}N_4O$.—*o*-Tolueneazo-*o*-tolueneazo-*β*-naphthol (Sudan IV, C. I. 258): *657.4*, 605.5 in H_2SO_4 (190); *cf.* (516).

$C_{24}H_{20}N_4O_4S$.—*o*-Tolueneazo-*o*-tolueneazo-*α*-naphthol-4-sulfonic acid: 629, 589 in H_2SO_4 (196).

o-Tolueneazo-*o*-tolueneazo-*β*-naphthol-6-sulfonic acid: *630*, 589 in H_2SO_4 (196).

o-Tolueneazo-*o*-tolueneazo-*β*-naphthol-8-sulfonic acid: *620*, 580 in H_2SO_4 (196).

$C_{24}H_{20}N_4O_5S$.—*m*-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol: Na salt, 506 in H_2O; 503 in 0.02*N* HCl; 592 in 0.02*N* NaOH; 530 in 85% EtOH; 587 in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol: Na salt, 506 in H_2O; 502 in 0.02*N* HCl; 497 in 0.02*N* NaOH; (566), 540 in 85% EtOH; *661*, 597 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol: Na salt, 513 in H_2O; 512 in 0.02*N* HCl; 596 in 0.02*N* NaOH; 530 in 85% EtOH; *631*, 586 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol: Na salt, 515 in H_2O; 511 in 0.02*N* HCl; 507 in 0.02*N* NaOH; (566), 545 in 85% EtOH; *633*, 610 in 80% HCOOH (436).

$C_{24}H_{20}N_4O_7S_2$.—*o*-Tolueneazo-*o*-tolueneazo-*α*-naphthol-4, 8-disulfonic acid: *630*, 575 in H_2SO_4 (196).

o-Tolueneazo-*o*-tolueneazo-*β*-naphthol-3, 6-disulfonic acid: *635*, 580 in H_2SO_4 (196).

p-Sulfo-*o*-tolueneazo-*o*-tolueneazo-*α*-naphthol-4-sulfonic acid: *647*, 589 in H_2SO_4 (196).

p-Sulfo-*o*-tolueneazo-*o*-tolueneazo-*β*-naphthol-6-sulfonic acid: *650*, 589 in H_2SO_4 (196).

p-Sulfo-*o*-tolueneazo-*o*-tolueneazo-*β*-naphthol-8-sulfonic acid: *630*, 585 in H_2SO_4 (196).

o-Tolueneazo-*o*-tolueneazo-*β*-naphthol-6,8-disulfonic acid: *675*, 580 in H_2SO_4 (196).

$C_{24}H_{20}N_4O_8S_2$.—*m*-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-4-sulfonic acid: Na salt, 591, 531 in H_2O; 604, *524* in 0.02*N* HCl; 555 in 0.02*N* NaOH; 583, 538 in 85% EtOH; *675*, 585, 542 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-4-sulfonic acid: Na salt, 594, *533* in H_2O; 601, *525* in 0.02*N* HCl; 586, *549* in 0.02*N* NaOH; 586, 549 in 85% EtOH; *676*, 588, 547 in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-5-sulfonic acid: Na salt, 608, *545* in H_2O; 616, *537* in 0.02*N* HCl; 587, 546 in 85% EtOH; 556 in 0.02*N* NaOH; *674*, 602, 554 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-5-sulfonic acid: Na salt, 604, *546* in H_2O; 612, *538* in 0.02*N* HCl; 598, *560* in 0.02*N* NaOH; 585, 546 in 85% EtOH; *677*, 606, (553) in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-7-sulfonic acid: Na salt, 522 in H_2O; 518 in 0.02*N* HCl; 576 in 0.02*N* NaOH; 523 in 85% EtOH; *629*, 586 in 80% HCOOH (436).

$\mathbf{C_{24}H_{20}N_4O_8S_2}$.—*p*-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-7-sulfonic acid: Na salt, 522 in H_2O; 518 in 0.02*N* HCl; 578 in 0.02*N* NaOH; 531 in 85% EtOH; *636*, 587 in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-8-sulfonic acid: Na salt, 528 in H_2O; 523 in 0.02*N* HCl; 635 in 0.02*N* NaOH; *626*, 582 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-8-sulfonic acid: Na salt, 535 in H_2O; 528 in 0.02*N* HCl; 635 in 0.02*N* NaOH; *631*, 586 in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-6-sulfonic acid: Na salt, 625 in H_2O; 617 in 0.02*N* HCl; 523 in 0.02*N* NaOH; 573, 541 in 85% EtOH; 660, 563 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-6-sulfonic acid: Na salt, 525 in H_2O; 522 in 0.02*N* HCl; 528 in 0.02*N* NaOH; 573, 544 in 85% EtOH; 666, 592, 564 in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-8-sulfonic acid: Na salt, 535 in H_2O; 533 in 0.02*N* HCl; 526 in 0.02*N* NaOH; 558, 533 in 85% EtOH; *651*, 598 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-8-sulfonic acid: Na salt, 539 in H_2O; 535 in 0.02*N* HCl; 527 in 0.02*N* NaOH; 563, 537 in 85% EtOH; *656*, 609 in 80% HCOOH (436).

$\mathbf{C_{24}H_{20}N_4O_{10}S_3}$.—*o*-Tolueneazo-*o*-tolueneazo-*α*-naphthol-3, 6, 8-trisulfonic acid: *640*, 592 in H_2SO_4 (196).

p-Sulfo-*o*-tolueneazo-*o*-tolueneazo-*α*-naphthol-4, 8-disulfonic acid: *630*, 575 in H_2SO_4 (196).

p-Sulfo-*o*-tolueneazo-*o*-tolueneazo-*β*-naphthol-3, 6-disulfonic acid: *630*, 580 in H_2SO_4 (196).

$\mathbf{C_{24}H_{20}N_4O_{11}S_3}$.—*m*-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-3, 6-disulfonic acid: Na salt, 585, *549* in H_2O; 550 in 0.02*N* HCl; 532 in 0.02*N* NaOH; *573*, 539 in 85% EtOH; *664*, 601 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-3, 6-disulfonic acid: Na salt, 580, *551* in H_2O; 586, *548* in 0.02*N* HCl; 554 in 0.02*N* NaOH; *579*, 538 in 85% EtOH; *667*, 602 in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-3, 8-disulfonic acid: Na salt, 574, *551* in H_2O; 545 in 0.02*N* HCl; 555 in 0.02*N* NaOH; *569*, 539 in 85% EtOH; *657*, 606 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-3, 8-disulfonic acid: Na salt, 573, 554 in H_2O; 552 in 0.02*N* HCl; 553 in 0.02*N* NaOH; *574*, 542 in 85% EtOH; *663*, 612 in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-3, 6-disulfonic acid: Na salt, 588, *543* in H_2O; 595, 542 in 0.02*N* HCl; 548 in 0.02*N* NaOH; 573, 549 in 85% EtOH; 664, 553 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-3, 6-disulfonic acid: Na salt, 590, *543* in H_2O; 596, *541* in 0.02*N* HCl; 549 in 0.02*N* NaOH; 573, 550 in 85% EtOH; 669, 594, 558 in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-6, 8-disulfonic acid: Na salt, 577, 537 in H_2O; 582, 534 in 0.02*N* HCl; 575, 539 in 0.02*N* NaOH; 567, 537 in 85% EtOH; 654 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-6, 8-disulfonic acid: Na salt, 574, 540 in H_2O; 597, 537 in 0.02*N* HCl; 575, 541 in 0.02*N* NaOH; 566, 537 in 85% EtOH; *658*, 580 in 80% HCOOH (436).

2, 4-Disulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-4-sulfonic acid: Na salt, 594, *547* in H_2O; 600, *544* in 0.02*N* HCl; (598), *564* in 0.02*N* NaOH; 584, 542 in 85% EtOH; *687*, 588, 547 in 80% HCOOH (436).

$\mathbf{C_{24}H_{20}N_4O_{12}S_3}$.—*m*-Sulfobenzeneazo-*p*-methylanisoleazo-1, 8-dihydroxynaphthalene-3, 6-disulfonic acid: Na salt, 602, *560* in H_2O; 610, *564* in 0.02*N* HCl; 596 in 0.02*N* NaOH; 603, 560 in 85% EtOH; *685*, 606, 561 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-1, 8-dihydroxynaphthalene-3, 6-disulfonic acid: Na salt, 600, *562* in H_2O; 602, 561 in 0.02*N* HCl; 599 in 0.02*N* NaOH; 604, 559 in 85% EtOH; *688*, 614, 567 in 80% HCOOH (436).

$\mathbf{C_{24}H_{20}N_4O_{13}S_4}$.—*p*-Sulfo-*o*-tolueneazo-*o*-tolueneazo-*α*-naphthol-3, 6, 8-trisulfonic acid: 650 in H_2SO_4 (196).

p-Sulfo-*o*-tolueneazo-*o*-tolueneazo-*β*-naphthol-3, 6, 8-trisulfonic acid; *630*, 585 in H_2SO_4 (196).

$\mathbf{C_{24}H_{20}N_4O_{14}S_4}$.—*m*-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-3, 6, 8-trisulfonic acid: Na salt (580), 558 in H_2O; (582), 561 in 0.02*N* HCl; 570 in 0.02*N* NaOH; 581 in 85% EtOH; *663*, 608 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-3, 6, 8-trisulfonic acid: Na salt, 566 in H_2O; (583), 559 in 0.02*N* HCl; 579, 559 in 0.02*N* NaOH; *584*, 545 in 85% EtOH; *669*, 613 in 80% HCOOH (436).

m-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-3, 6, 8-trisulfonic acid: Na salt, 593, *545* in H_2O; 594, *542* in 0.02*N* HCl; 547 in 0.02*N* NaOH; 576, 548 in 85% EtOH; *665*, 557 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-*β*-naphthol-3, 6, 8-trisulfonic acid: Na salt, 592, *545* in H_2O; 598, *543* in 0.02*N* HCl; 548 in 0.02*N* NaOH; 578, 550 in 85% EtOH; 673 in 80% HCOOH (436).

2, 4-Disulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-3, 8-disulfonic acid: Na salt, 573, 558 in H_2O; 576, 552 in 0.02*N* HCl; 565 in 0.02*N* NaOH; 575, 537 in 85% EtOH; 674 in 80% HCOOH (436).

$\mathbf{C_{24}H_{20}N_4O_{15}S_4}$.—2, 4-Disulfobenzeneazo-*p*-methylanisoleazo-1, 8-dihydroxynaphthalene-3, 6-disulfonic acid: Na salt, 603, 571 in H_2O; 598, 564 in 0.02*N* HCl; 602 in 0.02*N* NaOH; 606, 563 in 85% EtOH; 692, 613 in 80% HCOOH (436).

$\mathbf{C_{24}H_{20}N_4O_{17}S_5}$.—2, 4-Disulfobenzeneazo-*p*-methylanisoleazo-*α*-naphthol-3, 6, 8-trisulfonic acid: Ba salt, 577, 566 in H_2O; 565 in 0.02*N* HCl; 576 in 0.02*N* NaOH; 583, 547 in 85% EtOH; *678*, 618 in 80% HCOOH (436).

$\mathbf{C_{24}H_{21}N_5O_8S_2}$.—*m*-Sulfobenzeneazo-*p*-methylanisoleazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt, 592, *533* in H_2O; 525 in 0.02*N* HCl; 587, *532* in 0.02*N* NaOH; 558, 534 in 85% EtOH; 657 in 80% HCOOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt, 585, *536* in H_2O; 498 in 0.02*N* HCl; 591, 535 in 0.02*N* NaOH; 554, 533 in 80% EtOH; *662*, 600, 559 in 80% HCOOH (436).

$\mathbf{C_{24}H_{21}N_5O_{11}S_3}$.—*m*-Sulfobenzeneazo-*p*-methylanisoleazo-8, amino-*α*-naphthol-3, 6-disulfonic acid: Na salt, 593 in H_2O; 605-571 in 0.02*N* HCl; 587 in 0.02*N* NaOH; 607, 563 in 85% EtOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-8-amino-*α*-naphthol-3, 6-disulfonic acid: Na salt, 603, 575 in H_2O; 603, 569 in 0.02*N* HCl; 593 in 0.02*N* NaOH; 607, 567 in 85% EtOH (436).

2, 4-Disulfobenzeneazo-*p*-methylanisoleazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt, 575, *550* in H_2O; 591, *542* in 0.02*N* NaOH; 565, 539 in 85% EtOH; 676 in 80% HCOOH (436).

$\mathbf{C_{24}H_{21}N_5O_{14}S_4}$.—2, 4-Disulfobenzeneazo-*p*-methylanisoleazo-8-amino-*α*-naphthol-3, 6-disulfonic acid: Na salt, 619, 590 in H_2O; 559, 573 in 0.02*N* HCl; 605 in 0.02*N* NaOH; 612, 573 in 85% EtOH (436).

$\mathbf{C_{24}H_{30}N_4O_5}$.—*p*-Nitrobenzeneazocapsaicin: alkali salt, 593 in Me_2CO; 550 in EtOH; 510 in H_2O (643).

$\mathbf{C_{25}H_{22}N_4O_8S_2}$.—4-Sulfo-2-methylbenzeneazo-*p*-methylanisoleazo-*α*-naphthol-4-sulfonic acid: Na salt, (593), 530 in H_2O; (604), 524 in 0.02*N* HCl; 552 in 0.02*N* NaOH; 583, 542 in 85% EtOH (436).

$C_{25}H_{22}N_4O_{11}S_3$.—4-Sulfo-2-methylbenzeneazo-*p*-methylanisoleazo-*α*-naphthol-3, 8-disulfonic acid: Na salt, 576, 551 in H_2O; 545 in 0.02*N* HCl; 552 in 0.02*N* NaOH; 572, 538 in 85% EtOH; 667, 578, 552 in 80% HCOOH (436).

$C_{25}H_{22}N_4O_{12}S_3$.—4-Sulfo-2-methylbenzeneazo-*p*-methylanisoleazo-1, 8-dihydroxynaphthalene-3, 6-disulfonic acid: Na salt, 599, 563 in H_2O; 604, 562 in 0.02*N* HCl; 597 in 0.02*N* NaOH; 602, 561 in 85% EtOH; 554, 513 in 80% HCOOH (436).

$C_{25}H_{23}N_5O_8S_2$.—4-Sulfo-2-methylbenzeneazo-*p*-methylanisoleazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt (592), 533 in H_2O; 510 in 0.02*N* HCl; 588, 533 in 0.02*N* NaOH; 558, 533 in 85% EtOH (436).

$C_{25}H_{23}N_5O_{11}S_3$.—4-Sulfo-2-methylbenzeneazo-*p*-methylanisoleazo-8-amino-*α*-naphthol-3, 6-disulfonic acid: Na salt, 602, 582 in H_2O; 607, 568 in 0.02*N* HCl; 587 in 0.02*N* NaOH; 607, 567 in 85% EtOH (436).

$C_{26}H_{22}N_4O_2$.—5, 5′-*Bis*-*p*-tolueneazo-2, 2′-diphenol: 350 in EtOH (544).

$C_{26}H_{23}N_7$.—Benzeneazobenzeneazobenzeneazodimethylaniline: 513 (111).

$C_{27}H_{20}N_6O_7$.—Diphenylurea-*p*, *p*′-disazo-*bis*-salicylic acid (Na salt, C. I. 346): Cotton Yellow G (600).

$C_{28}H_{22}N_4O_{11}S_3$.—6-Sulfo-*β*-naphthaleneazo-*p*-methylanisoleazo-*β*-naphthol-3, 6-disulfonic acid: Na salt, 543 in H_2O; 539 in 0.02*N* HCl; 537 in 0.02*N* NaOH; 576, 546 in 85% EtOH; 692 in 80% HCOOH (436).

7-Sulfo-*α*-naphthaleneazo-*p*-methylanisoleazo-*β*-naphthol-3, 6-disulfonic acid: Na salt, 552 in H_2O; 548 in 0.02*N* HCl; 553 in 0.02*N* NaOH; 580, 556 in 85% EtOH (436).

$C_{28}H_{22}N_4O_{14}S_4$.—3, 6-Disulfo-*α*-naphthaleneazo-*p*-methylanisoleazo-*β*-naphthol-3, 6-disulfonic acid: Na salt, 553 in H_2O; (602), 553 in 0.02*N* HCl; (587), 551 in 0.02*N* NaOH; 586, 557 in EtOH (436).

3, 6-Disulfo-*β*-naphthaleneazo-*p*-methylanisoleazo-*β*-naphthol-3, 6-disulfonic acid: Na salt, 552 in H_2O; 558 in 0.02*N* HCl; 540 in 0.02*N* NaOH; 576, 500 in 85% EtOH; 705 in 80% HCOOH (436).

$C_{28}H_{22}N_4O_{17}S_5$.—3, 6, 8-Trisulfo-*β*-naphthaleneazo-*p*-methylanisoleazo-*β*-naphthol-3, 6-disulfonic acid: Na salt, 573, 556 in H_2O; 584, 556 in 0.02*N* HCl; 548 in 0.02*N* NaOH; 580, 555 in 85% EtOH; 707 in 80% HCOOH (436).

$C_{28}H_{23}N_5O_8S_2$.—6-Sulfo-*β*-naphthaleneazo-*p*-methylanisoleazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt, 592 in H_2O; 530 in 0.02*N* HCl; (598), 547 in 0.02*N* NaOH; 568, 546 in 85% EtOH (436).

7-Sulfo-*α*-naphthaleneazo-*p*-methylanisoleazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt, 543 in H_2O; 538 in 0.02*N* HCl; 543 in 0.02*N* NaOH; 551 in 85% EtOH (436).

$C_{28}H_{23}N_5O_{11}S_3$.—3, 6-Disulfo-*α*-naphthaleneazo-*p*-methylanisoleazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt, 543 in H_2O; 538 in 0.02*N* HCl; 543 in 0.02*N* NaOH; 551 in 85% EtOH (436).

3, 6-Disulfo-*β*-naphthaleneazo-*p*-methylanisoleazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt, (582), 548 in H_2O; 546 in 0.02*N* HCl; 544 in 0.02*N* NaOH; 572, 546 in 85% EtOH (436).

$C_{29}H_{21}N_5O_7S$.—2-Amino-6-sulfo-*α*-naphtholazodiphenylazosalicylic acid (Na salt, C. I. 419): Diamine Fast Red F, 532.5 on silk (627).

$C_{29}H_{23}N_5O_4S$.—4-Sulfo-*α*-naphthylamineazodiphenylazocresol: (Na salt, C. I. 374): Erie Orange 2R, 483 in H_2O; 490 in 0.1*N* NaOH; 480 in EtOH (677).

$C_{30}H_{22}N_8O$.—Benzeneazobenzeneazobenzeneazobenzeneazophenol: 436 (111).

$C_{30}H_{25}N_5O_8S_2$.—*m*-Sulfobenzeneazo-*p*-methylanisoleazo-6-phenylamino-*α*-naphthol-3-sulfonic acid: Na salt, (603), 544 in H_2O; 534 in 0.02*N* HCl; 553 in 0.02*N* NaOH; 572, 546 in 85% EtOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-6-phenylamino-*α*-naphthol-3-sulfonic acid: Na salt, 545 in H_2O; 535 in 0.02*N* HCl; (590), 552 in 0.02*N* NaOH; 574, 548 in 85% EtOH (436).

$C_{30}H_{25}N_5O_{11}S_3$.—2, 4-Disulfobenzeneazo-*p*-methylanisoleazo-6-phenylamino-*α*-naphthol-3-sulfonic acid: Na salt, 556 in H_2O; 567 in 0.02*N* HCl; 559 in 0.02*N* NaOH; 579, 550 in 85% EtOH (436).

$C_{31}H_{25}N_5O_9S_2$.—*m*-Sulfobenzeneazo-*p*-methylanisoleazo-6-benzoylamino-*α*-naphthol-3-sulfonic acid: Na salt, 604, *520* in H_2O; (614), 518 in 0.02*N* HCl; 536 in 0.02*N* NaOH; 568, 537 in 85% EtOH (436).

p-Sulfobenzeneazo-*p*-methylanisoleazo-6-benzoylamino-*α*-naphthol-3-sulfonic acid: Na salt, (603), 536 in H_2O; (610), 525 in 0.02*N* HCl; 540 in 0.02*N* NaOH; 570, 538 in 85% EtOH (436).

$C_{31}H_{25}N_5O_{12}S_3$.—2, 4-Disulfobenzeneazo-*p*-methylanisoleazo-6-benzoylamino-*α*-naphthol-3-sulfonic acid: Na salt, (603), 539 in H_2O; 532 in 0.02*N* HCl; (596), 544 in 0.02*N* NaOH; 575, 544 in 85% EtOH (436).

$C_{31}H_{27}N_5O_8S_2$.—4-Sulfo-2-methylbenzeneazo-*p*-methylanisoleazo-6-phenylamino-*α*-naphtholsulfonic acid: Na salt, (605), 542 in H_2O; 532 in 0.02*N* HCl; 548 in 0.02*N* NaOH; 571, 546 in 85% EtOH (436).

$C_{32}H_{22}N_4O_2$.—Diphenyldisazo-*bis*-*β*-naphthol (C. I. 381): 640.6, 595.1 in H_2SO_4 (190).

$C_{32}H_{22}N_4O_8S_2$.—Diphenyldisazo-*bis*-*α*-naphthol-2-sulfonic acid: Na salt (424q).

$C_{32}H_{22}N_4O_{11}S_3$.—Diphenyldisazo-8-sulfo-*β*-naphthol-*α*-naphthol-4, 8-disulfonic acid (Na salt, C. I. 386): metallic salts in H_2O; Al, 542, Ba, 540, Cu, 515 (677).

$C_{32}H_{23}N_5O_7S_2$.—Diphenyldisazo-8-sulfo-*β*-naphthol-*α*-naphthylamine-4-sulfonic acid (Na salt, C. I. 376): Congo Rubine (498).

Diphenyldisazo-4-sulfo-*α*-naphthylamine-*α*-naphthol-4-sulfonic acid (Na salt, C. I. 375): (269). Metallic salts in H_2O; Na, 520, Al, 518, Cu, 495 (677).

$C_{32}H_{23}N_7O_{10}S_3$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-*α*-naphthaleneazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt, 576 in H_2O (572 with alkali, 578 with acid) (436).

$C_{32}H_{23}N_7O_{13}S_4$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-7-sulfo-*α*-naphthaleneazo-6-amino-*α*-naphthol-3-sulfonic acid: Na salt, 555 in H_2O (551 with alkali, 566 with acid) (436).

p-Sulfobenzeneazo-*o*-sulfobenzeneazo-7-sulfo-*α*-naphthaleneazo-6-amino-*α*-naphthol-4-sulfonic acid: Na salt, 581 in H_2O (569 with alkali, 580 with acid) (436).

$C_{32}H_{24}N_6O_6S_2$.—Diphenyldisazo-*bis*-*α*-naphthylamine-4-sulfonic acid (Na salt, Congo Red, C. I. 370): 497, 319 in alk. EtOH; 577, (320) in dil. H_2SO_4 (215); *cf.* (468, 525); 500 on cotton (627); influence of concn. (269); quant. data (162q).

$C_{32}H_{24}N_6O_7S_2$.—Diphenyldisazo-4-sulfo-*α*-naphthylamine-7-amino-*α*-naphthol-3-sulfonic acid (Na salt): Pontamine Bordeaux B, metallic salts in H_2O; Na, 510, Ba, 505, Cr, 480, Al, 480 (677).

$C_{32}H_{24}N_6O_8S_2$.—Diphenyldisazo-*bis*-7-amino-*α*-naphthol-3-sulfonic acid (Na salt, C. I. 394): Pontamine Violet N, 520 in H_2O (concd.); 525 (dil.) (269); 545 in EtOH (266); Ba salt, 510 in H_2O (677). Erie Violet 3R identical with above when heated. When dissolved in cold—640, 585 in H_2O (545 in EtOH) (269); *cf.*(266); Ba salt, 635, 590 in H_2O (677).

$C_{32}H_{24}N_6O_{14}S_4$.—Diphenyldisazo-*bis*-8-amino-*α*-naphthol-3, 6-disulfonic acid (Na salt, C. I. 406): Pontamine Blue BBF, metallic salts in H_2O; Na, Ba, 580, Cu, 590, Al, 570, Cr, 595 (677).

$C_{32}H_{27}N_5O_9S_2$.—4-Sulfo-2-methylbenzeneazo-*p*-methylanisoleazo-6-benzoylamino-*α*-naphthol-3-sulfonic acid: Na salt, 641, (598), 530 in H_2O; 638, 522 in 0.02*N* HCl; (630), 542 in 0.02*N* NaOH; 571, 542 in 85% EtOH (436).

$\mathbf{C_{32}H_{27}N_{9}}$.—Benzeneazobenzeneazobenzeneazobenzeneazodimethylaniline: 514 (111).

$\mathbf{C_{33}H_{25}N_{5}O_{6}S_{2}}$.—*m*-Sulfobenzeneazo-$\alpha$-naphthaleneazo-*p*-tolyl-α-naphthylamine-8-sulfonic acid (Na salt, C. I. 289): influence of neutral salts (635, 636); influence of concn. (269).

$\mathbf{C_{33}H_{26}N_{8}O_{15}S_{4}}$.—3, 3′-Disulfodiphenylurea-4, 4′-disazo-*bis*-7-amino-α-naphthol-3-sulfonic acid (Na salt, C. I. 353): soln. and dyeing (22); influence of concn. (269).

$\mathbf{C_{34}H_{24}N_{8}O_{10}S_{2}}$.—Phenolazodiphenylazo-8-amino-3, 6-disulfo-α-naphtholazo-*p*-nitrobenzene (Na salt, C. I. 593): Pontamine Green X (269).

$\mathbf{C_{34}H_{26}N_{4}O_{2}}$.—Ditolyldisazo-*bis*-$\beta$-naphthol: 654.2, 606.1 in H_2SO_4 (190).

$\mathbf{C_{34}H_{26}N_{4}O_{4}}$.—Dimethoxydiphenyldisazo-*bis*-β-naphthol (C. I. 499): 663.2, 614.2 in H_2SO_4 (190).

$\mathbf{C_{34}H_{26}N_{4}O_{10}S_{2}}$.—Dimethoxydiphenyldisazo-*bis*-α-naphthol-4-sulfonic acid (Na salt, C. I. 502): Pontamine Blue AX, metallic salts in H_2O; Na, 552, Cr, 550, Ba, 540, Al, Cu, 520 (677).

$\mathbf{C_{34}H_{27}N_{5}O_{8}S_{2}}$.—7-Sulfo-$\alpha$-naphthaleneazo-*p*-methylanisoleazo-6-phenylamino-α-naphthol-3-sulfonic acid: Na salt, 560 in H_2O; 569 in 0.02*N* HCl; 550 in 0.02*N* NaOH (436).

$\mathbf{C_{34}H_{27}N_{5}O_{11}S_{3}}$.—3, 6-Disulfo-$\alpha$-naphthaleneazo-*p*-methylanisoleazo-6-phenylamino-α-naphthol-3-sulfonic acid: Na salt, (608), 556 in H_2O; 554 in 0.02*N* HCl; 553 in 0.02*N* NaOH (436).

3, 6-Disulfo-β-naphthaleneazo-*p*-methylanisoleazo-6-phenylamino-α-naphthol-3-sulfonic acid: Na salt, 555 in H_2O; 555 in 0.02*N* HCl; 558 in 0.02*N* NaOH; 582, 555 in 85% EtOH (436).

3, 6-Disulfo-8-amino-α-naphtholazoditolylazo-α-naphthol-4-sulfonic acid (Na salt, C. I. 472): Niagara Blue BR, 568 in H_2O at 23°; 567 at 49°; 565 at 76° (677).

$\mathbf{C_{34}H_{27}N_{5}O_{12}S_{3}}$.—3, 7-Disulfo-$\beta$-naphtholazoethoxybenzidineazo-7-amino-α-naphthol-3-sulfonic acid (Na salt, C. I. 492): 580 in H_2O (dissolved cold); 575 (dissolved hot); 565 in EtOH (266); *cf.* (269).

$\mathbf{C_{34}H_{27}N_{5}O_{14}S_{4}}$.—3, 6, 8-Trisulfo-$\beta$-naphthaleneazo-*p*-methylanisoleazo-6-phenylamino-α-naphthol-3-sulfonic acid: Na salt, 562 in H_2O; 561 in 0.02*N* HCl; 560 in 0.02*N* NaOH; 580, 556 in 85% EtOH (436).

$\mathbf{C_{34}H_{28}N_{6}O_{6}S_{2}}$.—Ditolyldisazo-*bis*-$\alpha$-naphthylamine-4-sulfonic acid (Na salt, C. I. 448): Erie Red 4B, 490 in H_2O (concd.); 498 (dil.); 505 in EtOH (269). Purpurine 4B (DuP.), 490 in H_2O (concd.), 496 (dil.), 510 in EtOH (677). Benzopurpurine 4B (By), on cotton, 505 (627). Diamine Red 4B, 512.5 on cotton (627).

Ditolyldisazo-*bis*-α-naphthylamine-5-sulfonic acid (Na salt, C. I. 449). Metallic salts of Benzopurpurine 6B in H_2O: Na, Cu, Al, 500; Cr, 505 (677).

$\mathbf{C_{34}H_{28}N_{6}O_{9}S_{2}}$.—Ethoxydiphenyldisazo-*bis*-7-amino-α-naphthol-3-sulfonic acid (Na salt, C. I. 493): Diamine Black BO, dissolved with heat, 600 in H_2O (concd.); 580 (dil.); dissolved cold, 580 in H_2O (concd.); 570 (dil.); 570 in EtOH (266); *cf.* (269).

$\mathbf{C_{34}H_{28}N_{6}O_{9}S_{3}}$.—Ditolyldisazo-3, 6-disulfo-β-naphthylamine-β-naphthylamine-6-sulfonic acid (Na salt, Vital Red, C. I. 456): 500 in H_2O (269).

$\mathbf{C_{34}H_{28}N_{6}O_{14}S_{4}}$.—Ditolyldisazo-*bis*-8-amino-α-naphthol-3, 6-disulfonic acid (Na salt, Trypan Blue, C. I. 477): 585 in H_2O (485q); *cf.* (473).

$\mathbf{C_{34}H_{28}N_{6}O_{16}S_{4}}$.—Dimethoxydiphenyldisazo-*bis*-8-amino-α-naphthol-3, 6-disulfonic acid (Na salt, C. I. 520): Pontamine Sky Blue 5BX, 595 in H_2O (concd.), 603 (dil.) (269). Metallic salts in H_2O: Na, 603, Al, 605, Cr, 610, Ba, 610, Cu, 580 (677).

Dimethoxydiphenyldisazo-*bis*-8-amino-α-naphthol-5, 7-disulfonic acid (Na salt, C. I. 518): Pontamine Sky Blue 6BX, lakes with Methylene Blue (265). Metallic salts in H_2O; Na, 620, Cu, 620, 670, Cr, 590, Ba, 618 (677).

$\mathbf{C_{35}H_{27}N_{5}O_{12}S_{3}}$.—3, 6-Disulfo-$\beta$-naphthaleneazo-*p*-methylanisoleazo-6-benzoylamino-α-naphthol-3-sulfonic acid: Na salt (601), 535 in H_2O; 516 in 0.02*N* HCl; 543 in 0.02*N* NaOH: 560 in 85% EtOH (436).

$\mathbf{C_{35}H_{27}N_{5}O_{15}S_{4}}$.—3, 6, 8-Trisulfo-$\beta$-naphthaleneazo-*p*-methylanisoleazo-6-benzoylamino-α-naphthol-3-sulfonic acid: Na salt, (596), 540 in H_2O; 535 in 0.02*N* HCl; 543 in 0.02*N* NaOH; 576, 538 in 85% EtOH (436).

$\mathbf{C_{38}H_{27}N_{7}O_{10}S_{3}}$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-α-naphthaleneazo-6-phenylamino-α-naphthol-3-sulfonic acid: Na salt, 593 in H_2O (580 with alkali, 621 with acid) (436).

$\mathbf{C_{38}H_{27}N_{7}O_{13}S_{4}}$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-7-sulfo-α-naphthaleneazo-6-phenylamino-α-naphthol-3-sulfonic acid: Na salt, 575 in H_2O (556 with alkali, 578 with acid) (436).

p-Sulfobenzeneazo-*o*-sulfobenzeneazo-7-sulfo-α-naphthaleneazo-6-phenylamino-α-naphthol-4-sulfonic acid: Na salt, 601 in H_2O (580 with alkali, 608 with acid) (436).

$\mathbf{C_{39}H_{29}N_{7}O_{10}S_{3}}$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-α-naphthaleneazo-6-*p*-tolylamino-α-naphthol-3-sulfonic acid: Na salt, 595 in H_2O (587 with alkali, 620 with acid) (436).

$\mathbf{C_{39}H_{29}N_{7}O_{13}S_{4}}$.—*p*-Sulfobenzeneazo-*o*-sulfobenzeneazo-7-sulfo-α-naphthaleneazo-6-*p*-tolylamino-α-naphthol-3-sulfonic acid: Na salt, 578 in H_2O (560 with alkali, 579 with acid) (436).

p-Sulfobenzeneazo-*o*-sulfobenzeneazo-7-sulfo-α-naphthaleneazo-6-*p*-tolylamino-α-naphthol-4-sulfonic acid: Na salt, 603 in H_2O; (576 with alkali, 604 with acid) (436).

$\mathbf{C_{46}H_{34}N_{10}O_{13}S_{3}}$.—4-Sulfo-$\alpha$-naphthaleneazo-3, 6-disulfo-α-naphthol-7-azo-*m*-toluylenediamineazodiphenylazosalicylic acid (Na salt, C. I. 561): Trisulfon Brown B (22).

Diazine Black D. R. Concd. (probably identical with Zambesi Black II): 560 in H_2O (concd.); 565 (dil.); 585 in EtOH (266, 269).

Diazo Dark Blue 3B: 560 in H_2O (concd.), 570 (dil.), 590 in EtOH (266, 269).

Pontachrome Yellow 3R: on wool (10).

Pontamine Copper Blue RRX (probably N. W. acid→benzidine →2-amino-8-naphthol-5-sulfonic acid): 545 in H_2O (concd.); 555 (dil.) (269). Metallic salts in H_2O: Na, 555, Ba, 550, Al, 510, Cu, 530 (677).

TABLE 3.—TRIPHENYLMETHANE DERIVATIVES

$\mathbf{C_{19}H_{10}Br_{4}O_{2}}$.—*m*-Tetrabromobenzaurin (subst. in phenol residues): 583 in alk. H_2O (461).

$\mathbf{C_{19}H_{13}BrO_{2}}$.—*o*-Bromobenzaurin (subst. in benzene residue): 568 in alk. H_2O (461).

m-Bromobenzaurin (subst. in benzene residue): 565 in alk. H_2O (461).

p-Bromobenzaurin (subst. in benzene residue): 539 in alk. H_2O (461).

$\mathbf{C_{19}H_{13}BrN_{2}O_{4}}$.—*p*-Bromo-*p*-dinitrotriphenylmethane: 274 in EtOH; Na salt, 513 in EtOH and C_6H_6 (221).

$\mathbf{C_{19}H_{13}N_{3}O_{6}}$.—*p*-Trinitrotriphenylmethane: Na salt, 549 in EtOH (221).

$\mathbf{C_{19}H_{14}O}$.—Fuchsone: *381*, 262, 250 in EtOH; *462*, 402, (289), *248* in concd. H_2SO_4; 472, 381, 283, 278, 270 in EtOH + HCl; 286, *250*, in EtOH + KOH (491q); 379, (262) in $CHCl_3$ (219); (471 with excess $SnCl_4$ (438)); *cf.* (213, 218, 438, 442, 454, 470).

$\mathbf{C_{19}H_{14}O_{2}}$.—Benzaurin: *435*, 343, (284), 275 in EtOH; *504*, 402, (284, 276, 266) in EtOH + HCl; *473*, 410, (292, 285?), 256 in concd. H_2SO_4; 567, 379, 296, *250* in EtOH + KOH; 345, 296, 247 in 33% KOH (489q); *cf.* (155, 438, 442, 454, 461, 463, 491q).

$\mathbf{C_{19}H_{14}O_{3}}$.—Aurin: *463*, (385, 297, 276), 265 in EtOH; *476*, (428, 333, 298, 289), *260* in concd. H_2SO_4; *482*, (338, 309), 272, 266 in EtOH + HCl; *536*, (500), 283 in EtOH + KOH; (364), 298, *248* in concd. aq. KOH (491q); *cf.* (57, 155, 174, 196, 231, 454, 461, 525).

(520) Pope, *4*, **93:** 532; 08. (521) Pope and Willett, *4*, **103:** 1258; 13. (522) Porai-Koschitz and Auschkap, *Z. Farben-Ind.*, **10:** 321; 11. (523) Porai-Koschitz, Auschkap and Amsler, *53*, **43:** 1587; 11. (524) Posner, *25*, **59:** 1799; 26. (525) Prideaux, *The theory and use of indicators.* London, 1917. (526) Priest, *348*, **3:** 37; 20. (527) Przibram, *278*, **153:** 385; 13. (528) Pulfrich, *8*, **14:** 177; 81. (529) Pummerer, Eckert and Gassner, *25*, **47:** 1494; 14.

(530) Pummerer and Rebmann, *25*, **61:** 1099; 28. (531) Purvis, *4*, **97:** 2535; 10. (532) Purvis, *4*, **105:** 590; 14. (533) Purvis, *4*, **107:** 660; 15. (534) Purvis and McCleland, *4*, **101:** 514; 12. (535) Quagliariello, *Arch. sci. biol.*, **3:** 65; 22. (536) Quagliariello, *Pubbl. staz. zool. Napoli, Ric. fisiol. chim. biol.*, **1:** 57; 22. (537) Regnier, *206*, **95:** 77; 26. (538) Reinhard, *223*, **11:** 1; 27. (539) Reitzenstein and Bönitsch, *52*, **86:** 1; 12.

(540) Reitzenstein and Breuning, *13*, **372:** 257; 10. (541) Reitzenstein and Schwerdt, *52*, **75:** 369; 07. (542) Reitzenstein and Stamm, *52*, **81:** 150; 10. (543) Robertson, *4*, **103:** 1473; 13. (544) Robertson and Brady, *4*, **103:** 1479; 13. (545) Rodio, *22*, **1:** 188; 25. (546) Rohn, *8*, **38:** 987; 12. (547) Romieu and Obata, *34*, **175:** 51; 22. (548) Rost, Franz and Heise, *291*, **31:** 223; 09. (549) Sando, *Am. J. Botany*, **6:** 242; 19.

(550) Sando, *141*, **68:** 407; 26. (551) Sando and Bartlett, *141*, **54:** 629; 22. (552) Sando and Lloyd, *141*, **58:** 737; 24. (553) Scheff, *205*, **168:** 451; 26. (554) Scheibe, *25*, **56:** 137; 23. (555) Scheibe and Fischer, *25*, **59:** 502; 26. (556) Scheibe and Rossner, *25*, **56:** 137; 23. (557) Schertz, *341*, **26:** 383; 23. (558) Schertz, *341*, **30:** 253; 25. (559) Schneider and Kunzl, *Z. Mikroskopie*, **23:** 394; 06.

(560) Schou, *37*, **10:** 907; 27. (561) Schultz, *205*, **127:** 112; 22. (562) Schumm, *202*, **83:** 1; 13. (563) Schumm, *202*, **90:** 1; 14. (564) Schumm, *202*, **132:** 34; 24. (565) Schumm, *202*, **136:** 243; 24. (566) Schumm, *202*, **139:** 219; 24. (567) Schumm, *202*, **147:** 221; 25. (568) Schumm, *202*, **149:** 1; 25. (569) Schumm, *202*, **149:** 111; 25.

(570) Schumm, *202*, **150:** 276; 25. (571) Schumm, *202*, **152:** 1; 26. (572) Schumm, *202*, **152:** 55; 26. (573) Schumm, *202*, **152:** 147; 26. (574) Schumm, *202*, **153:** 225; 26. (575) Schumm, *202*, **156:** 268; 26. (576) Schumm, *202*, **159:** 194; 26. (577) Schumm, *202*, **164:** 143; 27. (578) Schumm, *202*, **169:** 52; 27. (579) Schumm and Mertens, *202*, **156:** 61; 26.

(580) Schumm and Papendieck, *202*, **159:** 190; 26. (581) Scott and French, *Military Surgeon*, Sept., 1924. (582) Semper, *13*, **381:** 234; 11. (583) Shaeffer, Paulus and Jones, *1*, **37:** 776; 15. (584) Shapiro, *1*, **50:** 1772; 28. (585) Sheard, Baldes, Mann and Bollman, *131*, **76:** 577; 26. (586) Sheard, Mann and Bollman, *131*, **81:** 774; 27. (587) Sheppard, *204*, **48:** 300; 08. (588) Sheppard, *5*, **82:** 256; 09. (589) Shibata, *558*, **1:** 106; 23.

(590) Shibata and Kimotsuki, *41*, **39:** 771; 18. (591) Shibata and Kimotsuki, *558*, **1:** 91; 23. (592) Shibata and Nagai, *41*, **43:** 101; 22. (593) Shibata and Nagai, *558*, **2:** 25; 24. (594) Singh, Rai and Lal, *4*, **121:** 1421; 22. (595) Sircar, *4*, **109:** 757; 16. (596) Smith and Boord, *1*, **44:** 1449; 22. (597) Stevens and Ward, *4*, **125:** 1324; 24. (598) Stobbe and Nowak, *25*, **46:** 2887; 13. (599) Strub, *99*, **24:** 97; 26.

(600) Stumpf, *99*, **20:** 183; 21. (601) Suhrmann and Kollath, *205*, **184:** 216; 27. (602) Svedberg and Pihlblad, *7*, **74:** 513; 10. (603) Szceniovski, *165*. **1927A:** 127. (604) Szilárd, *205*, **170:** 185; 26. (605) Tasaki, *558*, **2:** 49; 25. (606) Tasaki, *558*, **2:** 119; 25. (607) Tasaki, *558*, **2:** 129; 25. (608) Tasaki, *558*, **3:** 1; 27. (609) Tasaki, *558*, **3:** 21; 27.

(610) Teodoresco, *34*, **163:** 62; 16. (611) Téthi, *205*, **192:** 105; 28. (612) Thiel and Dassler, *25*, **56:** 1667; 23. (613) Thiel, Dassler and Wülfken, *237*, **18:** No. 3; 24. (614) Treibs, *202*, **168:** 68; 27. (615) Tschirch and Ludy, *37*, **6:** 994; 23. (616) Tswett, *34*, **152:** 788; 11. (617) Tswett, *Ber. botan. Ges.*, **29:** 630; 11. (618) Tuck, *4*, **91:** 449; 07. (619) Tuck, *4*, **95:** 1809; 09.

(620) Uemura and Tabei, *41B*, **2:** 229; 27. (621) Uemura and Tabei, *41B*, **2:** 249; 27. (622) Uemura, Yokojima and Endo, *41B*, **2:** 10; 27. (623) Uemura, Yokojima and Endo, *41B*, **2:** 48; 27. (624) Uemura, Yokojima and Tan, *41B*, **1:** 260; 26. (625) Unger and Hofmann, *25*, **29:** 1362; 96. (626) Ursprung, *Ber. botan. Ges.*, **36:** 73; 18. (627) Uspenski and Woronkoff, *96*, **17:** 112; 23. (628) Vaillant, *34*, **184:** 939; 27. (629) Vaillant, *51*, **8:** 391; 27.

(630) Venable, *48*, **10:** 133; 25. (631) Ville and Derrien, *34*, **140:** 1195; 05. (632) Vlès, *34*, **169:** 303; 19. (633) Vlès, *561*, **2:** 125; 20. (634) Vlès, *561*, **2:** 223; 20. (635) Vlès, *34*, **185:** 644; 27. (636) Vlès and Gex, *34*, **185:** 946; 27. (637) Vogel, *8*, **43:** 449; 91. (638) Vogt, *7*, **132:** 101; 28. (639) Volta and Viterbi, *Boll. soc. ital. biol. sper.*, **2:** 431; 27.

(640) Wahl and Bagard, *27*, **15:** 336; 14. (641) Wahl and Faivret, *14*, **5:** 314; 26. (642) Wales, *1*, **45:** 2420; 23. (643) Wales and Palkin, *1*, **48:** 810; 26. (644) Watson and Meek, *4*, **107:** 1567; 15. (645) Watson, Sen and Medhi, *4*, **107:** 1477; 15. (646) Weber, *Z. biol. Tech. Methodik*, **2:** 29; 10. (647) Weigert, *25*, **49:** 1496; 16. (648) Wick, *2*, **24:** 356; 07. (649) Willgerodt and Maffezzoli, *52*, **82:** 205; 10.

(650) Wille, *Ber. botan. Ges.*, **40:** 188; 22. (651) Willstätter and Asahina, *13*, **385:** 188; 11. (652) Willstätter and Benz, *13*, **358:** 267; 08. (653) Willstätter and Bolton, *13*, **408:** 42; 15. (654) Willstätter and Escher, *202*, **64:** 47; 10. (655) Willstätter and Escher, *202*, **76:** 214; 12. (656) Willstätter and Everest, *13*, **401:** 189; 13. (657) Willstätter and Fischer, *202*, **87:** 423; 13. (658) Willstätter and Fritzsche, *13*, **371:** 33; 09. (659) Willstätter and Mallison, *13*, **408:** 15; 15.

(660) Willstätter and Mieg, *13*, **408:** 61; 15. (661) Willstätter and Pfannenstiel, *13*, **358:** 205; 08. (662) Willstätter and Stoll, *Untersuchungen über Chlorophyll.* Berlin, 1913. (663) Willstätter, Stoll and Utzinger, *13*, **385:** 156; 11. (664) Willstätter, Zechmeister and Kindler, *25*, **57:** 1938; 24. (665) Willstätter and Zollinger, *13*, **408:** 83; 15. (666) Winther, *9*, **19:** 389; 13. (667) Wise and Adams, *45*, **10:** 801; 18. (668) Wise and Adams, *45*, **11:** 460; 19. (669) Wolff, *91*, **17:** 65; 78.

(670) Yaoi and Tamiya, *543*, **4:** 436; 28. (671) Zaleski, *25*, **46:** 1687; 13. (672) Zaleski, *53*, **48:** 1337; 16. (673) Zechmeister and Cholnoky, *13*, **454:** 54; 27. (674) Zeynek, *75*, **121:** 1495; 12. (675) Zeynek, *75*, **121:** 1539; 12. (676) Zilner, *205*, **192:** 118; 28. (677) Holmes, *0*.

VISCOSITY OF PURE LIQUIDS

F. Giordani

Units.—All values of the viscosity, η, are expressed in poises. The values tabulated are those of 100η which are equivalent to values of η expressed in centipoises.	*Unités.*—Toutes les valeurs de la viscosité, η, sont exprimées en poises. Les valeurs mentionnées dans les tables sont celles de 100η qui sont équivalentes aux valeurs de η exprimées en centipoises.	*Einheiten.*—Alle Werte der Viskosität, η, sind in C. G. S.-Einheiten ausgedrückt. Die in Zahlentafeln stehen Werte gelten für 100η und entsprechen den Werten von η, die in Hundert-C. G. S.-Einheiten gegeben sind.	*Unità.*—Tutti i valori della viscosità, η, sono espressi in poise. I valori nelle tabelle sono quelli di 100η che sono equivalenti al valore di η espresso in centipoise.

𝔄-TABLE, ELEMENTARY SUBSTANCES

$$100\eta_t = \frac{a}{1 + 10^{-3}bt + 10^{-6}ct^2}$$

Br_2 (84)

t, °C	100η
−2.6	1.287*
+7	1.136
13.6	1.058
19.5	0.995
27	0.925
31.4	0.901
−4.3	1.311†
+4.9	1.164
12.6	1.071
19.1	1.003

a = 1.241
b = 12.257
c = 8.721

* Purified with KOH.

† Prepared from pure KBr.

Cl_2 (84)

t, °C	100η
−76.5	0.729
−74	0.710
−70.5	0.680
−65.8	0.649
−65.4	0.646
−60.2	0.616
−60	0.610
−53	0.569
−52.4	0.566
−45.1	0.530
−44.1	0.524
−35.4	0.494
−33.8	0.489

a = 0.385
b = 5.878
c = −3.92

H_2 (94)

−252.57	0.0130

I_2 (84)

116	2.268
116.6	2.246
121.9	2.157
122.8	2.180
128.7	2.080
136.1	1.979
142.7	1.870
147.8	1.822
149	1.813
152.5	1.770
157.7	1.716
158.9	1.688
169.8	1.572
171.4	1.545
178.7	1.462

a = 9.68
b = 21.833
c = 52.01

O_2 (96%) (95)

−252.07	0.189

S (37)

t, °C	100η
123	10.94
135.5	8.66
149.5	7.09
156.3	7.19
158.8	7.59
159.2	9.48
159.5	14.45
160	22.83
160.3	77.32
165	500
171	4 500
184	16 000
190.5	19 700
197.5	21 300
200	21 500
210	20 500
217	19 100
222	18 600
	(8)
121	9.94
	9.92 *
	11.4 †
	10.27 ‡

* After 1 hour standing at 121°.

† After many hours standing at 200° and subsequent cooling to 121°.

‡ After further standing 1 hour at 121°.

𝔅-TABLE, STANDARD ARRANGEMENT (*v.* Vol. III, p. viii)

H_2O

v. Vol. V, p. 10

SO_2 (38)

t, °C	100η
−33.5	0.5508
−10.5	0.4285
0.1	0.3936

H_2SO_4

v. Vol. V, p. 11

N_2O_4 (91)

0.72	0.5220
5.09	0.4954
9.15	0.4720
11.87	0.4578
15.36	0.4401

$$\eta_t = \frac{28.155}{(140.89 + t)^{1.7349}}$$

NH_3

−33.5	0.254 (34)
−33.5	0.266 (38)

NOCl (15)

−33.3	0.642
−29.5	0.604
−27	0.586
−25.2	0.567
−20	0.547

$SbBr_3$ (57)

t, °C	100η
95	3.31
100	3.12

$BiCl_3$ (4)

260	32.0
270	29.5
280	27.0
290	25.0
300	23.0
310	21.5
320	20.5
330	19.0
340	18.0

CO_2

v. Vol. V, p. 11

For other C-compounds, *v.* the ℭ-Table *infra*

$SnCl_4$ (56)

25	0.919
30	0.806
40	0.725
50	0.668
70	0.60

$PbCl_2$ (63)

t, °C	100η
498	5.53
508	5.06
518	4.66
528	4.30
538	4.02
548	3.78
558	3.59
568	3.42
578	3.28
588	3.16
598	3.06
608	2.95

$PbBr_2$ (63)

372	10.2
382	8.80
392	8.06
402	7.47
412	6.97
422	6.53
432	6.13
442	5.74
452	5.38
462	5.03
472	4.70
482	4.38
492	4.07

$HgBr_2$ (8)

t, °C	100η
240	3.31
247	2.97
258	1.97

HgI_2 (8)

258	3.54

AgCl (62)

603	1.60
632	1.46
669	1.37
734	1.18

AgBr (62)

609	1.86
649	1.66
688	1.49
770	1.22
803	1.19

AgI (62)

605	3.02
611	2.85
630	2.75
698	2.37
730	2.12
792	1.85
806	1.68
827	1.55

$AgNO_3$ (40)

244	3.77
265	3.27
275	3.04
309	2.61
342	2.29

B_2O_3 (2)

750	43 600
800	26 000
850	17 000
900	11 800
950	9 000
1 000	7 000
1 050	5 300
1 100	4 000

$LiNO_3$ (40)

t, °C	100η
259	5.58
269	5.10
274	4.85
284	4.50
310	3.69
317.5	3.49
319	3.48
320	3.47

NaOH (3)

350	4.0
400	2.8
450	2.2
500	1.8
550	1.5

NaCl (61)

841	1.30
850	1.20
896	1.01
924	0.97

NaBr (61)

762	1.42
766	1.35
780	1.28

$NaNO_3$ (63)

308	2.92
318	2.78
328	2.66
338	2.54
348	2.44
358	2.33
368	2.24
378	2.14
388	2.06
398	1.98
408	1.90
418	1.83
	(40)
337	2.53
353	2.29
356	2.28
385.2	1.99
406	1.77
495	1.32

$NaPO_3$ (2)

650	1250
700	700
750	440
800	300
850	210

KOH (3)

t, °C	100η
400	2.3
450	1.7
500	1.3
550	1.0
600	0.8

KCl (61)

790	1.42
835	1.21
920	0.99
1035	0.71

KBr (61)

745	1.48
775	1.34
805	1.19

KNO_3 (63)

333	2.97
343	2.83
353	2.69
363	2.56
373	2.44
383	2.33
393	2.21
403	2.11
413	2.01
	(40)
347	2.79
371	2.35
377	2.29
396	2.14
418	1.89
462	1.58
506	1.34

$K_2Cr_2O_7$ (63)

397	13.4
407	12.6
417	11.8
427	11.2
437	10.6
447	9.9
457	9.4
467	8.8
477	8.2
487	7.7
497	7.1
507	6.6

ℭ-TABLE; ℭ-ARRANGEMENT (*v.* Vol. III, p. viii)

A, B, n are the coefficients in the formula $\eta = \frac{A}{(B + t)^n}$

CCl_4 (91), Carbon tetrachloride

t, °C	100η	t, °C	100η
0.60	1.3322	42.08	0.7198
7.15	1.8884	49.51	0.6567
14.89	1.0476	56.29	0.6078
21.21	0.9517	62.87	0.5659
27.56	0.8705	69.89	0.5246
35.21	0.7855	74.16	0.5017

A = 32.780
B = 95.05
n = 1.7121

(60)

t, °C	100η
25	0.8876

CS_2 (91)
Carbon disulfide

t, °C	100η
0.4	0.428
4.88	0.413
9.45	0.397
14.91	0.381
19.94	0.367
25.34	0.356
30.30	0.342
35.51	0.328
40.60	0.317
45.96	0.306

A = 24.379
B = 199.17
n = 1.6328

$CHBr_3$
Bromoform

(8)	
6.4	2.381
(20)	
10	2.217
76.5	1.009

$CHCl_3$
Chloroform
v. Vol. V, p. 11

HCN (102)
Hydrogen cyanide

−7.5	0.259
+5.0	0.232
10.8	0.218
15.1	0.211
20.2	0.201

CH_2Br_2 (26)
Methylene bromide

25	0.1225

CH_2Cl_2 (91)
Methylene chloride

0.46	0.5329
5.73	0.5023
10.18	0.4794
15.45	0.4545
20.53	0.4330
25.59	0.4137
30.98	0.3933
37.51	0.3707

A = 5.8768
B = 128.88
n = 1.4408

CH_2O_2 (91); *cf.* (10, 68, 82)
Formic acid

7.59	2.385
15.96	1.951
24.16	1.635
32.86	1.379
40.36	1.208
48.03	1.064
56.30	0.937
64.20	0.838
72.05	0.754
80.22	0.681
97.23	0.558

CH_2O_2.—*(Cont'd)*
A = 32.8143
B = 59.799
n = 1.7164

CH_3I (91); *cf.* (39)
Methyl iodide

t, °C	100η
0	0.593
0.42	0.5914
6.06	0.5576
10.53	0.5330
15.81	0.5064
21.37	0.4810
27.22	0.4564
33.38	0.4323
39.96	0.4090

A = 6.6577
B = 134.32
n = 1.4329

CH_3NO (20)
Formamide

0	7.552
76.5	1.254
(68)	
25	3.359
40	2.379
(27)	
105	0.768
120	0.659

A = 874
B = 60.78
n = 2.2780

CH_3NO_2 (18)
Nitromethane

25	0.619
(74)	
0	0.843
25	0.631
40	0.526
55	0.450
70	0.392
85	0.342

CH_4O
Methyl alcohol
v. Vol. V, p. 11

CH_5N (38)
Methylamine

0	0.2364

C_2Cl_4 (91)
Tetrachloroethylene

0	1.133
11.24	0.986
22.30	0.869
32.34	0.784
42.78	0.707
52.68	0.645
64.14	0.585
74.67	0.536
85.75	0.491
95.60	0.455
106.03	0.422
117.09	0.390

C_2Cl_4.—*(Cont'd)*
A = 30.656
B = 126.17
n = 1.6325

t, °C	100η
(13)	
25	0.841
50	0.656
75	0.534

C_2Cl_6
Hexachloroethane

(79)	
25	2.26

C_2HBr_3O (33)
Bromal

25	5.31
40	3.725
50	3.026
60	2.501
70	2.081
85	1.607
100	1.264

C_2HCl_3 (44)
Trichloroethylene

25	0.550
50	0.446
75	0.371

C_2HCl_3O (33)
Chloral

25	0.1263
40	1.01
50	0.87
70	0.68
85	0.56

$C_2HCl_3O_2$ (49)
Trichloroacetic acid

60	3.97
70	3.15

C_2HCl_5 (79)
Pentachloroethane

0	3.73
25	2.26
(44)	
25	2.176
50	1.480
75	1.061

$C_2H_2Br_2$ (91)
1, 2-Acetylene dibromide

0.86	1.217
10.95	1.070
19.93	0.960
30.14	0.859
39.49	0.782
47.80	0.722
57.96	0.659
67.19	0.610
76.72	0.565
85.95	0.525
97.10	0.483
105.72	0.454

A = 14.868
B = 112.29
n = 1.5032

$C_2H_2Cl_2$ (44)
cis-1, 2-Acetylene dichloride

t, °C	100η
25	0.391

$C_2H_2Cl_2$ (44)
trans-1, 2-Acetylene dichloride

25	0.4564
50	0.3685

$C_2H_2Cl_4$ (17*)
1, 1, 2, 2-Tetrachloroethane

0	2.656
10	2.147
15	1.952
25	1.637
35	1.389
50	1.132
(44)	
75	0.8185
(20)	
80	0.763

$*1/\eta_t = 0.13796 \times [1 + 0.019171t + 0.00000925t^2] \times (273.1 + t)$.

$C_2H_3Br_3O_2$ (33)
Bromal hydrate

40	46.14
50	20.69
60	10.9
70	6.349
85	5.166
100	2.00

C_2H_3N (78)
Acetonitrile

25	0.36

$C_2H_4Br_2$
Ethylene bromide

(91)	
9.49	2.053
20.63	1.698
31.21	1.445
41.64	1.252
51.81	1.099
62.87	0.967
73.48	0.862
85.97	0.762
95.81	0.694
105.71	0.634
117.01	0.577
126.71	0.532

A = 30.535
B = 80.802
n = 1.6222

$C_2H_4Cl_2$ (91)
1,1-Dichloroethane

7.06	0.5686
11.24	0.5413
15.34	0.5156
19.31	0.4934
23.22	0.4736
27.85	0.4506
31.55	0.4337

$C_3H_4Cl_2$.—*(Cont'd)*

t, °C	100η
35.61	0.4160
40.18	0.3976
43.74	0.3836
47.95	0.3695
54.54	0.3476

A = 22.247
B = 132.02
n = 1.6762

$C_2H_4Cl_2$ (91)
Ethylene chloride

0.31	1.1211
7.23	1.0021
14.73	0.8961
21.84	0.8129
28.78	0.7417
36.88	0.6695
43.89	0.6166
51.74	0.5668
58.53	0.5239
65.53	0.4912
72.95	0.4558
81.07	0.4217

A = 24.256
B = 100.67
n = 1.6641

C_2H_4O (91)
Acetaldehyde

0.33	0.2663
5.35	0.2538
9.56	0.2442
13.92	0.2345
19.17	0.2234

A = 15652.2
B = 286.11
n = 2.7550

C_2H_4O (64)
Ethylene oxide

−49.8	0.5772
−45.7	0.5387
−38.2	0.4883
−32.6	0.4505
−21	0.3937
−13.6	0.3637
0	0.3202
+ 9.3	0.2927

$C_2H_4O_2$ (91)
Acetic acid

30.86	1.025
39.88	0.903
48.47	0.806
57.46	0.721
68.10	0.638
76.66	0.580
84.53	0.534
93.97	0.484
102.89	0.445
112.57	0.406

A = 267.814
B = 112.207
n = 2.0492

$C_2H_4O_2$.—*(Cont'd)*

t, °C	100η
(13*)	
25	1.148
35	0.991
45	0.865
55	0.760
65	0.676
75	0.607
85	0.546
95	0.489
(39)	
20	1.234
(49)	
25	1.121

$*1/\eta_t = 0.2072 [1 + 0.01597t + 0.0000178t^2] \times (273.1 + t)$.

$C_2H_4O_2$ (92)
Methyl formate

0.58	0.4263
6.39	0.3999
10.88	0.3809
15.63	0.3626
20.15	0.3467
25.52	0.3298
29.25	0.3190

A = 0.144673
B = 68.234
n = 0.8325

(39)	
20	0.367

C_2H_5Br (91)
Ethyl bromide

0.34	0.4759
5.18	0.4525
9.67	0.4327
15.46	0.4087
20.54	0.3903
25.28	0.3734
30.03	0.3581
36.15	0.3394

A = 6.8898
B = 138.65
n = 1.4749

(46)	
19.2	0.3973
19.9	0.3968
46	0.3037
77	0.2336

C_2H_5I (91)
Ethyl iodide

0.28	0.7167
7.70	0.6605
13.18	0.6235
20.80	0.5782
26.09	0.5496
32.98	0.5151
38.74	0.4891
45.24	0.4621
51.39	0.4387
57.51	0.4168
63.72	0.3966
69.38	0.3792

A = 50.810
B = 157.42
n = 1.7520

C_2H_5I.—(*Cont'd*)

t, °C	100η

(79)

0	0.725

C_2H_5NO (27)

Acetamide

105	1.32
120	1.06

$C_2H_5NO_2$ (81)

Methyl carbamate

55.6	2.28
74.6	1.37
82.2	1.24
99	0.85

C_2H_6O

Ethyl alcohol

v. Vol. V, p. 11

$C_2H_6O_2$ (23)

Glycol

25	17.4

$C_2H_6O_4S$ (20)

Dimethyl sulfate

0	2.73_2
76.5	0.80_2

C_2H_6S (91)

Methyl sulfide

0.27	0.3529
5.56	0.3351
10.05	0.3209
14.75	0.3075
20.19	0.2927
26.14	0.2776
31.35	0.2655
35.81	0.2559

A = 21.768
B = 170.34
n = 1.6981

C_2H_6S (22)

Ethylmercaptan

25	0.210

C_2H_7N (34)

Dimethylamine

−33.5	0.3208

C_2H_7N (34)

Ethylamine

−33.5	0.4368

$C_2H_8N_2$ (26)

Ethylenediamine

25	1.54

$C_3H_2N_2$ (103)

Malonic nitrile

32.68	2.85
50	2.15

C_3H_5Br (91)

3-Bromopropylene

0.30	0.6168
6.64	0.5730
12.42	0.5372
18.34	0.5046
24.73	0.4727
30.84	0.4449
37.22	0.4198
42.84	0.3988
47.86	0.3805
54.55	0.3587

C_3H_5Br.—(*Cont'd*)

t, °C	100η
61.15	0.3402
68.67	0.3193

A = 30.360
B = 145.03
n = 1.7075

C_3H_5Cl (91)

3-Chloropropylene

0.53	0.4035
5.98	0.3800
11.19	0.3598
16.66	0.3408
21.93	0.3230
28.32	0.3039
33.97	0.2885
38.37	0.2774
42.10	0.2681

A = 27.705
B = 157.08
n = 1.7549

C_3H_5ClO (18)

α-Epichlorohydrin

25	1.03

C_3H_5I (91)

3-Iodopropylene

0.33	0.926
9.33	0.825
16.77	0.754
26.12	0.679
35.77	0.614
44.18	0.565
55.16	0.510
63.44	0.476
71.14	0.443
81.29	0.410
91.86	0.375
98.45	0.358

A = 28.411
B = 126.05
n = 1.6592

C_3H_5N (96)

Propionitrile

0	0.54_1
25	0.41_3

C_3H_5NS (96)

Ethyl thiocyanate

0	1.10_5
25	0.77_9

$C_3H_6Br_2$ (91)

1,2-Dibromopropane

0.36	2.285
12.91	1.816
25.27	1.494
38.02	1.247
50.08	1.072
63.19	0.918
76.46	0.797
89.13	0.704
101.18	0.628
113.71	0.565
127.97	0.501
136.67	0.468

A = 48.803
B = 88.757
n = 1.7075

$C_3H_6Br_2$ (26)

1, 3-Dibromopropane

t, °C	100η
25	1.79_7

$C_3H_6Cl_2$ (26)

1, 3-Dichloropropane

25	0.87_3

C_3H_6O (91)

Allyl alcohol

7.41	1.810
15.31	1.508
22.81	1.283
30.50	1.096
38.05	0.946
46.36	0.811
54.10	0.708
60.77	0.633
68.86	0.557
76.81	0.492
84.50	0.440
92.26	0.394
95.24	0.379

A = 10 748.4
B = 109.42
n = 2.7925

(23)

25	1.23_7

C_3H_6O (18)

Propionaldehyde

25	0.435

(96)

0	0.467
25	0.344

C_3H_6O (91)

Acetone

7.86	0.3638
11.72	0.3495
15.24	0.3376
19.02	0.3258
23.01	0.3131
27.22	0.3007
32.43	0.2863
36	0.2772
40.04	0.2675
44.12	0.2584
47.62	0.2503
52.20	0.2405
53.86	0.2377

A = 572.63
B = 209.08
n = 2.2244

(21)

10	0.362
20	0.331

(6)

0	0.399
15	0.345
25	0.316

(14)

0	0.397
10	0.361
20	0.325
30	0.296

C_3H_6O.—(*Cont'd*)

t, °C	100η
40	0.271
50	0.249

(1)

0	0.389
−10.6	0.451
−20.4	0.516
−30.3	0.613
−40	0.713
−49.9	0.818
−59.7	0.981
−69.7	1.200
−79.7	1.505
−89.7	2.051

$C_3H_6O_2$ (91)

Propionic acid

4.70	1.404
16.87	1.151
28.21	0.979
40.04	0.839
52.03	0.729
63.63	0.642
76.70	0.562
89.56	0.496
101.01	0.448
112.98	0.403
123.67	0.368
137.05	0.329

A = 105.746
B = 109.53
n = 1.8840

(39)

20	1.109

$C_3H_6O_2$ (92)

Ethyl formate

0.46	0.5024
6.57	0.4656
11.52	0.4409
16.58	0.4171
22.59	0.3910
27.90	0.3699
33.25	0.3501
38.09	0.3344
43.36	0.3178
48.61	0.3030
52.03	0.2942

A = 22.2406
B = 139.932
n = 1.7006

(39)

20	0.4132

(58)

25	0.389
30	0.375
40	0.345
50	0.311

(31)

25	0.379

$C_3H_6O_2$ (92)

Methyl acetate

0.34	0.4762
6.31	0.4436
11.41	0.4186
16.70	0.3948
22.74	0.3706

$C_3H_6O_2$.—(*Cont'd*)

t, °C	100η
28.38	0.3492
33.85	0.3304
40.45	0.3100
46.06	0.2942
50.34	0.2828
54.33	0.2727

A = 57.4012
B = 154.499
n = 1.8636

(39)

20	0.3831

$C_3H_6O_3$ (23)

Lactic acid

25	40.5

C_3H_7Br (91)

n-Propyl bromide

0.45	0.6414
7.86	0.5884
13.66	0.5523
19.17	0.5209
25.44	0.4903
31.88	0.4588
38.60	0.4300
45.64	0.4032
51.01	0.3844
57.37	0.3633
61.98	0.3495
67.86	0.3328

A = 65.713
B = 155.75
n = 1.8282

C_3H_7Br (91)

Isopropyl bromide

0.33	0.6021
5.12	0.5688
10.14	0.5371
15.30	0.5068
20.28	0.4803
25.46	0.4551
29.94	0.4343
35.90	0.4095
41.17	0.3894
46.36	0.3704
50.91	0.3555
56.76	0.3371

A = 188.08
B = 169.03
n = 2.0166

C_3H_7Cl (91)

n-Propyl chloride

0.45	0.4327
5.24	0.4104
10.06	0.3894
14.65	0.3709
20.71	0.3495
25.76	0.3344
30.38	0.3178
35.38	0.3038
40.82	0.2887
44.68	0.2784

A = 662.52
B = 203.36
n = 2.2453

C_3H_7Cl (91)

Isopropyl chloride

t, °C	100η
0.27	0.4000
6.68	0.3714
11.02	0.3540
16.47	0.3341
22.50	0.3137
28.22	0.2962
33.02	0.2829

A = 9.2541
B = 133.60
n = 1.5819

C_3H_7I (91)

n-Propyl iodide

0.30	0.934
10.98	0.817
20.81	0.730
28.31	0.673
38.83	0.605
46.17	0.564
55.59	0.516
65.46	0.474
74.38	0.439
83.88	0.406
90.78	0.384
98.89	0.362

A = 50.893
B = 136.84
n = 1.7483

C_3H_7I (91)

Isopropyl iodide

0.30	0.875
9.18	0.782
15.92	0.722
23.43	0.664
32.69	0.601
40.67	0.555
49.43	0.509
57.01	0.475
65.44	0.440
71.49	0.418
80.45	0.388
88.72	0.361

A = 129.85
B = 150.03
n = 1.9161

C_3H_7N (72)

Allylamine

25	0.37_{45}

C_3H_7NO (27)

Propionamide

105	1.27
120	1.03

$C_3H_7NO_2$ (85)

Urethane

60	2.35_7
70	1.80_5
80	1.45_6

(27)

105	0.91_6
120	0.71_5

C_3H_8O (91)
n-Propyl alcohol

t, °C	100η
7.35	3.145
15.06	2.555
22.86	2.101
30.83	1.732
31.02	1.724
38.79	1.440
46.47	1.218
54.33	1.030
61.74	0.888
69.04	0.771
76.75	0.666
84.82	0.576
93.10	0.499
95.59	0.477

A = 8 801 350
B = 135.75
n = 3.9188

(39)

10	2.877
20	2.230
30	1.756
40	1.389
50	1.125

(73)

0	4.137
13.4	2.868

C_3H_8O (91)
Isopropyl alcohol

0.36	4.5018
7.21	3.5568
14.41	2.8157
22.22	2.2204
30.55	1.7275
37.92	1.4053

A = 2 175 320 000
B = 141.72
n = 4.9635

(91)

45.15	1.1604
51.97	0.9770
59.39	0.8157
66.60	0.6923
72.02	0.6141
78.09	0.5407

A = 192 398
B = 86.259
n = 3.4079

(39)

10	3.319
20	2.431
30	1.810
40	1.375
50	1.063

(29)

20	2.19
25	1.95
30	1.74

$C_3H_8O_2$ (39)
1, 2-Propyleneglycol

20	44.80

C_3H_9N (72)
n-Propylamine

t, °C	100η
25	0.35_3

C_3H_9N (34)
Trimethylamine

−33.5	0.3208

$C_3H_{10}N_2$ (26)
Trimethylenediamine

25	1.81

C_4H_4S (91)
Thiophene

0.24	0.8676
8.39	0.7692
16.61	0.6876
22.50	0.6384
31.12	0.5754
37.83	0.5328
44.94	0.4934
53.08	0.4540
61.66	0.4170
68.60	0.3907
75.06	0.3682
82.53	0.3447

A = 15.677
B = 105.87
n = 1.6078

C_4H_5NS (59)
Allyl thiocyanate

25	0.67_3
50	0.54_1
80	0.42_7

(57.5)

100	0.316
125	0.263

$C_4H_6O_2$ (88)
Trimethylenecarboxylic acid

25	2.9_8

$C_4H_6O_3$ (91)
Acetic anhydride

0.18	1.238
12.52	1.007
24.10	0.852
35.40	0.734
48.15	0.630
60.39	0.551
71.04	0.494
84.42	0.434
95.09	0.394
108.92	0.351
120.23	0.320
133.39	0.289

A = 27.713
B = 97.10
n = 1.6851

(39)

20	0.946

(20)

10	1.05_8
15	0.97_9
76.5	0.46_2

$C_4H_8Br_2$ (91)
1, 2-Dibromo-2-methylpropane

t, °C	100η
0.39	3.290
13.67	2.456
26.94	1.916
40.80	1.528
53.18	1.274
66.90	1.065
80.60	0.903
93.63	0.781
107.15	0.680
121.74	0.593
133.75	0.532
142.44	0.494

A = 79.485
B = 75.60
n = 1.7988

C_4H_8O (91)
Methyl ethyl ketone

0.32	0.5361
7.04	0.4923
14.10	0.4522
21.31	0.4170
28.36	0.3861
35.42	0.3586
42.49	0.3342
48.72	0.3149
55.92	0.2944
63.74	0.2750
70.26	0.2595
76.25	0.2465

A = 36.972
B = 139.33
n = 1.7895

(65)

25	0.497

(39)

20	0.442

$C_4H_8O_2$ (91)
n-Butyric acid

3.21	2.128
18.02	1.591
31.83	1.263
44.49	1.049
59.39	0.860
73.36	0.727
86.55	0.628
101.55	0.537
115.24	0.470
130.26	0.408
144.97	0.358
155.76	0.327

A = 195.765
B = 94.462
n = 1.99205

(39)

10	1.920
20	1.599
30	1.341
40	1.160
50	1.004

$C_4H_8O_2$ (91)
Isobutyric acid

t, °C	100η
3.69	1.761
17	1.383
29.33	1.137
42.53	0.945
54.54	0.811
70.49	0.674
88.06	0.560
98.94	0.499
109.78	0.450
120.97	0.407
134.50	0.361
147.47	0.323

A = 212.41
B = 104.63
n = 2.00595

$C_4H_8O_2$ (92)
Ethyl acetate

0.25	0.5763
8.90	0.5144
14.46	0.4795
21.38	0.4418
28.12	0.4096
36.54	0.3738
44.12	0.3455
51.15	0.3224
60.16	0.2960
68.43	0.2741
74.60	0.2594

A = 45.322
B = 135.423
n = 1.8268

(39)

20	0.4521

(58)

25	0.44_1
50	0.34_5
70	0.28_3

(101)

0	0.588

(46, 47)

20.9	4.53_3
46.2	3.37_5
77.7	2.51_5
99.6	2.09_0

(51)

25	0.4239

(49)

25	0.4236

$C_4H_8O_2$ (92)
Methyl propionate

0.38	0.5788
9.73	0.5142
16.79	0.4725
23.46	0.4368
29.61	0.4098
38.66	0.3746
45.59	0.3477
52.65	0.3254
60.37	0.3028
68.49	0.2812

A = 74.898
B = 146.621
n = 1.89725

$C_4H_8O_2$.—(*Cont'd*)

t, °C	100η

(39)

20	0.461

$C_4H_8O_2$ (92)
n-Propyl formate

0.35	0.6647
7.33	0.6041
15.54	0.5457
23.16	0.4975
30.77	0.4558
38.53	0.4184
45.73	0.3875
54.14	0.3565
61.56	0.3315
67.13	0.3136
74.98	0.2928
77.55	0.2861

A = 35.3453
B = 139.283
n = 1.9154

(39)

20	0.5134

$C_4H_8O_2$ (39)
Isopropyl formate

20	0.5649

C_4H_9Br (91)
Isobutyl bromide

0.34	0.820
7.40	0.745
16.08	0.669
23.71	0.611
32.17	0.556
40.34	0.510
48.39	0.470
56.14	0.435
64.17	0.404
72.57	0.373
80.18	0.348
87.93	0.323

A = 472.23
B = 161.62
n = 2.1547

C_4H_9Cl (91)
Isobutyl chloride

0.35	0.5816
5.97	0.5401
11.95	0.5015
18.69	0.4637
23.47	0.4386
29.46	0.4102
37.32	0.3768
42.43	0.3575
48.71	0.3359
53.74	0.3197
60.26	0.3007
65.30	0.2877

A = 61.940
B = 141.87
n = 1.8706

C_4H_9I (91)
Isobutyl iodide

0.45	1.154
11.23	0.978
22.44	0.844

C_4H_9I.—(*Cont'd*)

t, °C	100η
33.84	0.739
44.56	0.658
54.65	0.593
65.11	0.536
77.33	0.480
86.83	0.442
97.84	0.403
109.20	0.368
116.07	0.349

A = 27.652
B = 108.86
n = 1.6577

C_4H_9N (88)
Tetrahydropyrrole

25	0.69_7

C_4H_{10} (54)
n-Butane

−23.6	0.265
0	0.207
18.5	0.176
34.5	0.153

$C_4H_{10}O$ (91)
n-Butyl alcohol

0.27	5.154
10.69	3.796
21.83	2.801
31.73	2.172
42.91	1.661

A = 65 187 500
B = 139.05
n = 4.2452

52.17	1.344
61.99	1.090
72.24	0.8860
83.13	0.7183
94.88	0.5817
102.96	0.5096
114.11	0.4259

A = 117 255
B = 91.997
n = 3.2150

$C_4H_{10}O$ (91)
Isobutyl alcohol

0.45	7.9111
9.90	5.5735
19.01	3.9779
27.77	3.0658
38.16	2.2392

A = 1 486 370
B = 92.248
n = 3.6978

47.44	1.7217
56.48	1.3571
56.59	1.3502
65.95	1.0697
74.61	0.8748

A = 1 112 440
B = 86.751
n = 3.6708

83.95	0.7173
93.85	0.5864
105.07	0.4753

$C_4H_{10}O$.—(*Cont'd*)

A = 29 790.3
B = 63.14
n = 3.0537

(67)

t, °C	100η
18.8	3.93
(35)	
25	3.382

$C_4H_{10}O$ (91)

tert.-Butyl alcohol

t, °C	100η
22.41	5.887
32.08	3.004
37.22	2.367
42.41	1.909
47.82	1.550

A = 2.05152
B = −7.803
n = 1.3242

t, °C	100η
52.99	1.296
57.94	1.097
62.09	0.9678
68.35	0.8102
73.47	0.7057
77.05	0.6447

A = 46.3090
B = 5.077
n = 2.0143

$C_4H_{10}O$

Ethyl ether

v. Vol. V, p. 11

$C_4H_{10}O$ (91)

Methyl propyl ether

t, °C	100η
0.30	0.3064
5.14	0.2914
10.47	0.2759
15.17	0.2630
20.10	0.2513
25.73	0.2385
29.48	0.2300
35.15	0.2187

A = 8.4251
B = 146.862
n = 1.5863

$C_4H_{10}S$ (91)

Ethyl sulfide

t, °C	100η
0.21	0.5575
8.32	0.5064
15.85	0.4652
24.64	0.4233
32.63	0.3901
40.19	0.3623
47.75	0.3374
56.49	0.3118
63.50	0.2933
71.25	0.2749
80.31	0.2555
87.99	0.2406

A = 49.886
B = 149.15
n = 1.8175

$C_4H_{11}N$ (72)

n-Butylamine

t, °C	100η
25	0.681

$C_4H_{11}N$ (72)

Isobutylamine

t, °C	100η
25	0.553

$C_4H_{11}N$ (59)

Diethylamine

t, °C	100η
25	0.346
35	0.279
25 (72)	0.367
(34)	
−33.5	0.8236

C_5H_5N (14)

Pyridine

t, °C	100η
0	1.328
10	1.112
20	0.945
30	0.824
40	0.717
60	0.580
80	0.489
110	0.386
(77)	
25	0.889
(27)	
25	0.884
(41)	
0	1.33
25.08	0.888

C_5H_8 (91)

Isoprene

t, °C	100η
0.35	0.2589
5.62	0.2459
10.27	0.2358
15.33	0.2249
20.41	0.2147
25.25	0.2060
28.94	0.1996
32.02	0.1944
29.93	0.1985

A = 3.3891
B = 144.01
n = 1.4433

C_5H_8O (88)

Cyclopentanone

t, °C	100η
25	1.07

C_5H_8O (48)

Ethyl propargyl ether

t, °C	100η
25	0.529

$C_5H_8O_2$ (88)

Cyclobutanecarboxylic acid

t, °C	100η
25	2.45

$C_5H_8O_3$ (39)

Methyl acetoacetate

t, °C	100η
20	1.702

C_5H_{10} (16)

Cyclopentane

t, °C	100η
0	0.572
15	0.477
20	0.456
25	0.427
30	0.406

C_5H_{10} (91)

2-Methyl-2-butene

t, °C	100η
0.20	0.2529
5.46	0.2406
10.21	0.2306
15.82	0.2192
20.03	0.2114
25.75	0.2015
30.69	0.1931
32.59	0.1903

A = 28.916
B = 187.24
n = 1.7855

$C_5H_{10}Br_2$ (26)

1, 5-Dibromopentane

t, °C	100η
25	0.305

$C_5H_{10}Cl_2$ (26)

Dichloropentane

t, °C	100η
25	1.60

$C_5H_{10}O$ (91)

Diethyl ketone

t, °C	100η
0.46	0.5914
9.10	0.5302
18.70	0.4748
27.07	0.4328
36.21	0.3939
44.70	0.3623
53.44	0.3339
62.43	0.3079
72.20	0.2834
81.47	0.2623
90.97	0.2426
98.82	0.2279

A = 64.487
B = 146.67
n = 1.8626

(39)

t, °C	100η
20	0.4799
(88)	
25	0.442

$C_5H_{10}O$ (91)

Methyl propyl ketone

t, °C	100η
0.38	0.6404
9.40	0.5692
18.30	0.5109
27.77	0.4592
35.43	0.4234
45.29	0.3831
53.94	0.3525
62.24	0.3262
72.74	0.2980
80.64	0.2787
90.06	0.2574
98.77	0.2400

A = 51.543
B = 137.75
n = 1.8248

(88)

t, °C	100η
25	0.473

$C_5H_{10}O_2$ (39)

Methylethylacetic acid

t, °C	100η
20	2.055

$C_5H_{10}O_2$ (24)

n-Valeric acid

t, °C	100η
16.5	2.41
20	2.30
25	2.05
50	1.315
70	0.986
90	0.753
(31)	
50	1.25
70	0.979
(39)	
20	2.233

$C_5H_{10}O_2$ (93)

Isovaleric acid

t, °C	100η
20	2.411

$C_5H_{10}O_2$ (39)

n-Butyl formate

t, °C	100η
20	0.5627

$C_5H_{10}O_2$ (39)

Isobutyl formate

t, °C	100η
20	0.6650
(66)	
20	0.644

$C_5H_{10}O_2$ (92)

Ethyl propionate

t, °C	100η
0.39	0.6890
10.09	0.6037
20.08	0.5310
29.74	0.4735
39.88	0.4230
49.68	0.3817
59.14	0.3477
69.24	0.3155
72.12	0.3073
80.14	0.2854
89.69	0.2627

A = 72.981
B = 133.905
n = 1.8914

(39)

t, °C	100η
20	0.5367
(66)	
20	0.549

$C_5H_{10}O_2$ (92)

Methyl *n*-butyrate

t, °C	100η
0.32	0.7551
10.45	0.6527
20.38	0.5727
30.64	0.5049
40.58	0.4503
50.30	0.4058
60.20	0.3667
71.50	0.3295
79.45	0.3057
90.63	0.2767
98.28	0.2592

A = 53.0991
B = 123.745
n = 1.8375

$C_5H_{10}O_2$ (92)

Methyl isobutyrate

t, °C	100η
0.28	0.6687
9.40	0.5914
18.11	0.5299
28.98	0.4660
35.81	0.4317
44.66	0.3932
52.55	0.3631
62.72	0.3289
76.22	0.3036
79.77	0.2813
88.84	0.2588

A = 98.0935
B = 139.956
n = 1.9405

(39)

t, °C	100η
20	0.5170

$C_5H_{10}O_2$ (92)

n-Propyl acetate

t, °C	100η
0.38	0.7652
9.78	0.6659
20.59	0.5762
30.13	0.5108
39.75	0.4563
50.04	0.4079
61.36	0.3624
69.90	0.3331
80	0.3028
89.50	0.2775
96.90	0.2602

A = 73.6005
B = 125.269
n = 1.8972

(6)

t, °C	100η
25	0.557
(66)	
20	0.592
(39)	
20	0.5959

$C_5H_{10}O_2$ (39)

Isopropyl acetate

t, °C	100η
20	0.5247

$C_5H_{11}N$ (88)

Piperidine

t, °C	100η
25	1.37
(59)	
25	1.36
50	0.845
80	0.738

C_5H_{12}* (91)

Isopentane

A = 391.101
B = 208.6
n = 2.2186

* Data given for isopentane prepared from English, Scotch, and Irish amyl alcohols.

C_5H_{12} (91)

n-Pentane

t, °C	100η
0.74	0.2805
7.47	0.2620
13.16	0.2481
18.91	0.2351
26.30	0.2192
30.41	0.2110
32.66	0.2070

A = 19.459
B = 165.59
n = 1.7295

$C_5H_{12}O$ (91)

d-Amyl alcohol

t, °C	100η
0.40	10.9672
11.63	6.9581
23.30	4.5372
34.75	3.0788

A = 66 652 700
B = 101.51
n = 4.3736
0° ≤ *t* ≤ 35°

t, °C	100η
47.40	2.0880
56.94	1.5956
67.52	1.2183

A = 97 413.3
B = 64.67
n = 3.2542
35° ≤ *t* ≤ 73°

t, °C	100η
79.25*	0.9254
91.88*	0.7075
100.03*	0.6033
112.78*	0.4819
124.36*	0.4008

A = 71.8436
B = 7.838
n = 2.0050

$$* \; 273.1 + t = \frac{0.26970}{\eta} \quad 335.66 + \frac{1425.7}{1/\eta} + \frac{7618.7}{1/\eta^2}$$

$C_5H_{12}O$ (91)

Isoamyl alcohol

t, °C	100η
0.24	8.4610
11.91	5.6249
23.83	3.8633
34.25	2.8303

A = 77 360 200
B = 117.79
n = 4.3249
0° ≤ *t* ≤ 40°

t, °C	100η
47.66	1.9654
58.74	1.4847
71.05	1.1210

A = 211 442
B = 79.872
n = 3.3395
40° ≤ *t* ≤ 80°

t, °C	100η
81.87	0.8888
94.94	0.6872
104.58	0.5794
117.60	0.4654
128.10	0.3974

$C_5H_{12}O$.—(*Cont'd*)

A = 1156.78
B = 37.682
n = 2.4618
80° ≤ t ≤ 128°

$C_5H_{12}O$ (91)

tert.-Amyl alcohol

t, °C	100η
0.49	13.7969
9.31	8.2034
18.48	4.9978
27.24	3.3643

A = 35 091
B = 47.922
n = 3.2081
0° ≤ t ≤ 27°

36.42	2.3322
45.05	1.7135
53.18	1.3199
62.95	0.9943

A = 3255.20
B = 37.007
n = 2.7578
27° ≤ t ≤ 63°

71.91	0.7931
81.06	0.6400
89.94	0.5301
95.70	0.4718
96.70	0.4643

A = 2159.86
B = 38.340
n = 2.6611
60° ≤ t ≤ 95°

(16)

25	3.697
40	1.975
50	1.401
70	0.798
85	0.573

$C_5H_{12}O$ (29)

sec.-Amyl alcohol

25	3.10_3

$C_5H_{12}O$ (29)

Methylisopropyl carbinol

25	3.52_5

$C_5H_{12}O$ (92)

Ethyl propyl ether

0.35	0.3952
5.65	0.3714
10.65	0.3510
15.66	0.3324
20.32	0.3165
25.34	0.3006
30.08	0.2864
35.08	0.2727
39.98	0.2598
45.62	0.2466
50.30	0.2363
55	0.2264
60.18	0.2159

A = 284.675
B = 183.355
n = 2.1454

$C_5H_{12}O$ (92)

Methyl isobutyl ether

t, °C	100η
0.36	0.3797
6.92	0.3526
14.51	0.3246
21.35	0.3022
28.89	0.2800
35.98	0.2620
42.55	0.2458
49.75	0.2305
55.22	0.2192

A = 122.591
B = 174.318
n = 2.0109

$C_5H_{13}N$ (72)

Isoamylamine

25	0.7235

$C_5H_{13}N$ (88)

Ethyl-*n*-propylamine

25	0.903

$C_5H_{14}N_2$ (26)

Pentamethylendiamine

25	2.36

$C_6H_3N_3O_6$ (57)

1, 3, 5-Trinitrobenzene

152	1.5_7

$C_6H_4N_2O_4$ (55)

m-Dinitrobenzene

90	2.5_3

C_6H_5Br (69)

Bromobenzene

0.1	1.573
5.9	1.445
10.1	1.332
18.2	1.171
28.3	1.023
43.6	0.842
61.4	0.694
71.2	0.626
80.7	0.579
91	0.526
102.2	0.485
111.7	0.445
121.7	0.417
132.3	0.373
142.3	0.351
(79)	
0	1.5_0

C_6H_5Cl (69)

Chlorobenzene

0	1.053
4.7	0.988
9.7	0.917
15.9	0.848
17.6	0.827
20.1	0.800
25.1	0.751
30.2	0.704
40.2	0.629

C_6H_5Cl.—(*Cont'd*)

t, °C	100η
49.9	0.570
60	0.513
72.1	0.460
80.4	0.428
88.1	0.393
96.2	0.369
107.8	0.344
119.6	0.307
(26)	
25	0.76
(14)	
20	0.77

C_6H_5ClO (14.5)

o-Chlorophenol

0	10.7
10	6.39
20	4.21
30	3.08
40	2.32
60	1.51
80	1.07
110	0.76
150	0.54
(86)	
45	2.291
(90)	
25	4.11
50	2.0

C_6H_5ClO (86)

m-Chlorophenol

45	4.82
(90)	
25	11.5
50	4.0

C_6H_5ClO (86)

p-Chlorophenol

45	6.15
(90)	
50	5.0

C_6H_5F (69)

Fluorobenzene

9.3	0.647
15.9	0.615
19.9	0.577
29.1	0.514
33.2	0.495
38.1	0.468
44	0.438
50.2	0.412
60.5	0.370
71.9	0.334
80.9	0.305

C_6H_5I (69)

Iodobenzene

4.6	2.207
17.4	1.780
27.5	1.504
36.8	1.316
48.1	1.135
58.1	1.005
68.2	0.902
80.6	0.792
98	0.673

C_6H_5I.—(*Cont'd*)

t, °C	100η
107.5	0.623
117.7	0.549
126.9	0.529
137.6	0.487
148.8	0.448

$C_6H_5NO_2$ (9); *cf.* (14, 18, 19, 20, 21, 81, 89)

Nitrobenzene

0.3	3.083
10	2.509
20	2.013
30	1.682
40	1.438
50	1.251
60	1.094
70	0.970
90	0.779
100.5	0.704

$C_6H_5NO_3$ (14)

o-Nitrophenol

40	2.75
60	1.82
80	1.35
(86)	
45	2.388

C_6H_6

Benzene

v. Vol. V, p. 12

C_6H_6ClN (87)

o-Chloroaniline

55	1.65

C_6H_6ClN (87)

m-Chloroaniline

55	1.76
(78)	
25	3.50

C_6H_6ClN (87)

p-Chloroaniline

55	1.96

C_6H_6O (80)

Phenol

18.30	12.744
20.38	11.384
25.03	8.976
29.26	7.371
35.25	5.779
38.04	5.151
39.51	4.876
40.20	4.771
49.84	3.449
55.52	2.903
60.46	2.531
66.45	2.163
70.30	1.973
(12*)	
35	6.024
40	4.803
45	4.000
50	3.419
55	2.938
60	2.562

C_6H_6O.—(*Cont'd*)

t, °C	100η
65	2.249
70	1.997
75	1.779
80	1.596
85	1.439
90	1.306

* $\eta t = \dfrac{1}{(0.001511t + 0.00001075t^2 - 0.01219)} \times (273.1 + t)$.

C_6H_7N (36*)

Aniline

−5.50	13.86
−0.06	10.25
0	10.24
+2.50	9.15
10.35	6.44
15.35	5.20
16.32	5.01_5
17.38	4.84_5
31.76	2.97_7
49.01	1.84
61.27	1.48_8
80.33	1.099
100.39	0.829
119.87	0.660
120	0.653
(9)	
0.5	10.050
10	6.491
15	5.379
20	4.429
25	3.781
30	3.221
35	2.826
45	2.158
60	1.553
80	1.094
98	0.838

* $\log (100\eta) = -1.1485 \times \left(\dfrac{t - 85.26}{t + 97.1}\right)$.

C_6H_7N (32)

α-Picoline

25	0.79_5

C_6H_7N (32)

β-Picoline

25	0.87_6

$C_6H_8N_2$ (90)

Phenylhydrazine

50	4.58

C_6H_{10} (91)

Diisopropenyl

0.37	0.3374
5.95	0.3169
10.78	0.3010
15.46	0.2866
20.76	0.2719
25.46	0.2599
30.71	0.2474
36.06	0.2355
41.99	0.2229

C_6H_{10}.—(*Cont'd*)

t, °C	100η
46.76	0.2137
51.54	0.2047
56.20	0.1966

A = 72.193
B = 173.01
n = 1.9340

(39)

20	0.2733

$C_6H_{10}O$ (42.5)

Cyclohexanone

17.3	2.30
39.1	1.55
65.9	1.01
(88)	
25	2.8

$C_6H_{10}O$ (25)

Mesityl oxide

25	0.87_9

$C_6H_{10}O_2$ (88)

Ethyl cyclopropanecarboxylate

25	0.98

$C_6H_{10}O_3$ (91)

Propionic anhydride

0.47	1.592
14.70	1.220
29.97	0.960
44.86	0.780
59.52	0.651
74.87	0.549
94.87	0.450
104.52	0.412
119.57	0.361
134.65	0.319
148.66	0.287
164.56	0.254

A = 31.312
B = 85.011
n = 1.7049

$C_6H_{10}O_3$ (39)

Ethyl acetoacetate

20	1.712
(89)	
25	1.53* 1.54†

* Freshly distilled.

† After standing 90 min.

$C_6H_{10}O_4$ (26)

Diethyl oxalate

25	1.76

C_6H_{12} (16)

Cyclohexane

15	1.043
20	0.960
30	0.797
(19)	
22	0.93

C_6H_{12} (16)
Methylcyclopentane

t, °C	100η
0	0.665
15	0.545
20	0.521
25	0.484
30	0.456

$C_6H_{12}O$ (42.5)
Cyclohexanol

39.1	20.3
65.9	5.8
90	2.45

$C_6H_{12}O$ (39)
Methyl *n*-butyl ketone

20	0.6261
(88)	
25	0.58_4

$C_6H_{12}O$ (39)
Methyl isobutyl ketone

20	0.5799

$C_6H_{12}O_2$ (39)
Caproic acid

20	3.198
(24)	
16.1	3.56
20	3.23
25	2.84
40	2.12
50	1.75
70	1.29
90	0.98

$C_6H_{12}O_2$ (39)
Diethylacetic acid

20	3.159

$C_6H_{12}O_2$ (39)
Methylpropylacetic acid

20	2.867

$C_6H_{12}O_2$ (66)
Isoamyl formate

20	0.794

$C_6H_{12}O_2$ (39)
Isobutyl acetate

20	0.7034
(46)	
19.9	0.724
78.1	0.366
99.4	0.287

$C_6H_{12}O_2$ (39)
Ethyl *n*-butyrate

20	0.6668
(66)	
20	0.668
(58)	
25	0.62_8
50	0.46_6
70	0.38_1

$C_6H_{12}O_2$ (39)
Ethyl isobutyrate

t, °C	100η
20	0.588
(88)	
25	0.55_7

$C_6H_{12}O_2$ (39)
Methyl *n*-valerate

20	0.7119

$C_6H_{12}O_2$ (39)
n-Propyl propionate

20	0.6722
(66)	
20	0.678

$C_6H_{12}O_3$ (71)
Paraldehyde

15	1.31
20	1.17

C_6H_{14} (16)
Diisopropyl

0	0.495
15	0.409
20	0.385
25	0.361
30	0.342

C_6H_{14} (13)
n-Hexane

25	0.3289
35	0.2828
50	0.2746
65	0.2177
(91)	
0.80	0.3931
9.15	0.3581
14.75	0.3378
19.98	0.3202
25.39	0.3035
30.23	0.2894
36.76	0.2722
43.47	0.2557
47.42	0.2470
52.90	0.2351
58.76	0.2231
63.59	0.2143

A = 276.01
B = 189.42
n = 2.1264

C_6H_{14} (16)
Isohexane

0	0.371
15	0.324
20	0.310
25	0.295
30	0.280

C_6H_{14} (16)
2, 2-Dimethylbutane

0	0.477
15	0.397
20	0.375
25	0.351
30	0.330

C_6H_{14} (91)
2-Methylpentane

t, °C	100η
0.61	0.3688
5.59	0.3487
10.25	0.3316
15.26	0.3147
20.51	0.2987
25.45	0.2841
31.97	0.2670
36.63	0.2550
41.07	0.2450
45.38	0.2355
51.17	0.2235
55.43	0.2151

A = 917.96
B = 209.35
n = 2.3237

C_6H_{14} (16)
3-Methylpentane

0	0.394
15	0.339
25	0.307
30	0.292

$C_6H_{14}O$ (30)
Ethylisopropyl carbinol

25	4.0_5

$C_6H_{14}O$ (31)
Hexyl alcohol

25	0.437
50	0.216

$C_6H_{14}O$ (30)
Methylbutyl carbinol

25	3.9_9

$C_6H_{14}O$ (92)
Ethyl isobutyl ether

0.36	0.4803
7.34	0.4397
15.10	0.4003
21.70	0.3709
28.14	0.3454
35.39	0.3200
41.76	0.2996
48.97	0.2791
55.99	0.2615
63.17	0.2440
70.66	0.2280
77.48	0.2147

A = 98.4046
B = 152.69
n = 1.9733

$C_6H_{14}O$ (92)
Propyl ether

0.58	0.5359
8.58	0.4826
16.95	0.4358
24.65	0.3985
32.45	0.3654
40.47	0.3360
48.06	0.3114
56.14	0.2876
64.16	0.2664
72.59	0.2469

$C_6H_{14}O$.—(*Cont'd*)

t, °C	100η
81.47	0.2284
88.01	0.2154

A = 104.068
B = 148.362
n = 1.9734

$C_6H_{14}O$ (39)
Isopropyl ether

20	0.322

$C_6H_{15}N$ (34)
Triethylamine

−33.5	0.7726
(72)	
25	0.363

$C_7H_5Cl_3$ (21)
Benzotrichloride

10	3.07
17	2.05

C_7H_5N (18)
Benzonitrile

25	1.25

C_7H_5N (9)
Phenyl isocyanide

0.28	1.957
10	1.615
20	1.330
30	1.133
40	0.983
50	0.863
60	0.767
70	0.687
80	0.622
100	0.514

C_7H_5NS (59)
Phenyl thiocyanate

25	1.4
35	1.2
50	0.98

C_7H_6O (18)
Benzaldehyde

25	1.40

$C_7H_6O_2$ (86)
Salicylaldehyde

45	1.798

$C_7H_6O_2$ (26)
Benzoic acid

122.5	1.6_7
130	1.2_6

C_7H_7NO (27)
Formanilide

120	1.6_5
(65)	
55	8.70

C_7H_8 (46)
Toluene

20.6	0.583
78.2	0.323
100	0.272
(50)	
25	0.5520
(60)	
25	0.5512

C_7H_8.—(*Cont'd*)

t, °C	100η
(91)	
0.26	0.7655
9.88	0.6683
19.47	0.5900
30.25	0.5184
39.86	0.4667
49.43	0.4219
60.18	0.3799
69.13	0.3503
80.59	0.3164
91.74	0.2877
99.95	0.2695
107.08	0.2554

A = 18.954
B = 112.99
n = 1.6522

C_7H_8O (39)
Benzyl alcohol

20	5.582
(83)	
25	5.054
30	4.326
35	3.739
40	3.288
45	2.906
50	2.574

C_7H_8O (14.5)
o-Cresol

0	39.7
10	17.9
20	9.56
30	6.12
40	4.10
60	2.24
80	1.43
110	0.89

C_7H_8O (14.5)
m-Cresol

0	84.4
10	34.6
20	16.9
30	9.47
40	5.92
60	2.99
80	1.80
110	1.02

C_7H_8O (14.5)
p-Cresol

0	98.4
10	39.6
20	18.9
30	10.5
40	6.54
60	3.28
80	1.93
110	1.08

C_7H_8O (5)
Phenyl methyl ether

25	1.01

C_7H_9N (72)
Benzylamine

25	1.5_9
130	0.44_2

C_7H_9N (32)
2, 6-Lutidine

t, °C	100η
25	0.88_1

C_7H_9N (9); *cf.* (59, 72, 87)
Methylaniline

0.3	4.265
10	3.065
20	2.303
30	1.811
40	1.466
50	1.215
70	0.886

C_7H_9N (9);*cf.*(72, 87)
o-Toluidine

0.31	10.105
10	6.428
20	4.392
30	3.194
40	2.436
50	1.919
60	1.578
70	1.302
80	1.109
90	0.952
100	0.831

C_7H_9N (72)
m-Toluidine

25	3.31
130	0.50
(87)	
55	1.5_1

C_7H_9N (87)
p-Toluidine

55	1.5_6
(72)	
130	0.52
(14)	
39.9	2.08
59.9	1.39
79.8	1.01
99.9	0.77_6
125	0.60_8
150	0.49_1
175	0.42_3

C_7H_9NO (87)
o-Anisidine

55	2.2_1

C_7H_9NO (87)
p-Anisidine

55	3.2_1

$C_7H_{12}O$ (42.5)
o-Methylcyclohexanone

17.3	1.82
39.1	1.21
65.9	0.83

$C_7H_{12}O$ (42.5)
m-Methylcyclohexanone

17.3	1.83
39.1	1.22
65.9	0.85

$C_7H_{12}O$ (42.5)
p-Methylcyclohexanone

t, °C	100η
17.3	1.83
39.1	1.23
65.9	0.87
90	0.69

$C_7H_{12}O$ (75)
Methylcyclohexanone

20	1.76

$C_7H_{12}O$ (88)
Suberone

25	2.59

$C_7H_{12}O_2$ (88)
Ethyl cyclobutanecarboxylate

25	0.996

$C_7H_{12}O_2$ (88)
Hexahydrobenzoic acid

50	8.38

$C_7H_{12}O_4$ (26)
Diethyl malonate

25	1.88

C_7H_{14} (16)
Methylcyclohexane

0	0.976
15	0.780
30	0.627

$C_7H_{14}O$ (39)
Diethylacetone

20	0.6989

$C_7H_{14}O$ (42.5)
o-Hexahydrocresol

39.1	6.97
65.9	2.56
90	1.26
(99)	
20	21.8

$C_7H_{14}O$ (99)
m-Hexahydrocresol

20	23.0

$C_7H_{14}O$ (99)
p-Hexahydrocresol

20	30.7

$C_7H_{14}O$ (88)
Dipropyl ketone

25	0.685

$C_7H_{14}O$ (39)
Methylpropylacetone

20	0.8398

$C_7H_{14}O$ (87)
Methyl *n*-amyl ketone

25	0.766

$C_7H_{14}O_2$ (87)
α-Ethylvaleric acid

25	3.80
50	2.06

$C_7H_{14}O_2$ (39)
Heptylic acid

t, °C	100η
20	4.357
(24)	
17.5	4.60
20	4.33
25	3.80
50	2.30
70	1.61
90	1.19

$C_7H_{14}O_2$ (53)
n-Amyl acetate

11	1.58
(6)	
25	0.811

$C_7H_{14}O_2$ (39)
Ethyl *n*-valerate

20	0.8362
(31)	
25	0.76
50	0.536

$C_7H_{14}O_2$ (87)
Ethyl α-methylbutyrate

25	0.675

$C_7H_{14}O_2$ (31)
Isobutyl propionate

25	0.67

$C_7H_{14}O_2$ (39)
Propyl *n*-butyrate

20	0.8296

$C_7H_{14}O_2$ (39)
Propyl isobutyrate

20	0.7389

C_7H_{16} (91)
n-Heptane

6.43	0.4797
6.56	0.4795
13.45	0.4418
21.74	0.4027
30.27	0.3685
38.34	0.3397
47.25	0.3112
55.03	0.2890
62.04	0.2714
70.09	0.2526
77.70	0.2372
85.49	0.2218
92.21	0.2096

A = 445.97
B = 180.14
n = 2.1879

(60)	
25	0.3855

C_7H_{16} (91)
2-Methylhexane

0.42	0.4743
7.70	0.4343
15.88	0.3959
24.63	0.3607
32.31	0.3333
40.05	0.3092
49.01	0.2839

C_7H_{16}.—(*Cont'd*)

t, °C	100η
56.46	0.2651
63.92	0.2484
71.84	0.2316
80.66	0.2149
88.41	0.2012

A = 362.79
B = 180.47
n = 2.1633

$C_7H_{16}O$ (39)
n-Heptyl alcohol

20	7.009
(31)	
25	5.68
50	2.68
90	1.00

$C_7H_{16}O$ (30)
n-Propylisopropyl carbinol

25	4.76

$C_7H_{16}O$ (30)
Methylamyl carbinol

25	5.08

C_8H_6 (48)
Phenylacetylene

25	0.886

C_8H_7N (26)
Benzyl cyanide

25	1.98

C_8H_8 (48)
Styrene

25	1.11

C_8H_8O (14.6)
Acetophenone

16	1.99
25	1.67
(57)	
25	1.67
50	1.24
95	0.653
(74.5)	
25	1.67
(49)	
25	1.681

$C_8H_8O_2$ (18)
Methoxybenzaldehyde

25	4.22

$C_8H_8O_2$ (26)
Phenylacetic acid

77	3.54
130	1.40

$C_8H_8O_2$ (39)
Methyl benzoate

20	2.067

$C_8H_8O_2$ (86)
Phenyl acetate

45	1.832

C_8H_9Cl (26)
β-Chloroethylbenzene

t, °C	100η
25	1.92

C_8H_9NO (65)
Form-*o*-toluide

55	12.91

C_8H_9NO (27)
Acetanilide

120	2.22
(72)	
130	1.90

C_8H_{10} (91)
Ethylbenzene

0.41	0.869
11.41	0.744
21.66	0.654
32.90	0.572
47.11	0.491
60.51	0.430
73.81	0.381
83.62	0.349
95.60	0.316
107.97	0.287
119.19	0.263
131.40	0.241

A = 41.215
B = 121.68
n = 1.7616

(26)	
25	0.632

C_8H_{10} (91), *o*-Xylene

0.49	1.095
13.88	0.881
26.54	0.738
39.33	0.628
51.94	0.544
65.41	0.473
78.78	0.416
90.82	0.373
101.78	0.340
116.61	0.302
128.15	0.276
141.14	0.252

A = 19.644
B = 96.352
n = 1.6386

C_8H_{10} (91), *m*-Xylene

0.24	0.799
11.52	0.684
23.36	0.595
35.97	0.513
48.71	0.450
59.94	0.404
60.27	0.403
71.20	0.366
86.35	0.322
98.68	0.293
109.75	0.269
123.53	0.244
135.28	0.225

A = 19.395
B = 115.66
n = 1.6400

C_8H_{10} (91)
p-Xylene

t, °C	100η
8.28	0.752
20.53	0.639
31.23	0.561
41.85	0.498
53.59	0.441
64.87	0.396
77.27	0.353
88.87	0.320
100.84	0.290
111.83	0.267
123.26	0.245
135.21	0.225

A = 32.7453
B = 117.730
n = 1.7326

$C_8H_{10}O$ (26)
2-Phenylethyl alcohol

25	7.61
50	3.20

$C_8H_{10}O$ (86)
Benzyl methyl ether

45	1.042

$C_8H_{10}O$ (86)
o-Cresyl methyl ether

45	0.858

$C_8H_{10}O$ (86)
m-Cresyl methyl ether

45	0.885

$C_8H_{10}O$ (86)
p-Cresyl methyl ether

45	0.814

$C_8H_{10}O$ (39)
Phenetole

20	1.261
(51)	
25	1.158
(86)	
45	0.833
(14)	
0	1.86
9.9	1.53
20.2	1.24
29.6	1.03
40	0.875
60	0.687
80	0.558

$C_8H_{11}N$ (9)
Dimethylaniline

10	1.688
20	1.413
30	1.201
40	1.036
50	0.905
60	0.800
70	0.714

$C_8H_{11}N$.—(*Cont'd*)

t, °C	100η
80	0.642
90	0.579
98	0.537
(14)	
0	2.025
10	1.654
20	1.387
30	1.17
40	1.024
60	0.798
80	0.658
126	0.461
177	0.341

$C_8H_{11}N$ (9); *cf.* (72, 87)
N-Ethylaniline

0.27	4.123
10	2.979
20	2.251
40	1.434
60	1.013
80	0.766
90	0.674
100	0.603

$C_8H_{11}N$ (72)
α-Phenylethylamine

25	1.66

$C_8H_{11}N$ (72)
β-Phenylethylamine

25	3.07

$C_8H_{11}N$ (87)
Methyl-*o*-toluidine

55	1.17

$C_8H_{11}N$ (87)
Methyl-*p*-toluidine

55	1.22

$C_8H_{12}O_3$ (88)
Ethyl 1-acetylcyclopropanecarboxylate

25	1.73

$C_8H_{12}O_3$ (88)
Ethyl cyclopentanonecarboxylate

25	3.50

$C_8H_{12}O_4$ (86.5)
Diethyl fumarate

24.7	2.45

$C_8H_{12}O_4$ (86.5)
Diethyl maleate

24.7	3.01

C_8H_{14} (97)
n-Hexylacetylene

25	0.657

$C_8H_{14}O_3$ (39)
Methyl propylacetoacetate

20	2.339

$C_8H_{14}O_3$ (88)
Ethyl ethylacetoacetate

25	1.69

$C_8H_{14}O_3$ (88)
Ethyl dimethylacetoacetate

t, °C	100η
25	1.60

$C_8H_{14}O_4$ (26)
Diethyl succinate

25	2.41

C_8H_{16} (16)
o-Dimethylcyclohexane

C_8H_{16} (16)
m-Dimethylcyclohexane

C_8H_{16} (16)
p-Dimethylcyclohexane

$C_8H_{16}O$ (39)
Ethylpropylacetone

20	0.8482

$C_8H_{16}O_2$ (39)
n-Caprylic acid

20	5.7482
(31)	
50	2.62
70	1.84
90	1.30

$C_8H_{16}O_2$ (39)
Dipropylacetic acid

20	7.642

$C_8H_{16}O_2$ (31)
Hexan-β-ol acetate

25	0.944

$C_8H_{16}O_2$ (31)
Isobutyl *n*-butyrate

25	0.84

$C_8H_{16}O_2$ (39)
n-Propyl *n*-valerate

20	1.038

$C_8H_{16}O_2$ (39)
Propyl methylethylacetate

20	0.8479

C_8H_{18} (91)
n-Octane

0.25	0.700
12.18	0.594
22.92	0.520
32.96	0.463
43.89	0.411
54.73	0.367
66.46	0.328
77.82	0.296
88.33	0.269
98.52	0.247
109.07	0.227
122.07	0.204

A = 171.82
B = 145.50
n = 2.029

$C_8H_{18}O$ (39)
n-Octyl alcohol

t, °C	100η
20	8.925
(31)	
25	7.21
50	3.22
90	1.21

$C_8H_{18}O$ (87)
d-sec.-Octyl alcohol

25	6.33

$C_8H_{18}O$ (87)
l-sec.-Octyl alcohol

25	6.55

$C_8H_{18}O$ (87)
dl-sec.-Octyl alcohol

25	6.49

$C_8H_{18}O$ (29)
Isopropylbutyl carbinol

25	7.12

$C_8H_{18}O$ (39)
Isobutyl ether

20	0.7491

$C_8H_{18}O$ (31)
Ethyl hexyl ether

25	0.929
50	0.653

$C_8H_{19}N$ (72)
Diisobutylamine

25	0.687

C_9H_7N (72)
Isoquinoline

25	3.57

C_9H_7N (14)
Quinoline

9.8	4.80
20.1	3.64
29.9	2.94
40	2.38
60	1.67
80	1.25
125	0.786
175	0.547
(52)	
25	3.361

$C_9H_{10}O_2$ (86)
Benzyl acetate

45	1.423

$C_9H_{10}O_2$ (39)
Ethyl benzoate

20	2.238
(51)	
25	2.014
(79)	
25	2.03
50	1.28
70	0.95
(49, 50)	
25	1.986

$C_9H_{10}O_2$ (26)
β-Phenylpropionic acid

t, °C	100η
49.7	9.8
130	1.72

$C_9H_{10}O_3$ (86)
Ethyl salicylate

45	1.803

$C_9H_{10}OS$ (76)
Ethyl thiobenzoate

25	2.42

$C_9H_{10}S_2$ (76)
Ethyl dithiobenzoate

25	3.12

$C_9H_{11}Cl$ (26)
γ-Chloropropylbenzene

25	2.47

$C_9H_{11}N$ (87)
Allylaniline

55	1.41
(72)	
130	0.506

$C_9H_{11}N$ (72)
1, 2, 3, 4-Tetrahydroquinoline

25	5.25

$C_9H_{11}NO$ (27)
N-Methylacetanilide

120	0.82

$C_9H_{11}NO$ (65)
Ethylformanilide

55	2.42

$C_9H_{11}NO_2$ (87)
Ethyl anthranilate

55	3.26

$C_9H_{11}NO_2$ (65)
Phenylurethane

55	85.35

C_9H_{12} (26)
n-Propylbenzene

25	0.793

$C_9H_{12}O$ (26)
β-Phenylpropyl alcohol

25	15.6
50	52.3

$C_9H_{12}O$ (39)
Ethyl *o*-cresyl ether

20	1.449(?)

$C_9H_{12}O$ (39)
Ethyl *p*-cresyl ether

20	1.467

$C_9H_{12}O$ (39)
Propyl phenyl ether

20	1.588

$C_9H_{13}N$ (88)
Dimethyl-*o*-toluidine

55	0.88

$C_9H_{13}N$ (88)
Dimethyl-*p*-toluidine

t, °C	100η
55	0.86

$C_9H_{13}N$ (72)
Ethyl-*o*-toluidine

25	1.98
(88)	
25	2.00
55	1.10

$C_9H_{13}N$ (88)
Ethyl-*p*-toluidine

25	2.40
55	1.21

$C_9H_{13}N$ (88)
Methylethylaniline

55	0.97

$C_9H_{13}N$ (88)
n-Propylaniline

25	2.53

$C_9H_{13}N$ (26)
3-Phenylpropylamine

25	3.6
(72)	
25	3.9

$C_9H_{14}O$ (25)
Phorone

25	1.40

$C_9H_{14}O_4$ (86.5)
Diethyl citraconate

24.7	3.25

$C_9H_{14}O_4$ (86.5)
Diethyl mesaconate

24.7	2.40

$C_9H_{14}O_4$ (88)
Diethyl cyclopropane 1, 1-dicarboxylate

25	2.36

$C_9H_{14}O_6$ (65)
Triacetin

55	4.79

$C_9H_{16}O_2$ (88)
Ethyl cyclohexanecarboxylate

25	1.79

$C_9H_{16}O_3$ (39)
Methyl diethylacetoacetate

20	4.108

$C_9H_{16}O_3$ (39)
Methyl methylpropylacetoacetate

20	2.826

$C_9H_{16}O_3$ (39)
Ethyl propylacetoacetate

20	2.264

$C_9H_{16}O_3$ (39)
Ethyl methylethylacetoacetate

20	2.357

$C_9H_{16}O_4$ (88)
Diethyl dimethylmalonate

t, °C	100η
25	1.95

$C_9H_{16}O_4$ (26)
Diethyl glutarate

25	2.49

$C_9H_{18}O$ (39)
Dipropylacetone

20	1.282

$C_9H_{18}O_2$ (31)
Isobutyl *n*-valerate

25	1.01

$C_9H_{18}O_2$ (31)
Ethyl *n*-heptylate

25	1.11

$C_9H_{18}O_2$ (88)
Ethyl α-ethylvalerate

25	0.905

$C_9H_{18}O_2$ (39)
Propyl methylpropylacetate

20	1.128

$C_9H_{18}O_2$ (39)
Propyl diethylacetate

20	1.182

$C_9H_{18}O_2$ (39)
Ethyl ethylpropylacetate

20	0.994

$C_9H_{18}O_2$ (39)
Methyl dipropylacetate

20	1.204

$C_9H_{18}O_2$ (31)
Hexan-β-ol propionate

25	1.04

$C_9H_{18}O_2$ (31)
Heptan-β-ol acetate

25	1.17

$C_9H_{18}O_2$ (31)
Methyl octoate

25	1.26
50	0.846

$C_9H_{18}O_2$ (39)
Pelargonic acid

20	8.333
(24)	
20	8.08
25	7.00
50	3.79
70	2.41
90	1.73

C_9H_{20} (7)
n-Nonane

22.3	0.624

$C_9H_{20}O$ (30)
Amylisopropyl carbinol

25	7.32

$C_9H_{20}O$ (30)
Methylheptyl carbinol

t, °C	100η
25	8.31

$C_{10}H_8$ (57)
Naphthalene

80	0.886
90	0.759
(55)	
150	0.217
152	0.196

$C_{10}H_9N$ (90)
α-Naphthylamine

50	11.2
(72)	
130	1.44

$C_{10}H_9N$ (72)
β-Naphthylamine

130	1.34

$C_{10}H_{10}O_2$ (25)
Safrol

25	2.30

$C_{10}H_{10}O_2$ (25)
Isosafrol

25	4.00

$C_{10}H_{12}$ (88)
Tetrahydronaphthalene

25	2.14
(45)	
25	2.00
50	1.30
75	0.906

$C_{10}H_{12}O_2$ (48)
Eugenol

25	6.96

$C_{10}H_{12}O_2$ (48)
Isoeugenol

25	2.68

$C_{10}H_{12}O_2$ (26)
Ethyl phenylacetate

25	2.39

$C_{10}H_{12}O_3$ (87)
Ethyl mandelate

25	19.7

$C_{10}H_{13}N$ (87)
Methylallylaniline

55	1.068

$C_{10}H_{13}N$ (72)
5, 6, 7, 8-Tetrahydro-α-naphthylamine

130	1.18

$C_{10}H_{13}N$ (72)
5, 6, 7, 8-Tetrahydro-β-naphthylamine

130	1.08

$C_{10}H_{13}NO_2$ (65)
Methylphenylurethane

55	2.55

$C_{10}H_{14}$ (88)
o-Cymene

t, °C	100η
25	1.02

$C_{10}H_{14}$ (88)
n-Butylbenzene

25	1.05

$C_{10}H_{14}O$ (88)
d-Carvol

25	3.39

$C_{10}H_{14}O$ (39)
Propyl o-tolyl ether

20	2.014(?)

$C_{10}H_{15}N$ (9)
Diethylaniline

0.5	3.841
10	2.850
20	2.185
40	1.425
60	1.021
80	0.777
98	0.630

$C_{10}H_{16}O_4$ (88)
Diethylcyclobutane-1, 1-dicarboxylate

25	2.61

$C_{10}H_{18}$ (45)
Decahydronaphthalene

25	2.41
50	1.58
75	1.08

$C_{10}H_{18}O$ (88)
Menthone

25	2.31

$C_{10}H_{18}O_3$ (39)
Methyl ethylpropylacetoacetate

20	4.869

$C_{10}H_{18}O_3$ (39)
Ethyl methylpropylacetoacetate

20	2.720

$C_{10}H_{18}O_3$ (39)
Ethyl diethylacetoacetate

20	3.502

$C_{10}H_{18}O_4$ (88)
Diethyl methylethylmalonate

25	2.47

$C_{10}H_{18}O_4$ (26)
Diethyl adipate

25	2.78

$C_{10}H_{20}O$ (47)
Menthol

34.9	25.05
37.8	20.36
43.4	13.68
56.9	6.89

$C_{10}H_{20}O$.—(Cont'd)

t, °C	100η
(81)	
55.6	6.28
74.6	2.47
82.2	1.85
99	1.04

$C_{10}H_{20}O_2$ (31)
Butan-β-ol n-hexoate

25	1.27

$C_{10}H_{20}O_2$ (39)
Ethyl dipropylacetate

20	1.425

$C_{10}H_{20}O_2$ (31)
Ethyl n-caprylate

25	1.38
50	0.94

$C_{10}H_{20}O_2$ (31)
Hexan-β-ol n-butyrate

25	1.33

$C_{10}H_{20}O_2$ (31)
Heptan-β-ol propionate

25	1.25

$C_{10}H_{20}O_2$ (31)
Octan-β-ol acetate

25	1.52

$C_{10}H_{20}O_2$ (31)
n-Capric acid

50	4.34
70	2.88

$C_{10}H_{22}$ (7)
n-Decane

22.3	0.78

$C_{10}H_{22}$ (13)
2, 7-Dimethyloctane

25	0.8278
35	0.6702
50	0.5540
65	0.4686

$C_{10}H_{22}O$ (30)
Methyl-n-octyl carbinol

25	10.1

$C_{10}H_{22}O$ (30)
Isopropyl-n-hexyl carbinol

25	10.2

$C_{11}H_{14}O_2$ (26)
Ethyl β-phenylpropionate

25	3.07

$C_{11}H_{15}NO$ (6)
Acetoethyl-o-toluidine

25	9.99

$C_{11}H_{15}NO_2$ (65)
Ethylphenylurethane

55	2.76

$C_{11}H_{16}O$ (39)
Thymyl methyl ether

t, °C	100η
20	2.288(?)

$C_{11}H_{17}N$ (87)
Isoamylaniline

55	1.72

$C_{11}H_{20}$ (97)
Nonylacetylene

25	2.00

$C_{11}H_{20}O_4$ (26)
Diethyl n-pimelate

25	3.29

$C_{11}H_{22}O_2$ (26)
Undecylic acid

50	7.30

$C_{11}H_{22}O_2$ (31)
Hexan-β-ol n-valerate

25	1.56

$C_{11}H_{22}O_2$ (31)
Heptan-β-ol n-butyrate (31)

25	1.57

$C_{11}H_{22}O_2$ (31)
Octan-β-ol propionate

25	1.59

$C_{11}H_{22}O_2$ (31)
Ethyl pelargonate

25	1.69
50	1.11

$C_{11}H_{22}O_2$ (31)
Isobutyl n-heptoate

25	1.52

$C_{11}H_{22}O_2$ (39)
Propyl dipropylacetate

20	1.791

$C_{11}H_{22}O_2$ (39)
Ethyl diethylpropylacetate

20	3.861

$C_{11}H_{24}$ (7)
n-Undecane

22.7	0.94

$C_{11}H_{24}O$ (30)
Methylnonyl carbinol

25	12.3

$C_{12}H_{10}O$ (51)
Diphenyl ether

25	3.864
(79)	
25	3.66

$C_{12}H_{11}N$ (87)
Diphenylamine

55	4.66
(14)	
61	4.18
81	2.53
(72)	
130	1.04

$C_{12}H_{13}N$ (87)
Dimethyl-α-naphthylamine

t, °C	100η
55	3.25
(72)	
130	0.87

$C_{12}H_{13}N$ (87)
Dimethyl-β-naphthylamine

55	3.36
(72)	
130	0.95

$C_{12}H_{14}O_4$ (6)
Diethyl phthalate

25	10.1
(65)	
55	4.182

$C_{12}H_{16}O_2$ (39)
Propyl hydrocinnamate

20	3.9377

$C_{12}H_{17}NO_2$ (6)
Ethyl-o-tolylurethane

25	9.44

$C_{12}H_{18}O$ (39)
Thymyl ethyl ether

20	2.513(?)

$C_{12}H_{18}O_6$ (97)
Triethyl aconitate

25	11.7

$C_{12}H_{22}O_3$ (39)
Ethyl dipropylacetoacetate

20	4.829

$C_{12}H_{22}O_4$ (26)
Diethyl suberate

25	4.05

$C_{12}H_{24}O_2$ (24)
Lauric acid

50	7.3
60	5.61
70	4.43
80	3.62
90	2.99

$C_{12}H_{24}O_2$ (31)
Isobutyl n-octoate

25	1.82

$C_{12}H_{24}O_2$ (31)
Hexan-β-ol n-hexoate

25	1.80

$C_{12}H_{24}O_2$ (31)
Heptan-β-ol n-valerate

25	1.79

$C_{12}H_{24}O_2$ (31)
Octan-β-ol n-butyrate

25	1.89

$C_{12}H_{26}$ (7)
n-Dodecane

23.3	1.15

$C_{12}H_{26}O$ (30)
Octylisopropyl carbinol

t, °C	100η
25	14.4

$C_{13}H_{10}O$ (57)
Benzophenone

25	13.6
95	1.74
(65)	
55	4.67

$C_{13}H_{12}$ (57)
Diphenylmethane

100	0.83

$C_{13}H_{13}N$ (87)
Benzylaniline

55	5.39
(72)	
130	1.20

$C_{13}H_{13}N$ (14)
N-Methyldiphenylamine

9.8	11.0
20.1	7.25
30	5.15
40	3.85
60	2.49
80	1.74
(72)	
130	0.81

$C_{13}H_{20}O$ (39)
Thymyl propyl ether

20	3.527

$C_{13}H_{26}O_2$ (31)
Methyl laurate

25	3.08
50	1.85

$C_{13}H_{26}O_2$ (31)
Isobutyl n-nonate

25	2.18

$C_{13}H_{26}O_2$ (31)
Hexan-β-ol n-heptoate

25	2.15

$C_{13}H_{26}O_2$ (31)
Heptan-β-ol hexoate

25	2.19

$C_{13}H_{26}O_2$ (31)
Undecan-β-ol acetate

25	2.81

$C_{13}H_{28}$ (7)
n-Tridecane

23.3	1.52

$C_{14}H_{12}O_2$ (51)
Benzyl benzoate

25	8.504
(11)	
5	19.28
15	12.12
25	8.292

$C_{14}H_{12}O_2$.—(Cont'd)

t, °C	100η
40	5.243
60	3.259
80	2.245
90	1.912
100	1.655
(50)	
25	8.454

$C_{14}H_{15}N$ (72)
Dibenzylamine

25	6.16
130	0.812

$C_{14}H_{26}O_4$ (26)
Diethyl sebacate

25	5.1
(97)	
25	5.42

$C_{14}H_{28}O_2$ (24)
Myristic acid

60	7.43
70	5.83
80	4.64
90	3.81
(31)	
70	6.76
90	4.16

$C_{14}H_{28}O_2$ (31)
Ethyl laurate

25	3.08
50	1.74

$C_{14}H_{28}O_2$ (31)
Heptan-β-ol n-heptoate

25	2.56

$C_{14}H_{28}O_2$ (31)
Octan-β-ol n-hexoate

25	2.55

$C_{14}H_{28}O_2$ (31)
Undecan-β-ol propionate

25	2.84

$C_{14}H_{30}$ (7)
n-Tetradecane

21.9	2.22

$C_{15}H_{17}N$ (87)
Ethylbenzylaniline

55	4.77

$C_{15}H_{30}O_2$ (31)
Isobutyl n-undecate

25	3.25

$C_{15}H_{30}O_2$ (31)
Hexan-β-ol n-nonate

25	3.08

$C_{15}H_{30}O_2$ (31)
Heptan-β-ol n-octoate

25	3.03

$C_{15}H_{30}O_2$ (31)
Octan-β-ol n-heptoate

25	3.07

$C_{15}H_{30}O_2$ (31)
Undecan-β-ol
n-butyrate

t, °C	100η
25	3.62

$C_{15}H_{32}$ (7)
n-Pentadecane

22	2.86

$C_{16}H_{17}NO_2$ (65)
Benzylphenylurethane

55	10.96

$C_{16}H_{27}N$ (87)
Diisoamylaniline

55	2.92

$C_{16}H_{32}O_2$ (24)
Palmitic acid

70	7.8
80	6.1
90	5.0
95	4.47

$C_{16}H_{32}O_2$ (31)
Isobutyl laurate

25	3.87

$C_{16}H_{32}O_2$ (31)
Heptan-β-ol
n-nonoate

25	3.69

$C_{16}H_{32}O_2$ (31)
Octan-β-ol
n-octoate

25	3.64

$C_{16}H_{32}O_2$ (31)
Undecan-β-ol
n-valerate

25	3.74

$C_{16}H_{34}$ (7)
n-Hexadecane

22.2	3.63

$C_{16}H_{34}O$ (31)
Cetyl alcohol

50	14.6
90	3.53

$C_{17}H_{34}O_2$ (31)
Hexan-β-ol
undecoate

25	4.3

$C_{17}H_{34}O_2$ (31)
Octan-β-ol
n-nonoate

25	4.22

$C_{17}H_{34}O_2$ (31)
Undecan-β-ol
n-hexoate

t, °C	100η
25	4.14

$C_{18}H_{15}N$ (72)
Triphenylamine

130	6.4

$C_{18}H_{15}O_4P$ (65)
Triphenyl phosphate

55	9.50

$C_{18}H_{15}P$ (97)
Triphenylphosphine

100	4.62

$C_{18}H_{15}Sb$ (97)
Triphenylstibine

70	9.34

$C_{18}H_{36}O_2$ (24)
Stearic acid

70	9.87
80	7.72
90	6.1
95	5.47
98	5.18
(31)	
70	9.4
90	5.6

$C_{18}H_{36}O_2$ (31)
Ethyl palmitate

25	5.76
50	3.14

$C_{18}H_{36}O_2$ (31)
Isobutyl myristate

25	5.32

$C_{18}H_{36}O_2$ (31)
Hexan-β-ol
laurate

25	5.4

$C_{18}H_{36}O_2$ (31)
Heptan-β-ol
n-undecoate

25	5.15

$C_{18}H_{36}O_2$ (31)
Undecan-β-ol
n-heptoate

25	4.91

$C_{19}H_{16}$ (57)
Triphenylmethane

95	3.5
100	3.22

$C_{19}H_{38}O_2$ (31)
Heptan-β-ol
laurate

t, °C	100η
25	5.9

$C_{19}H_{38}O_2$ (31)
Octan-β-ol
undecoate

25	5.82

$C_{20}H_{38}O_2$ (86.5)
Ethyl elaidate

24.7	8.17

$C_{20}H_{38}O_4$ (97)
Diisoamyl sebacate

25	12.0

$C_{20}H_{40}O_2$ (31)
Ethyl stearate

50	3.75

$C_{20}H_{40}O_2$ (31)
Hexan-β-ol
myristate

25	6.73

$C_{20}H_{40}O_2$ (31)
Octan-β-ol
laurate

25	6.87

$C_{20}H_{40}O_2$ (31)
Undecan-β-ol
nonoate

25	6.61

$C_{21}H_{21}N$ (72)
Tribenzylamine

130	2.09

$C_{21}H_{42}O_2$ (31)
Heptan-β-ol
myristate

25	7.75

$C_{22}H_{44}O_2$ (31)
Octan-β-ol
myristate

25	8.91

$C_{22}H_{44}O_2$ (31)
Undecan-β-ol
undecoate

25	8.73

$C_{23}H_{46}O_2$ (31)
Undecan-β-ol
laurate

25	9.66

$C_{25}H_{50}O_2$ (31)
Undecan-β-ol
myristate

25	12.3

INFLUENCE OF PRESSURE ON VISCOSITY (14.7)

η = viscosity of liquid under tabulated pressure and temperature.

$\eta_{30°}$ = viscosity of liquid at 30° and atmospheric pressure; poises.

P = pressure in kg/cm².

The reference value of $\eta_{30°}$ is indicated under the name of compound.

Values of $\log_{10} \frac{\eta}{\eta_{30°}}$

CCl_4, Carbon tetrachloride
$\eta_{30°}$ = 0.00845

P, kg/cm²	30°	75°
1	0.000	9.760
500	0.190	9.949
1 000	0.351	0.100
4 000		0.542

CS_2, Carbon disulfide
$\eta_{30°}$ = 0.00352

1	0.000	9.875
500	0.090	9.972
1 000	0.160	0.051
2 000	0.307	0.180
4 000	0.509	0.372
6 000	0.674	0.527
8 000	0.840	0.671
10 000	1.010	0.808
12 000	1.189	0.946

$CHCl_3$, Chloroform
v. Vol. V, p. 11

CH_4O, Methyl alcohol
v. Vol. V, p. 11

$C_2H_4Br_2$, Ethylene bromide
$\eta_{30°}$ = 0.0149

1	0.000	9.756
500	0.138	9.885
1 000		0.003
2 000		0.203

C_2H_5Br, Ethyl bromide
$\eta_{30°}$ = 0.00368

1	0.000	9.806
500	0.121	9.959
1 000	0.222	0.072
2 000	0.387	0.235
4 000	0.631	0.472
6 000	0.854	0.653
8 000	1.043	0.816
10 000	1.223	0.978
12 000	1.400	1.123

C_2H_5Cl, Ethyl chloride

1	0.000	9.850
500	0.134	0.017
1 000	0.242	0.131
2 000	0.405	0.285
4 000	0.649	0.514
6 000	0.837	0.683
8 000	1.008	0.834
10 000	1.172	0.977
12 000	1.323	1.111

C_2H_5I, Ethyl iodide
$\eta_{30°}$ = 0.00540

P, kg/cm²	30°	75°
1	0.000	9.837
500	0.115	9.954
1 000	0.218	0.057
2 000	0.385	0.227
4 000	0.656	0.467
6 000	0.888	0.672
8 000	1.108	0.854
10 000	1.330	1.030
12 000	1.549	1.200

C_2H_6O, Ethyl alcohol
v. Vol. V, p. 11

C_3H_6O, Acetone
$\eta_{30°}$ = 0.00285

1	0.000	9.895
500	0.135	0.017
1 000	0.226	0.113
2 000	0.373	0.245
4 000	0.605	0.445
6 000	0.804	0.610
8 000	0.987	0.762
10 000	1.160	0.898
12 000		1.031

C_3H_8O, *n*-Propyl alcohol
$\eta_{30°}$ = 0.01779

1	0.000	9.598
500	0.151	9.754
1 000	0.283	9.880
2 000	0.494	0.074
4 000	0.836	0.368
6 000	1.131	0.610
8 000	1.402	0.827
10 000	1.667	1.033
12 000	1.915	1.223

C_3H_8O, Isopropyl alcohol
$\eta_{30°}$ = 0.01757

1	0.000	9.505
500	0.193	9.695
1 000	0.343	9.851
2 000	0.591	0.087
4 000	0.982	0.425
6 000	1.318	0.701
8 000	1.640	0.957
10 000	1.977	1.191
12 000	2.311	1.424

$C_3H_8O_3$, Glycerol

$\eta_{30^\circ} = 3.8$

P, kg/cm²	30°	75°
1	0.000	8.810
500	0.134	8.920
1 000	0.260	9.023
2 000	0.497	9.204
4 000	0.936	9.529
6 000	1.346	9.818
8 000	1.741	0.094
10 000	2.133	0.369
12 000		0.628

$C_4H_8O_2$, Ethyl acetate

$\eta_{30^\circ} = 0.0039$

1	0.000	9.836
500	0.142	9.976
1 000	0.258	0.081
2 000	0.463	0.253
4 000	0.818	0.517
6 000	1.120	0.761
8 000	1.393	0.992
10 000	1.686	1.213
12 000	1.974	1.416

C_4H_9Br, *n*-Butyl bromide

$\eta_{30^\circ} = 0.00537$

1	0.000	9.832
500	0.143	9.975
1 000	0.269	0.090
2 000	0.474	0.273
4 000	0.816	0.564
6 000	1.115	0.811
8 000	1.408	1.040
10 000	1.715	1.264
12 000	2.018	1.484

$C_4H_{10}O$, *n*-Butyl alcohol

$\eta_{30^\circ} = 0.02237$

1	0.000	9.548
500	0.175	9.724
1 000	0.321	9.867
2 000	0.554	0.089
4 000	0.934	0.312
6 000	1.289	0.690
8 000	1.609	0.941
10 000	1.912	1.172
12 000	2.208	1.396

$C_4H_{10}O$, Isobutyl alcohol

$\eta_{30^\circ} = 0.02864$

1	0.000	9.444
500	0.210	9.659
1 000	0.388	9.824
2 000	0.696	0.075
4 000	1.203	0.488
6 000	1.655	0.838
8 000	2.075	1.158
10 000	2.483	1.459
12 000	2.898	1.747

$C_4H_{10}O$, Ethyl ether

v. Vol. V, p. 11

C_5H_{12}, Isopentane

$\eta_{30^\circ} = 0.00198$

1	0.000	9.821
500	0.202	0.040
1 000	0.344	0.193

C_5H_{12}.—(*Continued*)

P, kg/cm²	30°	75°
2 000	0.559	0.408
4 000	0.894	0.715
6 000	1.175	0.960
8 000	1.431	1.179
10 000	1.687	1.381
12 000	1.947	1.586

C_5H_{12}, *n*-Pentane

$\eta_{30^\circ} = 0.00220$

1	0.000	9.811
500	0.181	0.014
1 000	0.315	0.163
2 000	0.524	0.380
4 000	0.847	0.676
6 000	1.112	0.908
8 000	1.360	1.119
10 000	1.615	1.313
12 000	1.846	1.493

$C_5H_{12}O$, Isoamyl alcohol

1	0.000	9.424
500	0.209	9.618
1 000	0.386	9.787
2 000	0.686	0.065
4 000	1.185	0.492
6 000	1.636	0.848
8 000	2.069	1.168
10 000	2.505	1.483
12 000	2.952	1.780

$C_5H_{12}O$, *n*-Amyl alcohol

1	0.000	9.540
500	0.188	9.723
1 000	0.341	9.871
2 000	0.607	0.105
4 000	1.060	0.466
6 000	1.448	0.772
8 000	1.811	1.049
10 000	2.164	1.313
12 000	2.495	1.562

C_6H_5Br, Bromobenzene

$\eta_{30^\circ} = 0.00985$

1	0.000	9.801
500	0.138	9.930
1 000	0.262	0.044
2 000	0.486	0.228
4 000	0.897	0.558
6 000		0.874

C_6H_5Cl, Chlorobenzene

$\eta_{30^\circ} = 0.00711$

1	0.000	9.814
500	0.133	9.936
1 000	0.253	0.053
2 000	0.478	0.245
4 000	0.867	0.563
6 000	1.223	0.852
8 000		1.146
10 000		1.465

$C_6H_5NO_2$, Nitrobenzene

1	0.000	
500	0.134	
1 000	0.264	

C_6H_6, Benzene

v. Vol. V, p. 12

C_6H_{12}, Cyclohexane

$\eta_{30^\circ} = 0.00828$

P, kg/cm²	30°	75°
1	0.000	9.723
500	0.261	9.975
1 000		0.169

C_6H_7N, Aniline

$\eta_{30^\circ} = 0.0319$

1	0.000	9.551
500	0.195	9.703
1 000	0.376	9.847
2 000	0.709	0.102
4 000		0.560

C_6H_{14}, *n*-Hexane

$\eta_{30^\circ} = 0.00296$

1	0.000	9.803
500	0.184	0.028
1 000	0.332	0.171
2 000	0.561	0.379
4 000	0.914	0.701
6 000	1.224	0.961
8 000	1.514	1.198
10 000	1.803	1.426
12 000		1.646

C_7H_8, Toluene

$\eta_{30^\circ} = 0.00523$

1	0.000	9.796
500	0.145	9.939
1 000	0.274	0.065
2 000	0.497	0.267
4 000	0.897	0.597
6 000	1.285	0.896
8 000	1.699	1.186
10 000	2.177	1.504
12 000		1.832

C_7H_{14}, Methylcyclohexane

$\eta_{30^\circ} = 0.00639$

1	0.000	9.747
500	0.220	9.976
1 000	0.388	0.154
2 000	0.710	0.434
4 000	1.274	0.900
6 000	1.804	1.335
8 000	2.318	1.756
10 000		2.167
12 000		2.582

C_8H_{10}, *o*-Xylene

$\eta_{30^\circ} = 0.00709$

1	0.000	9.767
500	0.165	9.925
1 000	0.311	0.057
2 000	0.577	0.292
4 000		0.689
6 000		1.087

C_8H_{10}, *m*-Xylene

$\eta_{30^\circ} = 0.00552$

1	0.000	9.799
500	0.154	9.959
1 000	0.290	0.079
2 000	0.529	0.286
4 000	0.967	0.637
6 000		0.983
8 000		1.333

C_8H_{10}, *p*-Xylene

$\eta_{30^\circ} = 0.00568$

P, kg/cm²	30°	75°
1	0.000	9.797
500	0.152	9.957
1 000		0.092
2 000		0.315

C_8H_{18}, *n*-Octane

$\eta_{30^\circ} = 0.00483$

1	0.000	9.810
500	0.196	0.003
1 000	0.327	0.153
2 000	0.641	0.390
4 000	1.088	0.763
6 000	1.487	1.080
8 000		1.363
10 000		1.630

$C_{10}H_{12}O_2$, Eugenol

1	0.000	9.429
500	0.288	9.616
1 000	0.541	9.810
2 000	1.081	0.143
3 000	2.273	0.805
5 000		1.520
8 000		2.343

$C_{10}H_{14}$, *p*-Cymene

1	0.000	9.800
500	0.172	9.948
1 000	0.333	0.087
2 000	0.626	0.335
4 000	1.194	0.749
6 000	1.859	1.168
8 000		1.612
10 000		2.164

$C_{10}H_{15}N$, Diethylaniline

1	0.000	9.690
500	0.201	9.839
1 000	0.394	9.984
2 000	0.761	0.259
4 000		0.758
6 000		1.250
8 000		1.775

$C_{10}H_{18}O$, Cineole

1	0.000	9.654
500	0.315	9.905
1 000		0.142
2 000		0.575

$C_{10}H_{22}O$, *n*-Amyl ether

1	0.000	9.736
500	0.218	9.943
1 000	0.401	0.107
2 000	0.708	0.364
4 000	1.230	0.776
6 000	1.685	1.125
8 000	2.091	1.437
10 000		1.728
12 000		2.007

$C_{18}H_{34}O_2$, Oleic acid

1	0.000	9.419
500	0.306	9.671
1 000	0.616	9.989
2 000		0.255
4 000		0.843

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(60) Lewis, *1*, **47**: 626; 25. (60.5) Linebarger, *1*, **17**: 615, 690; 95. (61) Lorenz, *7*, **79**: 63; 12. (62) Lorenz and Hoechberg, *93*, **94**: 317; 16. (63) Lorenz and Kalmus, *7*, **59**: 244; 07. (64) Maass and Boomer, *1*, **44**: 1709; 22. (65) McBain, Harvey and Smith, *50*, **30**: 312; 26. (66) Mathews and Faville, *50*, **22**: 1; 18. (67) Menneret, *51*, **1**: 753; 11. (68) Merry and Turner, *4*, **105**: 748; 14. (69) Meyer and Mylius, *7*, **95**: 349; 20.

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MERLE RANDALL, SPECIAL EDITOR

Including

EQUILIBRIA BETWEEN TWO SOLID PHASES AND A GAS PHASE (DECOMPOSITION PRESSURES OF HYDRATES, AMMONIATES, ETC.)

FRITZ EPHRAIM[2]

and

SOLUBILITY OF SLIGHTLY SOLUBLE SALTS IN AQUEOUS SALT SOLUTIONS

MERLE RANDALL AND WILLIAM V. VIETTI[3]

SCOPE OF THE SECTION

This section includes all chemical equilibria except those which have been treated in previous sections. The section also includes miscellaneous thermodynamic data, such as partial molal quantities, activity coefficients, heat capacities of substances, etc., when these are combined with other data.

The tables are not as complete as could be desired. An attempt has been made to include as many types of systems as possible, and more space has been given to those systems which have not been widely discussed in the literature than to the more common systems. Omission of a table or mention by reference only in no way reflects upon the quality or importance of the data.

OBJET TRAITÉ DANS LA SECTION

Cette section comprend tous les équilibres chimiques, à l'exception de ceux dont il a déjà été traité dans des sections précédentes. La section renferme aussi des données thermodynamiques diverses, telles que des quantités moléculaires partielles, coefficients d'activité, capacités calorifiques des substances, etc., lorsque celles-ci sont combinées à d'autres données.

Les tables ne sont pas aussi complètes qu'on puisse le désirer. On s'est efforcé d'y mentionner un nombre aussi grand que possible de types de systèmes, et il a été réservé plus d'espace aux systèmes qui n'ont pas été largement discutés dans la littérature qu'aux systèmes plus communs. L'omission d'une table ou sa mention par une référence seulement ne se rapporte en aucune manière à la qualité ou à l'importance de la donnée.

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[1] *See also* Entropy, etc., Vol. V, p. 84.

[2] Editorial Note.—The data on this topic, compiled by Professor Ephraim, have been combined with the other data of this section according to the Standard Arrangement. They are identified by the symbol (E). Translation from the German and conversion into the units °K and atm. were effected by Gerald F. Breckenridge under the direction of the Special Editor.

[3] The senior author is alone responsible for the data on the complex ammines and for references subsequent to the year 1925. For this section, *see* p. 313.

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ARRANGEMENT

1. The systems or reactions are listed in the standard arrangement (*see* Vol. III, p. viii) in accordance with that substance in the reaction which has the highest key-formula. Thus, for example, in the reaction

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) = 2PbSO_4(s) + 2H_2O(l)$$

the key-formulae are:

Pb, 23; PbO_2, 23—12; H_2SO_4, 8—22—14; $PbSO_4$, 23—8—14; H_2O, 22—1.

The highest key-formula is that for $PbSO_4$, 23—8—14 and this reaction will therefore be found listed under $PbSO_4$ and can be found by turning the pages until 23 appears as the first member of the key-numbers which appear at the top of each right-hand page. After locating the proper section in this way, the desired system or reaction can then be located by inspection.

2. Where choice of condition or state is involved for a given substance the order is gas (g); liquid (l); solid (s); in aqueous solution (aq); in non-aqueous solution, standard arrangement by solvents.

3. *Important Exceptions.*—Solid hydrates, ammines, etc., containing water, ammonia, etc., "of crystallization" are listed under the parent material. Water, ammonia, etc., of crystallization should, therefore, be neglected in writing key-formulae. (These exceptions do not, however, apply to complex ions, complex cobaltammines, etc.) Solubility data are in all cases listed under the solute.

SYMBOLS AND ABBREVIATIONS

In general the notation of Lewis and Randall (885) is used.

a	Activity.
c	Concentration (moles per liter).
$c_\pm$	Geometrical mean of concentration of ions.
f	Fugacity.
het.	Two-phase system richest in solute.
ln	Logarithm to the base *e*.
log	Logarithm to the base 10.
m	Molality (moles per 1000 g H_2O, *in vacuo*).
$m_\pm$ $m^0_\pm$	*v.* p. 227.
n	Number of moles.
p	Vapor pressure (in atmospheres).
p.f.	Proportionality factor (*see* activity coefficients).
s	Solubility (moles per 1000 g H_2O, *in vacuo*).
s_c	Solubility (moles per liter).
t	Temperature, °C.
x	Mole fraction.
C_p	Molal heat capacity at constant pressure.
C_v	Molal heat capacity at constant volume.
E	Internal energy.
E	Electromotive force.
E^-	One gram atom of negative electricity.
F	Free energy.
H	Heat content.
I	Integration constant.
K	Equilibrium constant (activities) *v.* p. 227.
K'	Special equilibrium function.
K_c	Equilibrium function in terms of concentration.
K_m	Equilibrium function in terms of molalities.
K_p	Equilibrium function in terms of partial pressures.
$\bar{L}$	Relative partial molal heat content.
M	Molal.
P	Total pressure or vapor pressure, in atmospheres.
R	Gas constant.
S	Entropy.
T	Absolute temperature.
V	Volume.
w	Molal mass.

ARRANGEMENT

1. Les systèmes ou les réactions sont disposés en liste suivant l'arrangement type (*voir* Vol. III, p. viii) en accord avec la substance de la réaction qui possède la formule-clé la plus élevée. Ainsi, par exemple, dans la réaction

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) = 2PbSO_4(s) + 2H_2O(l)$$

les formules-clés sont

Pb, 23; PbO_2, 23—12; H_2SO_4, 8—22—14; $PbSO_4$, 23—8—14; H_2O, 22—1.

La formule-clé la plus élevée est celle de $PbSO_4$, 23—8—14 et par conséquent on trouvera la réaction mentionnée ci-dessus sous $PbSO_4$; on tournera donc les pages jusqu'à ce qu'on atteigne 23, premier membre des nombres-clés inscrits au haut de chacune des pages se trouvant à main droite. Ayant trouvé de cette façon la section convenable, on y recherchera alors, le système de réaction désiré.

2. Lorsque le choix de la condition ou de l'état est impliqué pour une substance donnée, l'ordre est gaz (g); liquide (l); solide (s); en solution aqueuse (aq); en solution non-aqueuse, arrangement type par dissolvants.

3. *Exceptions Importantes.*—Les hydrates solides, les ammines, etc., contenant de l'eau, de l'ammoniaque, etc., "de cristallisation" sont inscrits en liste sous la matière principale. L'eau, l'ammoniaque, etc., de cristallisation doivent donc être négligés lorsqu'on écrit la formule-clé. (Ces exceptions cependant ne s'appliquent pas aux ions complexes, cobaltammines complexes, etc.) Les données de solubilité sont dans tous les cas inscrits sous le corps dissous.

SYMBOLES ET ABRÉVIATIONS

C'est en général la notation de Lewis et Randall (885) quies utilisée.

a	Activité.
c	Concentration (mol gr. par litre).
$c_\pm$	Moyenne géométrique de la concentration des ions.
f	Fugacité.
het.	Système à deux phases le plus riche en corps dissous.
ln	Logarithme de base *e*.
log	Logarithme de base 10.
m	"Molalité" (mol gr. par 1000 g H_2O, dans le vide).
$m_\pm$ $m^0_\pm$	*v.* p. 227.
n	Nombre de molécules grammes.
p	Pression de vapeur (en atmosphères).
p.f.	Facteur de proportionalité (*voir* coefficients d'activité).
s	Solubilité (molécules gr. par 1000 g H_2O, dans le vide).
s_c	Solubilité (molécules gr. par litre).
t	Température, °C.
x	Fraction moléculaire gramme.
C_p	Capacité calorifique moléculaire à pression constante.
C_v	Capacité calorifique moléculaire à volume constant.
E	Énergie interne.
E	Force électromotrice.
E^-	Un atome gramme d'électricité négative.
F	Énergie libre.
H	Contenu de chaleur.
I	Constante d'intégration.
K	Constante d'équilibre (activités), *v.* p. 227.
K'	Fonction d'équilibre spéciale.
K_c	Fonction d'équilibre en termes de concentration.
K_m	Fonction d'équilibre en termes de molalité.
K_p	Fonction d'équilibre en termes de pressions partielles.
$\bar{L}$	Contenu de chaleur relatif partiel moléculaire.
M	Moléculaire gramme.
P	Pression totale ou pression de vapeur, en atmosphères.
R	Constante des gaz.

γ	Activity coefficient.
μ	Ionic strength.
μ_c	Ionic strength (for concentrations).
ν	Number of ions formed by dissociation of one molecule.
Δ	Increment.

Small cap roman: molal quantities, thus H.

Small cap roman with bar: Partial molal quantity, thus H.

Subscript $_1$ (resp. $_2$) identifies solvent (resp. solute).

UNITS AND VALUES OF CONSTANTS USED*

1 cal.	4.182 joules.
T	$t + 273.1$.
R	82.07 cm^3-atm. per deg. K.
R	1.9885 cal. per deg. K.
V	(for 1 mole of a perfect gas) 22 412 cm^3 at 1 atm. and 273.1°K.
F	96 494 coulombs per equiv.
F	23 074 cal. per volt equiv.

All pressures are expressed in atmospheres, all temperatures in degrees absolute, all electromotive forces in volts and all energy quantities in calories (*v. supra*) unless otherwise expressly stated. When making further transformations of the data, it is important to use only the constants and data of this section.

FREE ENERGY DATA

In general, the accuracy of the free energy equations may be judged by the constancy of the quantity I where this has been tabulated. The lack of a definite trend with a variation in temperature indicates that the choice of the particular form of substances taking part in the reaction and the values of the ΔH and ΔC_p are probably substantially correct. The individual variations indicate the degree of precision of the experimental measurements. Since many of the derived values involve addition and subtraction of other equations, it is not possible, at this time, to give the probable error, and the number of significant figures given should not be interpreted as an indication of the accuracy. Where "revised" values are indicated, it is usually necessary to use the unrevised (^{885}) values, when these are to be combined with other equations in this section.

The free energies are given in the form

$$\Delta F^0 = \Delta H_0^0 - \Delta\Gamma_0^0 T \ln T - \tfrac{1}{2}\Delta\Gamma' T^2 - \tfrac{1}{6}\Delta\Gamma'' T^3 - \cdots + IT \quad (1)$$

where $\Delta\Gamma$, $\Delta\Gamma'$ and $\Delta\Gamma''$, etc., are the coefficients in the algebraic expression for the increase in heat capacity of the reaction.

We thus have

$$\Delta H^0 = \Delta H_0^0 + \Delta\Gamma^0 T + \tfrac{1}{2}\Delta\Gamma' T^2 + \tfrac{1}{3}\Delta\Gamma'' T^3 \quad (2)$$

$$\Delta \mathrm{S}^0 = \Delta\Gamma_0^0(1 + \ln T) + \Delta\Gamma' T + \tfrac{1}{2}\Delta\Gamma'' T^2 + \cdots - I \quad (3)$$

The superscript ^{0} on the quantities ΔF, ΔH, ΔS indicates that the quantity is that for a stated or implied reaction in which all chemical substances involved are assumed to be at unit activity, at a fugacity of 1 atm. (or, when specifically so stated, at a pressure of 1 atm.), or hypothetical unit concentration. Where the reaction is not explicitly stated it is assumed to be the reaction of formation of a stated substance out of its elements in their standard states. The standard state of an element is that state to which the value $\Delta F^0 = 0$ is assigned in the tables, the pressure being always one atm. unless otherwise specifically stated. When no standard state is thus indicated in the tables, the "ordinary" solid form of the element is assumed.

In writing the equilibrium constant, K, the activities of the substances appearing on the right of the reaction as written always appear in the numerator. For gases the units are always atmospheres, and for solutes the units are always mole fractions, or moles per 1000 g of water. For the constant K so defined, $\Delta F^0 = -RT \ln K$.

S	Entropie.
T	Température absolue.
V	Volume.
w	Masse molale.
γ	Coefficient d'activité.
μ	Force ionique.
μ_c	Force ionique (pour concentrations).
ν	Nombre d'ions formées par dissociation d'un molécule.
Δ	Incrément.

Petite majuscule romaine: Quantités moléculaires, ainsi H.

Petite majuscule romaine avec barre: Quantité moléculaire partielle, ainsi $\bar{\text{H}}$.

L'indice $_1$ (resp. $_2$) identifie le solvant (resp. le corps dissous).

UNITÉS ET VALEURS DES CONSTANTES UTILISÉES*

1 cal.	4,182 joules.
T	$t + 273{,}1$.
R	82,07 cm^3-atm. par deg. K.
R	1,9885 cal. par deg. K.
V	(pour une molécule gramme d'un gaz parfait) 22 412 cm^3 à 1 atm. et à 273, 1°K.
F	96 494 coulombs par equiv.
F	23 074 cal. par volt equiv.

Toutes les pressions sont exprimées en atmosphères, toutes les températures en degrés absolus, toutes les forces électromotrices en voltes et toutes les quantités d'énergie en calories (*v.* ci-dessus), à moins d'une autre indication. Lorsqu'on veut effectuer des transformations ultérieures des données, il est important de n'utiliser que les constantes et les données de cette section.

DONNÉES RELATIVES À L'ÉNERGIE LIBRE

En général, on peut juger de la précision des équations relatives à l'énergie libre par la constance de la quantité I en consultant la table où celle-ci est mentionnée. Le manque d'une tendance définie avec la variation de la température indique que le choix de la forme particulière des substances prenant part à la réaction et des valeurs de ΔH et ΔC_p est probablement réellement exact. Les variations individuelles indiquent le degré de précision des mesures expérimentales. Comme plusieurs des valeurs dérivées comportent l'addition et la soustraction d'autres équations, il n'est pas possible, pour le moment, de donner l'erreur probable et le nombre de chiffres significatifs donnés ne doit pas être interprété comme une indication de la précision. Lorsque des valeurs "revised" sont indiquées, il est ordinairement nécessaire d'utiliser les valeurs non revisées (^{885}), lorsque celles-ci doivent être combinées avec d'autres équations de la section.

Les énergies libres sont données sous la forme

$$\Delta F^0 = \Delta H_0^0 - \Delta\Gamma_0^0 T \ln T - \tfrac{1}{2}\Delta\Gamma' T^2 - \tfrac{1}{6}\Delta\Gamma'' T^3 - \cdots + IT \quad (1)$$

où $\Delta\Gamma$, $\Delta\Gamma'$ et $\Delta\Gamma''$, etc., sont les coefficients dans l'expression algébrique de l'augmentation de la capacité calorifique de la réaction.

On a ainsi

$$\Delta H^0 = \Delta H_0^0 + \Delta\Gamma^0 T + \tfrac{1}{2}\Delta\Gamma' T^2 + \tfrac{1}{3}\Delta\Gamma'' T^3 \quad (2)$$

$$\Delta S^0 = \Delta\Gamma_0^0(1 + \ln T) + \Delta\Gamma' T + \tfrac{1}{2}\Delta\Gamma'' T^2 + \cdots - I \quad (3)$$

L'exposant ^{0} sur les quantités ΔF, ΔH, ΔS, indique que la quantité est celle se rapportant à une reaction établie ou implicite, dans laquelle toutes les substances chimiques engagées sont supposées être à l'activité unité, à une fugacité d'une atmosphère, (ou, lorsque cela est établi spécifiquement ainsi, à une pression d'une atm.), ou à une concentration unité hypothétique. Lorsque la réaction n'est pas établie explicitement, il s'agit d'une réaction de formation d'une substance donnée à partir de ses éléments dans leur état type. L'état type d'un élément est l'état pour lequel la

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*Note that these *are not* the accepted I. C. T. values (*see* Vol. I, p. 17). The data of the present section form a consistent whole but cannot be readily combined with other data in I. C. T.

*À noter que celles-ci *ne sont pas* les valeurs I. C. T. acceptées (*voir* Vol. I, p. 17). Les données de la présente section constituent un tout consistant, mais elles ne peuvent être directement combinées avec les autres données dans les I. C. T.

In some cases we use equilibrium functions (K_m) in which the molality of the substances or ions is used instead of the activity, and others (K_c) in which the concentrations (moles per liter) of the substances in solution are used instead of the activities. In still others we have used special functions (K'_m or K'_c) in which activities are used for all the substances except the ions present. The concentration of a gas is never used in these expressions. *See* Lewis and Randall (**885**), Randall and Vietti (**1192**), Randall (**1170.5**).

ACTIVITY COEFFICIENTS

In the case of all reactions involving only ions on the right-hand side of the equation, and a few others, the various equilibria are transformed in such a way that ($\log \gamma$ + a constant) and $\mu^{1/2}$ are given in the tables. By a simple graph of these quantities interpolations and comparisons may be made, and by superimposition of the curves so obtained upon the corresponding curves for suitable reference salts made upon the same scale, the extrapolation to unit activity coefficient can be easily made, and when these extrapolated numbers become available the activity coefficient of the particular pair of ions may be found by subtraction of log *p.f.* (given in a few cases) from the value of ($\log \gamma$ + a constant). The activity coefficient for concentration, the ionic strength for concentration, etc., are defined in the sense used by Randall and Vietti (**1192**), namely, the product of the-activity-coefficient-for-concentration by the concentration gives the activity (defined with reference to molalities).

$$\log \gamma + \text{const.} = \log \gamma - E^0/(0.00019844\nu T/N) = -E/(0.00019844\nu T/N) + \log (1/m_\pm) \quad (4)$$

where E^0 and E are the standard and measured electromotive forces, N the number of equivalents, and $m_\pm$ the mean molality of the ions studied in the cell.* Or

$$\log \gamma + \text{const.} = (1/\nu) \log p + \log (1/m_\pm) \quad (5)$$

where p is the vapor pressure of the solute. Or

$$\log \gamma + \text{const.} = (1/\nu) \log x_2 + \log (1/m_\pm)$$

where x_2 is the mole fraction of the solute in a second immiscible solvent. Or

$$\log \gamma + \text{const.} = \log (1/m_\pm)$$

where $m_\pm$ is the mean molality of the ions in equilibrium with the pure solid (solubility). Or

$$\log \gamma + \text{const.} = (1/\nu) \log (1/K'_m),$$

where K'_m is an equilibrium function in which activities are substituted for all substances taking part in the reaction (usually undissociable substances or gases) except the pair of ions considered. (*See* $CaCO_3$ (calcite) + H_2CO_3(aq) = Ca^{++} + $2HCO_3^-$, p. 296.)

INHALT DIESER ABTEILUNG

Zu dieser Abteilung gehören alle Gleichgewichte bis auf solche welche in den vorhergehenden behandelt worden sind. Die Abteilung enthält auch verschiedene thermodynamische Daten wie partielle molare Grössen, Aktivitätskoeffizienten, Molwärmen der Substanzen, usw., wenn dieselben mit anderen Daten verbunden sind.

Die Tabellen sind nicht so vollständig wie man sich wünschen könnte. Es wurde versucht, möglichst verschiedenartige Systeme zu behandeln; jenen Systemen, welche in der Literatur nicht so ausführlich diskutiert worden sind, ist mehr Raum gewidmet als den gewöhnlicheren. Das Weglassen einer Tabelle, oder die blosse Zitierung einer Arbeit ist nie als eine Unterschätzung der Qualität oder Wichtigkeit der Daten zu betrachten.

ANORDNUNG

1. Die Systeme und Reaktionen sind nach der Standardanordnung (*siehe* Bd. III, S. viii) geordnet, dem Reaktionsteilnehmer mit der höchsten Schlüsselformel entsprechend. So sind zum

valeur $\Delta F^0 = 0$ est assignée dans les tables, la pression étant toujours une atm. à moins d'une autre indication. Lorsque aucun état type n'est indiqué ainsi dans les tables, il s'agit de la forme "ordinaire" solide de l'élément.

En écrivant la constante d'équilibre, K, les activités des substances se trouvant au deuxième membre de la réaction sont écrites au numérateur comme d'habitude. Pour les gaz, les unités sont toujours atmosphères, et pour les corps dissous, les unités sont toujours fractions moléculaires grammes, ou molécules grammes pour 1000 g d'eau. Pour la constante K, ainsi définie, $\Delta F^0 = -RT \ln K$.

Dans quelques cas on s'est servi des fonctions d'équilibre (K_m), dans lesquelles la molalité des substances ou des ions est utilisée à la place de l'activité, et d'autres fonctions (K_c) dans lesquelles les concentrations (mol gr. par litre) des substances en solutions sont utilisées à la place des activités. Dans d'autres cas encore, il a été employé des fonctions spéciales (K'_m ou K'_c) dans lesquelles les activités ont été utilisées pour toutes les substances à l'exception des ions présents. La concentration d'un gaz n'est jamais utilisée dans ces expressions. *Voir* Lewis et Randall (**885**), Randall et Vietti (**1192**), Randall (**1170.5**).

COEFFICIENTS D'ACTIVITÉ

Dans le cas de toutes les réactions ne comportant que des ions au deuxième membre de l'équation, et dans quelques autres cas, les divers équilibres sont transformés de telle façon que ($\log \gamma$ + une constante) et $\mu^{1/2}$ soient donnés dans les tables. Au moyen d'un simple graphique de ces quantités, on peut faire des interpolations et des comparaisons et par superposition des courbes ainsi obtenues avec les courbes correspondantes de sels de référence convenables, dessinées à la même échelle, on peut effectuer facilement l'extrapolation pour le coefficient unité d'activité; lorsque ces nombres extrapolés sont disponibles, on trouvera le coefficient d'activité de la paire particulière d'ions en soustrayant log *p.f.* (donné dans quelques cas) de la valeur de ($\log \gamma$ + une constante). Le coefficient d'activité pour la concentration, la force ionique pour la concentration, etc., sont définis suivant le sens utilisé par Randall et Vietti (**1192**), c'est-à-dire, le produit du coefficient d'activité pour la concentration, par la concentration donne l'activité (définie avec référence aux molalité).

$$\log \gamma + \text{constante} = \log \gamma - E^0/0{,}00019844\nu T/N) = -E/(0{,}00019844\nu T/N) - \log (1/m_\pm) \quad (4)$$

où E^0 et E sont respectivement les forces électromotrices types et mesurées, N le nombre des équivalents et $m_\pm$ la molalité moyenne des ions étudiés dans la pile.* Ou

$$\log \gamma + \text{constante} = (1/\nu) \log p + \log (1/m_\pm) \quad (5)$$

où p est la pression de vapeur du corps dissous. Ou

$$\log \gamma + \text{constante} = (1/\nu) \log x_2 + \log (1/m_\pm)$$

où x_2 est la fraction moléculaire du corps dissous dans un deuxième dissolvant non miscible. Ou

$$\log \gamma + \text{constante} = \log (1/m_\pm)$$

où $m_\pm$ est la molalité moyenne des ions en équilibre avec le solide pur (solubilité). Ou

$$\log \gamma + \text{constante} = (1/\nu) \log (1/K'_m)$$

où K'_m est une fonction d'équilibre dans laquelle les activités sont substituées à toutes les substances prenant part à la réaction (ordinairement des substances non dissociables ou des gaz), à l'exception de la paire d'ions considérés. (*Voir* $CaCO_3$ (calcite) + H_2CO_3(aq) = Ca^{++} + $2HCO_3^-$, p. 296.)

ARGOMENTI COMPRESI IN QUESTO CAPITOLO

Questo capitolo comprende tutti gli equilibri chimici, eccettuati quelli dei quali si è parlato in capitoli precedenti. Vi sono pure contenuti dati termodinamici diversi, come quantità molari parziali, coefficienti di attività, capacità termiche, ecc.

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* In general $\Delta F = -NEF$.

* En général $\Delta F = -NEF$.

Beispiel in der Reaktion

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) = 2PbSO_4(s) + 2H_2O(l)$$

die folgenden als Schlüsselformeln zu nehmen:

Pb, 23; PbO_2, 23−12; H_2SO_4, 8−22−14; $PbSO_4$, 23−8−14; H_2O, 22−1.

Die höchste Schlüsselformel ist jene für $PbSO_4$, 23−8−14, und diese Reaktion wird deswegen unter $PbSO_4$ angegeben; man kann sie auffinden, indem man die Blätter des Bandes umschlägt, bis 23 als das erste Glied der Schlüsselnummern, die am oberen Ende jeder rechten Seite sind, erscheint. Nachdem die richtige Abteilung so gefunden worden ist, kann man das erwünschte System oder die erwünschte Reaktion nach Besichtigung festsetzen.

2. Wo es sich um eine Zustandswahl für die gegebene Substanz handelt, ist die Ordnung wie folgt: Gas (g); Flüssigkeit (l); fester Körper (s); in wässriger Lösung (aq); in nicht-wässriger Lösung, Standardanordnung nach Lösungsmitteln.

3. *Wichtige Ausnahmen.*—Feste Hydrate, Ammine, usw., Krystallwasser oder Krystall-Ammoniak enthaltend, stehen unter dem lösungsmittel-freien Salz verzeichnet. Krystall-Wasser, -Ammoniak, usw., sind deswegen im Schreiben der Schlüsselformeln fortzulassen. (Diese Ausnahmen sind aber für Komplexionen, Komplexkobaltammine, usw., nicht gültig.) Löslichkeitsdaten sind immer unter der Schlüsselformel des gelösten Stoffes zu finden.

ZEICHEN UND ABKÜRZUNGEN

Im allgemeinen werden die Formelzeichen von Lewis und Randall (885) gebraucht. (*Siehe* auch die deutsche Übersetzung von Redlich.)

a	Aktivität.
c	Konzentration (Mol pro Liter).
$c_\pm$	Geometrisches Mittel der Ionenkonzentrationen.
f	Flüchtigkeit. (Fugazität).
het.	Zwei-Phasen System am reichsten an gelöstem Stoff.
ln	Natürlicher Logarithmus.
log	Dekadischer Logarithmus.
m	Molarer Gehalt (Mol pro 1000 g H_2O *in vacuo*, Molarität).
$m_\pm$ $m^0_\pm$	*Siehe* S. 230.
n	Molzahl.
p	Dampfdruck (in Atmosphären).
$p.f.$	Proportionalitätsfaktor (*siehe* Aktivitätskoeffizienten).
s	Löslichkeit (Mol pro 1000 g H_2O *in vacuo*).
s_c	Löslichkeit (Mol pro Liter).
t	Temperatur, Grad Celsius.
x	Molenbruch.
C_p	Molwärme bei konstantem Druck.
C_v	Molwärme bei konstantem Volumen.
E	Innere Energie.
E	Elektromotorische Kraft.
E^-	Ein Gramm-Atom Äquivalent negativer Elektrizität.
F	Freie Energie.
H	Wärmeinhalt.
I	Integrationskonstante.
K	Gleichgewichtskonstante (Aktivitäten) *siehe* S. 230.
K'	Spezielle Gleichgewichtsfunktion.
K_c	Gleichgewichtsfunktion in Konzentrationen ausgedrückt.
K_m	Gleichgewichtsfunktion in Molaritäten ausgedrückt.
K_p	Gleichgewichtsfunktion in Partieldrücken ausgedrückt.
L	Relativer partieller molare Wärmeinhalt.
M	Molar.
P	Gesamtdruck oder Dampfdruck in Atmosphären.
R	Gaskonstante.
S	Entropie.
T	Absolute Temperatur.
V	Volumen.
w	Molare Masse (Molekulargewicht).

Le tabelle però non sono così complete come si potrebbe desiderare. Si è cercato di includervi il maggior numero possibile di tipi di sistemi, e sono stati trattati con maggiore estensione i sistemi non ampiamente discussi nella letteratura, anzichè quelli più comuni. Il fatto che qualche tabella sia stata omessa o che dei dati siani stati semplicemente citati non indica nulla rispetto alla qualità e alla importanza di essi.

DISPOSIZIONE

1. I sistemi e le reazioni sono elencate con l'ordinamento standard (*vedi* Vol. III, p. viii) seguendo l'ordine delle sostanze che hanno la formula-chiave più alta. Così, per esempio, nella reazione

$$Pb(s) + PbO_2(s) + 2H_2SO_4(aq) = 2PbSO_4(s) + 2H_2O(l)$$

le formule-chiavi sono:

Pb, 23; PbO_2, 23—12; H_2SO_4, 8—22—14; $PbSO_4$, 23—8—14; H_2O, 22—1.

La formula-chiave più alta è quella del $PbSO_4$, 23—8—14 e quindi questa reazione si troverà elencata sotto $PbSO_4$ e si troverà dove il 23 apparirà come il primo membro dei numeri-chiave che stannò in cima ad ogni pagina di destra. Stabilita a questo modo la sezione si può trovare il sistema di reazione per ispezione.

2. Quando una data sostanza è considerata in diversi stati, allora l'ordine è il seguente: gas (g); liquido(l); solido(s) in soluzione acquosa (aq); in soluzione non acquosa l'ordine è quello standard dei solventi.

3. *Eccezioni Importanti.*—Gli idrati solidi, le ammine, ecc., che contengono acqua, ammoniaca, ecc. "di cristallizzazione" sono elencati sotto la sostanza originaria. L'acqua, l'ammoniaca, ecc., di cristallizzazione dovrà essere tralasciata nello scrivere la formula-chiave. (Queste eccezioni non si riferiscono tuttavia agli ioni complessi, alle cobaltammine complesse, ecc.) I dati di solubilità sono in ogni caso elencati sotto i soluti.

ABBREVIAZIONI E SIMBOLI

In genere viene impiegata l'annotazione di Lewis e Randall (885).

a	Attività.
c	Concentrazioni (moli per litro).
$c_\pm$	Media geometrica della concentrazione degli ioni.
f	Fugacità.
het.	Sistema di due fasi più ricco in soluto.
ln	Logaritmo a base *e*.
log	Logaritmo a base 10.
m	Molarità (moli per 1000 g di H_2O, nel vuoto).
$m_\pm$ $m^0_\pm$	*v.* p. 230.
n	Numero di moli.
p	Tensione di vapore (in atmosfere).
$p.f.$	Fattore di proporzionalità (*vedi* coefficienti di attività).
s	Solubilità (moli per 1000 g H_2O, nel vuoto).
s_c	Solubilità (moli per litro).
t	Temperatura, °C.
x	Frazione di mole.
C_p	Capacità termica molare a pressione costante.
C_v	Capacità termica molare a volume costante.
E	Energia interna.
E	Forza elettromotrice.
E^-	Un grammo atomo di elettricità negativa.
F	Energia libera.
H	Contenuto termico.
I	Costante d'integrazione.
K	Costante di equilibrio (attività) *v.* p. 230.
K'	Funzione speciale di equilibrio.
K_c	Funzione d'equilibrio espressa in concentrazioni.

γ	Aktivitätskoeffizient.
μ	Ionenstärke.
μ_c	Ionenstärke (für Konzentrationen).
ν	Anzahl Ionen, die bei Dissoziation einer Molekül gebildet werden.
Δ	Zuwachs.

Kleingedruckte lateinische Grossbuchstaben, z. B. H, bedeuten molare Grössen.

Kleingedruckte lateinische Grossbuchstaben überstrichen, z. B. $\overline{\text{H}}$, bedeuten partielle molare Grössen.

Index $_1$ (bezw. $_2$) entspricht dem Lösungsmittel (bezw. gelöstem Stoff).

EINHEITEN UND WERTE DER GEBRAUCHTEN KONSTANTEN*

1 cal.	4,182 Joule.
T	$t + 273{,}1$.
R	82,07 cm^3-Atm. pro Grad K.
R	1,9885 Kal. pro Grad K.
V	(für einem Mol eines idealen Gases) 22 412 cm^3 bei 1 Atm. und 273,1°K.
F	96 494 Coulomb pro Äquiv.
F	23 074 Kal. pro Volt Äquiv.

Alle Drucke sind in Atmosphären, alle Temperaturen in Grad absolut, alle elektromotorischen Kräfte in Volt, und alle Energiegrössen in Kalorien (*siehe* weiter oben) ausgedrückt, wenn nicht ausdrücklich anders angegeben ist. Bei weiterer rechnerischer Verwendung dieser Daten ist es wichtig nur die Konstanten und Daten dieser Abteilung zu gebrauchen.

DATEN DER FREIEN ENERGIE

Im allgemeinen kann man die Genauigkeit der Gleichungen für die freie Energie nach der Konstanz der Grösse I beurteilen, wenn letztere tabellarisiert ist. Das Ausbleiben einer bestimmten Richtung der Konstante bei einer Temperaturänderung zeigt, dass die Wahl dieser besonderen Formen der Reaktionsteilnehmer, sowohl wie die Werte von ΔH und ΔC_p wahrscheinlich richtig ist. Die einzelnen Abweichungen zeigen den Präzisionsgrad der experimentellen Messungen. Da viele der abgeleiteten Werte durch Addition und Subtraktion anderer Gleichungen erhalten worden sind, ist es zu dieser Zeit nicht möglich, die Grösse des wahrscheinlichsten Fehlers anzugeben; die Zahl der angegebenen Ziffern soll deswegen nicht als Mass der Genauigkeit genommen werden. Wo "revised" Werte angegeben sind, ist es gewöhnlich nötig dass man die nicht revidierten (^{885}) Werte gebraucht, wenn man solche Daten mit anderen der Abteilung kombinieren will.

Die freien Energien sind in folgender Form gegeben

$$\Delta F^0 = \Delta H_0^0 - \Delta\Gamma_0^0 T \ln T - \tfrac{1}{2}\Delta\Gamma' T^2 - \tfrac{1}{6}\Delta\Gamma'' T^3 - \ . \ . \ . + IT \quad (1)$$

wo $\Delta\Gamma$, $\Delta\Gamma'$, $\Delta\Gamma''$, usw., die Koeffizienten in dem algebräischen Ausdruck für die Zunahme des Wärmeinhalts während der Reaktion sind.

So haben wir

$$\Delta H^0 = \Delta H_0^0 + \Delta\Gamma^0 T + \tfrac{1}{2}\Delta\Gamma' T^2 + \tfrac{1}{3}\Delta\Gamma'' T^3 \quad (2)$$

$$\Delta S^0 = \Delta\Gamma_0^0(1 + \ln T) + \Delta\Gamma' T + \tfrac{1}{2}\Delta\Gamma'' T^2 + \ . \ . \ . - I \quad (3)$$

Der Index ^{0} an den Grössen ΔF, ΔH, ΔS bedeutet dass die Grösse zu einer angegebenen oder angedeutenden Reaktion gehört, in welcher alle teilnehmenden chemischen Substanzen bei Aktivität Eins, bei einer Flüchtigkeit von 1 Atm. (oder, wenn es besonders angegeben ist, bei einem Druck von 1 Atm.), oder bei

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*Es ist zu beachten das diese Werte nicht diejenigen sind welche sonst in den I. C. T. (*siehe* Bd. I, S. 17) angenommen wurden. Die Daten dieser Abteilung bilden unter sich ein einheitliches System, aber können nicht leicht mit anderen Daten in den I. C. T. kombiniert werden.

K_m	Funzione d'equilibrio espressa in molarità.
K_p	Funzione d'equilibrio in termini delle pressioni parziali.
$\overline{\text{L}}$	Contenuto termico molare relativo parziale.
M	Molare.
P	Pressione totale o tensione di vapore in atmosfere.
R	Costante dei gas.
S	Entropia.
T	Temperatura assoluta.
V	Volume.
w	Massa molale.
γ	Coefficiente di attività.
μ	Forza ionica.
μ_c	Forza ionica per le concentrazioni.
ν	Numero degli ioni formatisi per la dissociazione d'una molecula.
Δ	Incremento.

Let. cap. rom. piccola. Quantità molari, per esempio H.

Let. cap. rom. pic. sbarrata. Quantità molari parziali, per esempio $\overline{\text{H}}$.

L'indicazione sottoscritta $_1$ (risp. $_2$) si riferisce al solvente (risp. soluto).

UNITÀ E VALORI DELLE COSTANTI IMPIEGATE*

1 cal.	4,182 joules.
T	$t + 273{,}1$.
R	82,07 cm^3-atm. per grado K.
R	1,9885 cal. per grado K.
V	(per una mole di gas perfetto) 22 412 cm^3 a 1 atm. e 273,1°K.
F	96 494 coulombs per equiv.
F	23 074 cal. per volt equiv.

Tutte le pressioni sono espresse in atmosfere, tutte le temperature in gradi assoluti, tutte le forze elettromotrici in volte e tutte le quantità di energia in calorie (*v.* sopra) a meno che non venga espressamente altrimenti indicato. Nel fare ulteriori trasformazioni dei dati è importante che vengano usati solo le costanti e i dati di questo capitolo.

DATI SULL'ENERGIA LIBERA

In genere, l'accuratezza delle equazioni dell'energia libera può essere giudicata dalla costanza di I, dove questo è riportato. Quando il valore di I non mostra tendenza a variare con la temperatura deve ritenersi che la scelta delle forme particolari delle sostanze prendenti parte alla reazione, e i valori di ΔH e ΔC_p sono da ritenersi con probabilità sostanzialmente corretti. Le singole variazioni indicano il grado di accuratezza delle misure sperimentali. Siccome molti dei valori dedotti implicano la addizione e la sottrazione di altre equazioni, non è possibile, oggi, indicare l'errore probabile; non bisogna prendere quindi come indice di accuratezza il numero delle cifre riportate. Dove sono riportati valori "revised" bisognerà usare i valori non corretti (^{885}) quando dovranno essere combinati con altre equazioni di questo capitolo.

Le energie libere sono date nella forma

$$\Delta F^0 = \Delta H_0^0 - \Delta\Gamma_0^0 T \ln T - \tfrac{1}{2}\Delta\Gamma' T^2 - \tfrac{1}{6}\Delta\Gamma'' T^3 - \cdot \cdot \cdot + IT \quad (1)$$

dove $\Delta\Gamma$, $\Delta\Gamma'$ e $\Delta\Gamma''$, ecc., sono i coefficienti dell'incremento della capacità termica della reazione nell'espressione algebrica.

Così si ha:

$$\Delta H^0 = \Delta H_0^0 + \Delta\Gamma^0 T + \tfrac{1}{2}\Delta\Gamma' T^2 + \tfrac{1}{3}\Delta\Gamma'' T^3 \quad (2)$$

$$\Delta S^0 = \Delta\Gamma_0^0(1 + \ln T) + \Delta\Gamma' T + \tfrac{1}{2}\Delta\Gamma'' T^2 + \cdot \cdot \cdot - I \quad (3)$$

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* Nota bene che questo *non sono* i valori accettati dalle I. C. T. (*vedi* Vol. I, p. 17). I dati di questa sezione formano un tutto unico, ma non possono essere combinati senz'altro con gli altri dati delle I. C. T.

einer hypothetischen Konzentration Eins angenommen sind. Ist die Reaktion nicht ausdrücklich angegeben, so wird angenommen, dass es sich um jene Reaktion handelt, in welcher eine gegebene Substanz aus ihren Elementen in dessen Normalzuständen gebildet wird. Der Normalzustand ist jener, welchem in den Tabellen der Wert $\Delta F^0 = 0$ zugeteilt ist, wobei der Druck immer 1 Atm. sein soll, falls kein anderer Wert dafür besonders angegeben wird. Im Fall, dass kein Normalzustand in den Tabellen derart angegeben ist, nimmt man den "gewöhnlichen" festen Zustand des Elementes an.

Die Gleichgewichtskonstante, K, ist immer so definiert, dass die Aktivitäten der Substanzen, welche rechts in der geschriebenen Reaktionsgleichung erscheinen, im Zähler stehen, Für Gase sind die Einheiten immer Atmosphäre, und für gelöste Stoffe immer Molenbrüche, oder Mol pro 1000 g Wasser. Für die Konstante K auf diese Weise definiert, ist $\Delta F^0 = -RT \ln K$.

In einigen Fällen gebrauchen wir Gleichgewichtsfunktionen (K_m), in welchen, anstatt Aktivitäten, die Molarität der Substanzen oder Ionen gebraucht wird, und anderere (K_c) in welchen die Aktivitäten durch Konzentrationen (Mol pro Liter) ersetzt sind. In noch anderen Fällen haben wir Spezialfunktionen (K'_m oder K'_c) gebraucht, in welchen für alle Substanzen, ausser den Ionen, Aktivitäten benutzt worden sind. Die Konzentration eines Gases kommt in solchen Ausdrücken nie vor. *Siehe* Lewis und Randall (885), Randall und Vietti (1192), und Randall (1170.5).

AKTIVITÄTSKOEFFIZIENTEN

Im Falle aller Reaktionen, welche auf der rechten Seite nur Ionen enthalten, und etlicher anderer, sind die verschiedenen Gleichgewichte so umgeformt, dass (log γ + Konstante) und $\mu^{1/2}$ in den Tabellen angegeben sind. Durch einfache graphische Auftragung dieser Grössen, kann man Interpolieren und Vergleiche ausführen; durch Auflegen der so erhaltenen Kurven auf entsprechende Kurven in demselben Massstabe für passende Bezugssalze kann man leicht zum Aktivitätskoeffizienten Eins extrapolieren. Wenn diese extrapolierten Grössen vorhanden sind, kann der Aktivitätskoeffizient für das betreffende Ionenpaar durch Subtraktion von log *p.f.* (in einigen Fällen angegeben) von dem Wert der Grösse (log γ + Konstante) erhalten werden. Der Aktivitätskoeffizient für Konzentration, die Ionenstärke für Konzentration, usw., sind in dem Sinne Randall und Viettis (1192) definiert, nämlich so, dass die Aktivität (in Bezug auf Molaritäten definiert) gleich ist dem Produkt von dem besagten Konzentrationsaktivitätskoeffizient und der Konzentration.

$$\log \gamma + \text{Konstante} = \log \gamma - E^0/(0{,}00019844\nu\ T/N) = E/(0{,}00019844\nu\ T/N) + \log(1/m_\pm) \quad (4)$$

wo E^0 die normalen und E die gemessenen elektromotorischen Kräfte, N die Nummer der Äquivalenten, und $m_\pm$ die mittlere Molarität der Ionen in der Kette bedeutet*. Oder

$$\log \gamma + \text{Konstante} = (1/\nu) \log p + \log(1/m_\pm) \quad (5)$$

wo p der Dampfdruck des gelösten Stoffes ist. Oder

$$\log \gamma + \text{Konstante} = (1/\nu) \log x_2 + \log(1/m_\pm)$$

wo x_2 den Molenbruch gelösten Stoffes in einem zweiten unvermischbaren Lösungsmittel bedeutet. Oder

$$\log \gamma + \text{Konstante} = \log(1/m_\pm)$$

wo $m_\pm$ die mittlere Molarität der Ionen in Gleichgewicht mit dem reinen festen Stoffe (Löslichkeit) ist. Oder

$$\log \gamma + \text{Konstante} = (1/\nu) \log(1/K'_m)$$

wo K'_m eine Gleichgewichtsfunktion ist, in welcher für alle Reaktionsteilnehmer (am gewöhnlichsten undissozierbare Stoffe oder Gase) bis auf das betrachtete Ionenpaar, Aktivitäten eingesetzt worden sind. (*Siehe* $CaCO_3$(Calcite) + H_2CO_3 (aq) = Ca^{++} + $2HCO_3^-$, S. 296.)

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* In allgemeinen $\Delta F = NEF$.

Il contrassegno ^{0} sulle quantità ΔF, ΔH, ΔS, indica che esse si riferiscono ad una reazione in cui tutte le sostanze che vi partecipano vengono considerate a una attività unitaria, a una fugacità di 1 atm. (oppure, quando sia specificamente indicato, alla pressione di 1 atmosfera) o a una concentrazione unitaria ipotetica. Quando la reazione non è esplicitamente indicata, si suppone sia quella di formazione di una data sostanza dagli elementi, nei loro stati standard. Lo stato standard di un elemento è quello per il quale nelle tabelle viene dato il valore $\Delta F^0 = 0$, la pressione essendo sempre di 1 atm. salvo che non venga altrimenti indicato. Quando nelle tabelle non è indicato nessuno stato standard, si tratta della forma solida "ordinaria" dell'elemento.

Nello scrivere la costante di equilibrio, K, le attività delle sostanze del membro di destra della reazione, come essa viene comunemente scritta, appaiono sempre al numeratore. Per i gas le unità sono sempre atmosfere, e per i soluti frazioni di moli o moli per 1000 g di acqua. Per la costante K così definita, $\Delta F^0 = -RT \ln K$.

In alcuni casi è fatto uso di funzioni di equilibrio (K_m) nelle quali invece dell'attività si impiega la molarità delle sostanze o dei ioni, in altri casi (K_c) nelle quali le concentrazioni (moli per litro) delle sostanze in soluzioni sono impiegate invece dell'attività. In altri casi sono state impiegate speciali funzioni (K'_m, o K'_c) nelle quali le attività sono usate per tutte le sostanze tranne che per gli ioni presenti. La concentrazione di un gas non viene mai impiegata in queste espressioni. *Vedi* Lewis e Randall (885), Randall e Vietti (1192), Randall (1170.5).

COEFFICIENTI DI ATTIVITÀ

Nel caso delle reazioni che implicano solo gli ioni del membro di destra dell'equazione, e in pochi altri casi, i vari equilibri vengono trasformati in modo che nelle tabelle sono riportati (log γ + una costante) e $\mu^{1/2}$. Con un semplice grafico, si potranno fare interpolazioni e confronti. Sovrapponendo le curve così ottenute ad altre corrispondenti (di sali di riferimento opportunamente scelti, e disegnate sulla stessa scala) si può facilmente fare l'estrapolazione rispetto al coefficiente di attività unitaria. Quando si abbiano questi valori estrapolati si può trovare il coefficiente di attività di questa particolare coppia di ioni sottraendo log *p.f.* (dato in pochi casi) dal valore di (log γ + una costante). Il coefficiente di attività per concentrazione, la forza ionica per concentrazione, ecc., sono definite nel senso in cui sono state impiegate da Randall e Vietti (1192), cioè il prodotto del coefficiente d'attività per concentrazione moltiplicato per la concentrazione dà l'attività (definita riferendosi alle molarità).

$$\log \gamma + \text{const.} = \log \gamma - E^0/(0{,}00019844\nu T/N) = -E/(0{,}00019844\nu\ T/N) + \log(1/m_\pm) \quad (4)$$

dove E^0 e E sono le forze elettromotrici standard e misurate, N il numero degli equivalenti e $m_\pm$ la molarità media degli ioni studiati nella cella.* Oppure

$$\log \gamma + \text{const.} = (1/\nu) \log p + \log(1/m_\pm) \quad (5)$$

dove p è la tensione di vapore del soluto. Oppure

$$\log \gamma + \text{const.} = (1/\nu) \log x_2 + \log(1/m_\pm)$$

dove x_2 è la frazione molare del soluto in un secondo solvente immiscibile. Oppure

$$\log \gamma + \text{const.} = \log(1/m_\pm)$$

dove $m_\pm$ è la molarità media degli ioni in equilibrio con li solido puro (solubilità). Oppure

$$\log \gamma + \text{const.} = (1/\nu) \log(1/K'_m),$$

dove K'_m è una funzione d'equilibrio nella quale si sono sostituite le attività per tutte le sostanze che prendono parte alla reazione (generalmente sostanze indissociabili o gas) eccettuata la coppia di ioni presa in considerazione. (*Vedi* $CaCO_3$ (calcite) + H_2CO_3 (aq) = Ca^{++} + $2HCO_3^-$, p. 296.)

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* In generale $\Delta F = NEF$.

DEHYDRATION OF MINERALS.—(*Continued*)

(1)	(2)	(3)	(1)	(2)	(3)
		Phacolite, $CaNa_2Al_2Si_4O_{12}.6H_2O$ (1422)			
0.02068	0.05	0.05	0.00386	1.81	1.76
0.01914	0.16		0.00162	2.90	
0.01642	0.31		0.00051	3.82	4.56
0.01199	0.60		0.00014	4.47	
0.00796	1.06				
		Chabasite, $CaNa_2Al_2Si_4O_{12}.6H_2O$ (1422)			
0.01914	0.11		0.00162	1.69	
0.01642	0.14		0.00014	3.14	
0.01199	0.37				
		Leonhardite, $CaAl_2Si_4O_{12}.4H_2O$ (1422)			
0.01914	0.06		0.00051	3.40	
0.01199	0.70				
		Laumontite, $CaAl_2Si_4O_{12}.4H_2O$ (1422)			
0.01914	0.05		0.00051	0.58	
		Phillipsite, $(CaK_2)Al_2Si_5O_{14}.5H_2O$ (1422)			
0.01914	0.18		0.00386	0.40	
0.01642	0.22		0.00051	1.41	
0.01199	0.24				
		Gismondite (1422)			
0.01914	0.02	0.16	0.00386	1.48	
0.01642	0.19		0.00162	2.51	
0.01199	0.25	0.29	0.00051	3.42	
0.00796	0.94		0.00014	3.73	
		Okenite, $CaO.2SiO_2.2H_2O$ (1422)			
0.02068	0.06	0.27	0.00386	2.10	
0.01914	0.84		0.00162	2.66	
0.01642	1.02	1.25	0.00051	3.21	
0.01199	1.29	1.49	0.00014	3.56	
0.00796	1.67				
		Natrolite, $Na_2Al_2Si_3O_{10}.2H_2O$ (1422)			
0.01914	0.21		0.01199	0.39	
0.01642	0.25		0.00051	0.79	

(1)	(2)	(3)	(1)	(2)	(3)
		Scolecite, $CaAl_2Si_3O_{12}.3H_2O$ (1422)			
0.02068	0.000	0.000	0.00796	0.029	0.029
0.01914	0.004		0.00386	0.042	
0.01642	0.013		0.00162	0.079	
0.01199	0.017		0.00014	0.105	
		Pyrophyllite, $Al_2Si_4O_{11}.H_2O$ (1422)			
0.02068		0.000	0.00796	0.050	
0.01914	0.004		0.00386	0.059	
0.01642	0.013		0.00014	0.060	
0.01199	0.017				
		Pitchstone (1422)			
		Brown form			
0.02068	0.005		0.00386	0.42	
0.01914	0.005		0.00162	0.60	
0.01642	0.04		0.00051	0.84	
0.01199	0.08		0.00014	0.92	
0.00796	0.17				
		Green form			
0.01642	0.04		0.00162	0.75	
0.01199	0.08		0.00051	0.95	
0.00796	0.31		0.00014	1.06	
0.00386	0.57				
		Black form			
0.01914	0.01		0.00386	0.04	
0.01642	0.02		0.00162	0.05	
0.01199	0.02		0.00051	0.06	
0.00796	0.04				
		Semiopal (1422)			
0.01914	2.96	8.28	0.00386	11.60	
0.01642	3.90	10.80	0.00162	12.09	
0.01199	9.95		0.00014	13.30	
0.00796	10.75	12.18			
		Hyalite (1422)			
0.01914		0.00	0.00386	0.05	
0.01642	0.01		0.00162	0.09	
0.01199	0.02		0.00051	0.10	
0.00796	0.03		0.00014	0.12	

LITERATURE; *v.* p. 347

SOLUBILITY OF SLIGHTLY SOLUBLE SALTS IN AQUEOUS SOLUTIONS OF ELECTROLYTES

MERLE RANDALL AND WILLIAM V. VIETTI

The Standard arrangement (Vol. III, p. viii) is used throughout this section. Under each A-component, printed in large type, are listed the B-components in the standard order. The A-component is the slightly soluble salt; the B-component is a solute in the aqueous solution.

L'arrangement type (Vol. III, p. viii) est utilisé dans toute cette section. Sous chaque constituant A, imprimé en grands caractères, se trouvent les constituants B disposés en liste suivant l'ordre type. Le constituant A est le sel peu soluble; le constituant B est un corps dissous dans la solution aqueuse.

In diesem Abschnitt ist die Standardanordnung (Bd. III, S. viii) durchweg verwendet. Unter jeder A-Komponente, die in grossen Buchstaben gedruckt ist, folgen die B-Komponenten in Standardanordnung. Die A-Komponente ist der wenig lösliche Salz; die B-Komponente ist ein Körper in der wässrige Lösung.

In tutto questo capitolo si fa uso dell'ordinamento standard (Vol. III, p. viii). Sotto ogni componente A stampato in lettere grosse, sono elencati i componenti B con l'ordinamento standard. Il componente A è il sale poco solubile; il componente B è un soluto nella soluzione acquosa.

SYMBOLS AND ABBREVIATIONS

c_B Concentration of B-component in moles/liter.

$c_\pm$ Geometric mean of concentration of ions.

SYMBOLES ET ABRÉVIATIONS

c_B Concentration du constituant B en mol. gr./litre.

$c_\pm$ Moyenne géométrique de la concentration des ions.

SYMBOLE UND ABKÜRZUNGEN

c_B Konzentration der B-Komponente in Mol/Liter.

$c_\pm$ Geometrisches Mittel der Ionenkonzentrationen.

ABBREVIAZIONI E SIMBOLI

c_B Concentrazione del componente B in moli/litro.

$c_\pm$ Media geometrica della concentrazione degli ioni.

M	Molal.
m_B	Moles of B-component/1000 g H_2O *in vacuo.*
$m_\pm$ $m^\circ_\pm$	*See* p. 227.
N	Normal
s_A	Solubility of A-component in moles/liter.
S_A	Solubility of A-component in moles/1000 g H_2O *in vacuo.*
γ	Activity coefficient (*see* p. 227).
μ	Ionic strength.
μ_c	Ionic strength (for concentrations).
	For other abbreviations, *see* p. 225.

M	Moléculaire.
m_B	Mol. gr. du constituant B/1000 g H_2O dans le vide.
$m_\pm$ $m^\circ_\pm$	*Voir* p. 227.
N	Normal.
s_A	Solubilité du constituant A en mol. gr./litre.
S_A	Solubilité du constituant A en mol. gr./1000 g H_2O dans le vide.
γ	Coefficient d'activité (*voir* p. 227).
μ	Force ionique.
μ_c	Force ionique (pour concentrations).
	Pour d'autres abréviations, *voir* p. 225.

M	Molar.
m_B	Gramm Mol der B-Komponente/1000 g H_2O *in vacuo.*
$m_\pm$ $m^\circ_\pm$	*Siehe* S. 230.
N	Normal.
s_A	Löslichkeit der A-Komponente in Gramm Mol/Liter.
S_A	Löslichkeit der A-Komponente in Gramm Mol/1000 g H_2O *in vacuo.*
γ	Aktivitätskoeffiziente (*siehe* S. 230).
μ	Ionenstärke.
μ_c	Ionenstärke (für Konzentrationen).
	Für andere Abkürzungen, *siehe* S. 228.

M	Molare.
m_B	Moli del componente B/1000 g di H_2O nel vuoto.
$m_\pm$ $m^\circ_\pm$	*Vedi* p. 230.
N	Normale.
s_A	Solubilità del componente A in moli/litro.
S_A	Solubilità del componente A in moli/1000 g di H_2O nel vuoto.
γ	Coefficiente di attività (*vedi* p. 230).
μ	Forza ionica.
μ_c	Forza ionica (per concentrazioni).
	Per altre abbreviazioni, *vedi* p. 228.

$(CH_3)_4NI(s) = (CH_3)_4N^+ + I^-$

B = NH_4OH; T = 298.1°K (626)

c_B	s_A	c_B	s_A
0.000	0.26248	0.5224	0.26158
.0494	.26223	1.0149	.26062
.1001	.26200	2.1099	.25877
.2102	.26180		

B = KOH; T = 298.1°K (625,* 626)

c_B	s_A	c_B	s_A
0.000	0.26228	0.112	0.25810
.057	.25999	.251	.25073

* For c_B = 0.000 to 8.2962, *v.* (625).

$PbCl_2(s) = Pb^{++} + 2Cl^-$

B = HCl*

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
T = 273.1°K (375)			
0.0	0.02104	1.4766	0.252
.01371	.01624	1.4868	.250
.02743	.01299	1.4771	.2572
.05485	.00794	1.4670	.293
.08228	.00577	1.4314	.361
.1646	.00505	1.2707	.411
.2743	.00433	1.1534	.538
2.743	.00433	0.4947	1.657
5.485	.01877	0.0808	2.354
6.857	.0379	−0.0868	2.639
8.228	.06315	−0.2147	2.900
10.471	.1443	−0.4374	3.375
T = 291.1°K (1147)			
0.0	0.03358	1.2732	0.3170
.0001	.03346	1.2730	.318
.0002	.03344	1.2727	.318
.0005	.03326	1.2740	.317
.00102	.03310	1.2746	.317
.0102	.03019	1.2681	.320
T = 298.1°K (1076)			
0.0	0.03885	1.2093	0.341
.05	.02393	1.2133	.349
.10	.01621	1.1821	.385
.20	.00964	1.1113	.477

B = HCl.—(*Continued*)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
T = 298.3°K (373.5)			
0.0	0.0388	1.2105	0.341
.0009	.03866	1.2066	.342
.0022	.03820	1.2066	.342
.003	.03794	1.2080	.340
.0045	.03735	1.2078	.341
.0091	.03580	1.2108	.341
.0114	.03499	1.2117	.341
.0151	.03375	1.2126	.341
.0226	.03146	1.2127	.342
.0302	.02932	1.2126	.344
.0452	.02546	1.2124	.348
.0910	.01712	1.1900	.364
.1850	.01012	1.1234	.464
.3714	.00635	1.0095	.617
.5142	.00537	0.9433	.728
.7386	.00473	.8591	.868
1.026	.00441	.7753	1.020
1.538	.00461	.6524	1.245
2.051	.00518	.5525	1.437
2.564	.00625	.3991	1.607
3.085	.00778	.3754	1.763
3.718	.00816	.3146	1.934
5.00	.01938	.2871	2.249
7.50	.06586	.0943	2.774
10.0	.14135	−0.0582	3.229
12.05	.1643	−0.0989	3.541

* For values at 290.9°K, *v.* (73); at 273.1, 293.1, 313.1, 328.1, 359.1°K, *v.* (341).

B = HNO_3; T = 298.3°K (373.5)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.001	0.03387	1.2097	0.343
.01	.03971	1.2004	.359
.051	.04291	.1666	.424
.01*	.04336	.1622	.424

* 0.01N HNO_3 + 0.04N KNO_3.

B = NH_4Cl

m_B	S_A	m_B	S_A
T = 290.1°K (326)			
0.0	0.323	0.8187	0.00263
.1817	.00762	.8432*	.00301
.4605	.00516		

* Complex in solid phase.

B = **NH_4Cl**.—*(Continued)*

m_B	S_A	$\log (1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 295.1°K (193)			
0.0	0.03745	1.2250	0.334
.1	.01625	1.1815	.385
.2	.0097	1.1102	.479
.3	.00765	1.0397	.569
.4	.0069	0.9758	.648
.5	.0065	.9222	.720
.52	.00635	.9148	.734

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
T = 298.3°K (373.5)			
0.0	0.03880	1.2105	0.341
.25	.00947	1.0548	.527
.50	.00711	0.9086	.722
1.00	.00435	.7630	1.005

m_B	S_A	$\log (1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 333.1°K (326)			
0.0	0.06404	0.9186	0.438
.09502	.03995	.9709	.463
.2886	.02472	.8497	.603
.4704	.02158	.7488	.732
.7529	.01887	.6428	.899
.8412	.02046	.5994	.950
.8763	.02204	.5763	.971
T = 373.1°K (326)			
0.0	0.11503	0.7386	0.587
.2535	.07440	.6390	.690
1.103	.06780	.3270	1.142
1.219	.06866	.2992	1.195
1.799	.07147	.1894	1.424

B = **$C_2H_4O_2$**, Acetic acid; T = 298.1°K (626)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.03877	1.2172	0.341
.050	.03891	1.2093	
.100	.03909	1.2073	
.150	.03880	1.2105	
.200	.03852	1.2136	
.465	.03696	1.2316	
.929	.03452	1.2612	
1.845	.02843	1.3455	
3.680	.01894	1.5218	

B = **C_2H_6O**, Ethyl alcohol; T = 298.1°K (758)

0.0	0.0388	1.2105	0.341
.0125	.0367	1.2347	
.025	.0338	1.2704	
.5	.0330	1.2989	
1.0	.0298	1.3251	
2.0	.0257	1.3893	
4.0	.0172	1.5638	

B = **$C_6H_{14}O_6$**, Mannitol; T = 298.1°K (758)

0.01563	0.0377	1.2230	
.03125	.0385	1.2138	
.0625	.0384	1.2497	
.125	.0394	1.2039	
.25	.0403	1.1939	
.5	.0408	1.1887	

B = **$Pb(NO_3)_2$**

m_B	S_A	$\log (1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 298.1°K (570)			
0.0	0.03903	1.2079	0.342
.01005	.03855	1.1798	.382
.02516	.03851	1.1410	.437
.0513	.03922	1.0847	.522
T = 298.1°K(24)			
0.1000	0.04204	0.9994	0.653
.250	.05127	.8331	.950

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
T = 298.1°K (570)			
0.0	0.03888	1.2099	0.341
.01001	.03838	1.1817	.381
.02503	.03832	1.1465	.436
.04983	.03899	1.0892	.517
.10*	.0416	1.0029	.652

* From (1076).

B = **$ZnCl_2$**; T = 298.1°K (1076)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.1	0.0110	1.0886	1.04

B = **$CdCl_2$**; T = 298.1°K (1076)

0.025	0.03005	1.1462	0.412
.05	.02405	1.0926	.472
.10	.01775	1.0023	.594

B = **$HgCl_2$**; T = 293.1°K (441)

c_B	s_A	c_B	s_A
0.0	0.03492	0.03683	.04413
.004604	.03569	.05*	.0496
.009208	.03665	.07367	.05348
.01842	.03886	.1474	.06822

* From (1076).

B = **$MnCl_2$**; T = 298.1°K (1076)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.025	0.02505	1.2001	0.387
.05	.01895	1.1478	.454
.10	.01085	1.0910	.577

B = **$MgCl_2$**; T = 298.1°K (1076)

0.025	0.02515	1.1990	0.730
.05	.0175	1.1621	.766

B = **$CaCl_2$**; T = 298.1°K (611)

0.0	0.03895	1.2088	0.342
.05*	.02515	1.1990	.388
.10*	.01775	1.1623	.450
.20	.01095	1.0894	.580
.26	.00696	0.9008	.894
.475	.00563	.7612	1.200
.955	.00771	.5114	1.699
1.515	.01268	.3089	2.140
2.06	.2057	.1495	2.499

*From (1076).

B = **$CaBr_2$**; T = 298.1°K
Solid phase contains $PbBr_2$(?) (611)

B = **$SrCl_2$**; T = 298.1°K (611)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.255	0.00678	0.9103	0.880
.51	.00640	.7219	1.245
.69	.00824	.6310	1.445
1.33	.01418	.3298	2.02
1.545	.01578	.2711	2.16
2.065	.02698	.1753	2.50

$PbCl_2$.—(*Continued*)

B = $\mathbf{SrBr_2}$; T = 298.1°K
Solid phase contains $PbBr_2$(?) (611)

B = $\mathbf{BaCl_2}$; T = 298.1°K (611)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.16	0.00699	1.0421	0.708
.32	.00553	0.8792	.988
.69	.01089	.5588	1.450
1.04	.02388	.3253	1.790

B = $\mathbf{BaBr_2}$; T = 298.1°K
Solid phase contains $PbBr_2$(?) (611)

B = **LiCl**; T = 323.1°K (326)

m_B	S_A	log $(1/m_\pm)$	$\mu^{\frac{1}{2}}$
0.4934	0.01649	0.7801	0.737
1.191	.01332	.5685	1.109
1.265	.01411	.5209	1.142
2.515	.01967	.2974	1.630
4.571	.03605	.0365	2.160
7.871	.1141	−0.2914	2.865
11.23	.2851	−0.5329	3.47
14.24	.4283	−0.6630	3.94
15.49	.4820	−0.7051	4.11
17.54	.5190	−0.7511	4.37
21.27	.5357	−0.7760	4.78
23.06	.4961	−0.8193	4.95

B = **NaCl**; T = 286.1°K (326)

m_B	S_A	m_B	S_A
0.0	0.02970	3.383	0.01337
.173	.00654	5.319	.05240
.903	.00344	6.221	.09396
2.65	.00794		

m_B	S_A	log $(1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 298.1°K (611)			
0.51	0.00648	0.9172	0.732
1.02	.00631	.7240	1.020
2.05	.00961	.4619	1.443
3.03	.01279	.3076	1.75
4.10	.04377	.0983	2.06
T = 323.1°K (326)			
0.2851	0.02111	0.8819	0.590
.7626	.01454	.6801	.898
1.428	.02328	.4359	1.220
2.83	.05309	.1132	1.725
3.463	.07005	.0138	1.915
4.121	.1165	−0.1134	2.115
4.856	.2069	−0.2531	2.34
5.173	.2599	−0.3085	2.44
T = 373.1°K (326)			
0.3565	0.06154	0.4823	0.736
.3638	.05974	.4843	.737
.7429	.05714	.4549	.956
.915	.05884	.3999	1.045
1.253	.06548	.3000	1.205
2.66	.1083	−0.0156	1.728
4.429	.2356	−0.2515	2.26
6.1307	.4830	−0.4293	2.75
6.346	.5223	−0.4858	2.81
6.704	.5855	−0.5207	2.91
7.181	.6900	−0.5685	3.04
7.27	.6928	−0.5725	3.06

B = **NaBr**; T = 298.1°K
Solid phase contains $PbBr_2$(?) (611)

B = **KCl**; T = 287.1°K (326)

m_B	S_A	m_B	S_A
0.0	0.03301	0.4769	0.00449
.1866	.0066	.5347*	.00567
.3358	.00517		

m_B	S_A	log $(1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 293.1°K (194)			
0.199	0.00967	1.1122	0.477
.306	.00744	1.0386	.573
.387	.00683	0.9873	.638
.475	.00648	.9373	.702
.497	.00652	.9235	.718
.502	.00643	.9228	.723
.523	.00644	.9110	.730
.545*	.00643	.8996	.750

*Solid phase contains $2PbCl_2.KCl$.

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
T = 298.1°K (1076)			
0.05	0.0241	1.2113	0.350
.10	.01705	1.1711	.389
.20	.1095	1.0894	.486
T = 298.3°K (373.5)			
0.0	0.0388	1.2105	0.341
.001	.03832	1.2128	.340
.0025	.03785	1.2151	.340
.0049	.03702	1.2123	.340
.0099	.03528	1.2138	.339
.02	.03216	1.2136	.341
.0599	.02262	1.2111	.357
.09991	.01690	1.1647	.387
.5006	.00740	0.9022	.610
.7018	.00738	.8088	.850
.9991	.00490	.7674	1.005
1.5018	.00483	.6524	1.23
2.0024	.00556	.5490	1.42
3.0036	.00974	.3502	1.74

m_B	S_A	log $(1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 298.1°K (326)			
0.1918	0.02840	0.9186	0.526
.3262	.02306	.8318	.628
.4860	.01880	.7626	.736
.6832	.02173	.6468	.865
.8476	.02237	.5831	.956
.8982	.02245	.5665	.982
.9213	.02248	.5593	.994
.9321	.02329	.5505	1.001
.9425	.02136	.5611	1.003
T = 373.1°K (326)			
0.1289	0.0838	0.7098	0.617
.143	.0844	.6942	.630
.431	.0656	.5600	.792
.5575	.06869	.4925	.874
.7234	.0667	.4395	.961
.8593	.0717	.3723	1.035
1.044	.0738	.3258	1.120
1.207	.0804	.2737	1.203
1.429	.08624	.2178	1.300
1.617	.1045	.1519	1.390
1.695	.10725	.1353	1.425

B = **KBr**; T = 298.1°K
Solid phase contains $PbBr_2$(?) (611)

B = $\mathbf{KNO_3}$; T = 298.3°K (373.5); *see* value in B = $\mathbf{HNO_3}$

$PbBr_2(s) = Pb^{++} + 2Br^-$

B = **HBr**; T = 283.1°K

Soln. contained $8.9m_B$ and $1.5S_A$ (341)

B = **HNO_3**; T = 298.1°K (373.5)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.00	0.02628	1.3797	0.281
.001	.02659	1.3746	.283
.01	.02735	1.3624	.304
.05*	.03025	1.3199	.375
.051	.03004	1.3216	.376

* 0.01N HNO_3 + 0.04N KNO_3.

B = **$Pb(NO_3)_2$**; T = 298.1°K (1192)

m_B	S_A	log $(1/m_\pm)$	$\mu^{1/2}$
0.00	0.02680	1.3723	0.283
.0020	.02664	1.3634	.293
.0050	.02644	1.3520	.307
.0100	.02622	1.3340	.330
.0200	.02612	1.3001	.372
.0500	.02663	1.2202	.479
.1000	.02954	1.1169	.624
.1326	.03159	1.0612	.692
.2000	.03544	0.9757	.841
.3134	.04333	.8573	1.035
.5000	.05342	.7332	1.288
.703	.06522	.6279	1.519
.9521	.07754	.5354	1.737
1.6547	.1268	.3138	2.310
1.964*	.1346	−0.2727	2.510

* Solid phase, $PbBr_2$ and $Pb(NO_3)_2$.

B = **$CdBr_2$**; T = 298.1°K (1192)

0.0010	0.02637	1.3674	0.286
.0020	.02591	1.3643	.289
.0050	.02466	1.3539	.298
.0100	.02307	1.3321	.315
.0200	.01999	1.2977	.346
.0500	.01450	1.2059	.440
.1000	.01117	1.0860	.577
.1305	.01038	1.0281	.650
.2000	.00939	0.9280	.793
.3236	.00969	.7890	1.000
.5000	.01072	.6505	1.238
.5607	.01143	.6083	1.310
1.000	.01597	.3939	1.745
1.692	.02445	.1803	2.270
4.182*	.06508	.2170	3.570

* Solid phase, $PbBr_2$ and $CdBr_2.4H_2O$.

B = **$CaCl_2$**; T = 298.1°K

Solid phase probably contained $PbCl_2(s)$ (611)

B = **$CaBr_2$**; T = 298.1°K (611)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.00	0.02625	1.3803	0.281
.26	.00667	0.9073	.893
.52	.01205	.6217	1.255
1.04	.0438	.2289	1.803
1.565	.1175	−0.0411	2.246
2.085	.5187	−0.3827	2.795

B = **$SrCl_2$**; T = 298.1°K

Solid phase probably contained $PbCl_2(s)$ (611)

B = **$SrBr_2$**; T = 298.1°K (611)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.26	0.00673	0.9060	0.883
.52	.01273	.6134	1.264
1.04	.04367	.2294	1.798
1.56	.1559	−0.0880	2.269
2.08	.5687	−0.4010	2.819

B = **$BaCl_2$**; T = 298.1°K

Solid phase probably contained $PbCl_2(s)$ (611)

B = **$BaBr_2$**; T = 298.1°K (611)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.225	0.00607	0.9624	0.832
.455	.01091	.6745	1.182
.91	.04443	.2639	1.692
1.38	.1604	−0.0609	2.150
1.835	.4140	−0.3077	2.597

B = **$Ba(NO_3)_2$**; T = 298.1°K (1192)

m_B	S_A	log $(1/m_\pm)$	$\mu^{1/2}$
0.002	0.02737	1.3664	0.297
.005	.02808	1.3509	.315
.01	.02883	1.3395	.341
.02	.03034	1.3173	.389
.05000	.03370	1.2717	.501
.09045	.03691	1.2322	.618
.1000	.03780	1.2219	.693
.2000	.04385	1.1574	.855
.2105	.04428	1.1532	.874
.3513	.05008	1.0997	1.097
.4116*	.05337	1.0720	1.222

* Solid phase, $PbBr_2(s)$ and $Ba(NO_3)_2(s)$.

B = **NaCl**, T = 298.1°K

Solid phase probably contained $PbCl_2(s)$ (611)

B = **NaBr**; T = 298.1°K (611)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.73	0.00860	0.7727	0.869
1.47	.02247	.4292	1.240
2.20	.07043	.1375	1.553
2.93	.1958	−0.1115	1.875
3.67	.3936	−0.2977	2.202
4.40	.7337	−0.4675	2.569

B = **KCl**; T = 298.1°K

Solid phase probably contained $PbCl_2(s)$ (611)

B = **KBr**; T = 298.1°K (1192)

m_B	S_A	log $(1/m_\pm)$	$\mu^{1/2}$
0.001	0.02645	1.3714	0.283
.002	.02611	1.3718	.283
.0050	.02500	1.3734	.283
.0100	.02345	1.3732	.283
.0200	.02043	1.3737	.285
.0500	.01380	1.3594	.303
.1000	.00859	1.3097	.347
.2000	.00694	1.1661	.470
.3740	.00687	0.9955	.628

$PbI_2(s) = Pb^{++} + 2I^-$

T = 298.1°K (862)

s_A	log $(1/c_\pm)$	μ_c
0.00165	2.5818	0.0703

PbI_2.—(*Continued*)

B = HNO_3; T = 298.3°K (373.5)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.00158	2.6006	0.0688
.001	.00165	2.5818	.0771
.01	.00184	2.5345	.1246
.051	.00223	2.4510	.240
.01*	.00223	2.4510	.240

* 0.01N HNO_3 + 0.04N KNO_3.

B = NH_4I

m_B	S_A	$\log(1/m_\pm)$	$\mu^{1/2}$
T = 293.1°K (326)			
0.0	0.001301	2.6850	0.0625
.2532	.0006507	1.4584	.505
.4448	.000694	1.2889	.668
.5207*	.00232	1.0645	.726
T = 333.1°K (326)			
0.0	0.00369	2.2656	0.1052
.4462	.00319	1.0616	.676
.7593	.00360	0.8916	.878
1.0986*	.00729	.6814	1.053

* Solid phase, $PbI_2(s)$ + $PbNH_4I_3.2H_2O(s)$.

B = KI

T = 286.1°K (326)			
0.0	0.00108	2.766	0.0569
.1361	.0000221	2.1292	.3691
.2626	.0000226	1.8057	.5125
.6024	.0000694	1.5329	.7741
.9813	.0000755	1.3794	.9910
1.1488*	.001291	0.9222	1.0740
T = 333.1°K (326)			
0.0	0.00369	2.2656	0.1052
.17608	.0000434	1.9567	.3195
.6199	.000477	1.2427	.788
1.0199	.0005076	1.0922	1.011
1.2669	.003154	0.7638	1.129
1.394	.003744	.7112	1.185
1.462	.004048	.6860	1.214
1.6072	.007442	.5761	1.276
2.5885	.05748	.1253	1.661
2.7523	.08169	.0528	1.731
2.939	.1036	−0.0036	1.803

* Solid phase, $PbI_2(s)$ + $PbKI_3.2H_2O$.

$Pb(IO_3)_2(s) = Pb^{++} + 2IO_3^-$

$\log(1/c_\pm^\circ) = 4.076$

B = $Pb(NO_3)_2$; T = 298.1°K (573)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{1/2}$	$\log \gamma_c$
0.0	0.0000551	4.0581	0.01286	−0.018
.00005	.0000435	4.0500	.01675	−0.026
.0005	.0000206	4.0186	.03952	−0.057
.005	.00000925	3.9219	.1226	−0.154
.050	.000008	3.6309	.3873	−0.445
.250	.000014	3.2359	.8660	−0.840
1.50	.000075	2.4906	2.121	−1.585

B = KIO_3; T = 298.1°K (573)

0.00005304	0.00003575	4.0855	0.01266	0.009
.0001061	.00002185	4.1032	.01310	.027

B = KNO_3; T = 298.1°K (573)

0.002	0.00005705	4.0431	0.04659	−0.033
.010	.0000667	3.9752	.1010	−0.101
.050	.0001019	3.7912	.2243	−0.285

$PbSO_4(s) = Pb^{++} + SO_4^{--}$

B = HCl; T = 291.1°K (71); *cf.* (1235)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.000126	3.899	0.0225
.1	.000917	3.037	.3220
.2	.00172	2.764	.4549
.3	.00267	2.573	.5575
.4	.00363	2.439	.6430

B = H_2SO_4; T = 298.1°K (1147); *cf.* (342)

0.0	0.000126	3.899	0.0225
.00005	.000110	3.877	.0243
.0001	.000101	3.846	.0265
.00025	.000064	3.848	.0317
.0005	.000043	3.816	.0409
.005	.000017	3.535	.1228

B = HNO_3; T = 291.1°K (71); *cf.* (1235)

0.1	0.000506	3.296	0.3193
.2	.000844	3.072	.4475
.3	.00113	2.947	.5518
.4	.00144	2.841	.6370

B = $NH_4C_2H_3O_2$, Ammonium acetate; T = 298.1°K (952, 1090.5)

m_B	S_A	m_B	S_A
0.0	0.000135	0.7365	0.01962
.104	.00212	1.580	.06320
.2094	.00459	3.708	.1715
.4285	.01037		

B = NaCl; T = 291.1°K (71)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{1/2}$
0.1	0.000546	3.263	0.3197
.2	.000904	3.044	.4512
.3	.00128	2.893	.5523
.4	.00163	2.775	.6377

B = $NaC_2H_3O_2$, Acetate; T = 298.1°K (443)

m_B	S_A	m_B	S_A
0.9098	0.02609	3.926	0.3714
1.8	.09992	4.673	.5224
2.981	.2342	2.5*	.1858

* 291 – 293°K.

B = $KC_2H_3O_2$, Acetate (443)

$Th(C_2O_4)_2.6H_2O(s) = Th^{++++} + 2C_2O_4^{--} + 6H_2O(l)$

B = HCl

m_B*	S_A†	m_B*	S_A†
T = 290.1°K (301)			
0.0	0.0000416	2.30	0.000416
.329	.0000857	3.59	.000686
.878	.0000115	4.44	.000931
.987	.0000149	5.43	.00157
1.26	.000230		
T = 333.1°K (301)			
0.0	0.0000416	4.42	0.00252
1.12	.000245	4.94	.00328
2.30	.000686	5.46	.00414
3.40	.00139	5.92	.00568

* *See* (301) for B = HCl + $H_2C_2O_4$. † Per 1000 g solution.

B = H_2SO_4

c_B	s_A*	c_B	s_A*
T = 298.1°K (592)			
0.5	0.00098	2.5	0.00757
.5	.00114		

B = H_2SO_4.—(*Continued*)

c_B	s_A*	c_B	s_A*
T = 298.1°K (1534)			
0.25	0.000975	1.544	0.00572
.50	.001475	1.672	.00679
.725	.001703	2.113	.00938
1.08	.00416		
T = 298.1°K (594); *cf.* (1324)			
0.0625	0.000264	0.525	0.00158
.125	.000529	.800	.00268
.250	.000983	1.225	.00499

* Per 1000 g solution.

B = $H_2C_2O_4$, Oxalic acid; T = 290.1°K (301); *cf.* (594)

c_B	s_A*†	c_B	s_A*†
0.189	0.0000049	1.033	0.000024
.722	.0000171	2.556	.00073
T = 298.1°K (594)			
	s_A = ThO_2†		s_A = ThO_2†
0.75	0.0015	satd.	0.0030

* *See* (301) for B = $H_2C_2O_4$ + HCl at 290.1 and 323.1°K. † Per 1000 g solution.

B = $(NH_4)_2C_2O_4$, Ammonium oxalate

T = 298.1°K (592)			
0.005	0.00004	satd.	0.561
.05	.0083	satd.	.550
.25	.0666		
T = 298.1°K (594)			
0.00033	0.000050	0.00120	0.000208
.00044	.000081	.00130	.000220
.00072	.00012	.00148	.000250
.00109	.000200	.00153	.000260

$Th(C_2O_4)_2.6H_2O$(amorph.) = $Th^{++++} + 2C_2O_4^{--} + 6H_2O$ (1)

B = HCl; T = 298.1°K (1324)

c_B	s_A	c_B	s_A
0.25	0.0000235	1.00	0.0001084
.50	.0000438		

B = H_2SO_4; T = 298.1°K (1324)

0.125	0.0001109	0.5	0.0005270
.25	.0002401		

TlCl(s) = $Tl^+ + Cl^-$

$\log(1/m_\pm^\circ) = 1.8630 \pm 0.002$; $\log 1/c_\pm^\circ = -1.8630 \pm 0.002$ (1192)

B = HCl

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
T = 298.1°K (1075, 1076) *corrected by* (175)			
0.0	0.01607	1.7940	0.1265
.025	.008654	1.7677	.1834
.0283 (1075)	.00834	1.7575	.191
.05	.00583	1.7437	.2364
.0560 (1075)	.00564	1.7294	.248
.01	.00383	1.7002	.3215
.1468 (1075)	.00315	1.6629	.387
.2	.002534	1.6452	.450
1.00 (1075)	.00200	1.3492	1.001

B = HNO_3; T = 298.1°K* (629, 630)

m_B	S_A	$\log(1/m_\pm)$	$\mu^{\frac{1}{2}}$
0.0	0.01657	1.7807	0.1285
.5169	.02571	1.6899	.736
1.0804	.03092	1.5098	1.055
2.3700	.03941	1.4044	1.550
5.4512	.05625	1.2499	2.350

* The temperature is probably higher than 298.1°K.

B = NH_4Cl; T = 298.1°K (1075, 1076) *corrected by* (175)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.025	0.00875	1.7647	0.1835
.05	.00591	1.7404	.236
.2	.00270	1.6301	.450

B = NH_4NO_3; T = 298.1°K (468)

0.0	0.01606	1.7943	0.1265
.5	.02587	1.5872	.7254
1	.03121	1.5057	1.015
2	.03966	1.4016	1.428

B = $C_2H_4O_2$, Acetic acid; T = 298.1°K (625); *cf.* (626)

m_B	d_4^{25}	S_A	$\log(1/m_\pm)$
0.0		0.01634	1.7828
.5310	0.9986	.01639	1.7854
1.080	1.0014	.01595	1.7973
2.272	1.0085	.01495	1.8254
5.43	1.0295	.01281	1.8925
14.53	1.0521	.00960	2.0177
31.00	1.0570	.00708	2.1500
70.00	1.0614	.00605	2.2183
150.00	1.0638	.00467	2.3307
c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
T = 298.1°K (626)			
0.0	0.016085	1.7934	
.0501	.016027	1.7951	
.0958	.016006	1.7956	
.263	.015662	1.8052	
.524	.015258	1.8164	

B = $TlClO_3$; T = 298.1°K (1075) *corrected by* (175)

0.025	0.00893	1.7591	0.184

B = $TlBrO_3$; T = 312.85°K (1077)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.02523	1.5981	0.1588
0.01567	0.01952	1.5816	0.1876

B = Tl_2SO_4; T = 298.1°K (231)

m_B	S_A	$\log(1/m_\pm)$	$\mu^{\frac{1}{2}}$
0.0	0.01612	1.7926	0.1268
.02511	.00683	1.7132	.2865
.05039	.00467	1.6537	.394
c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
T = 298.1°K (175)			
0.0	0.01615	1.7918	0.1271
.01004	.01039	1.7497	.2012
.01415*	.00883	1.7415	.1515
.02511	.006804	1.7056	.2865
.0280*	.00624	1.7054	.185
.05029	.004708	1.6524	.394
m_B	S_A	$\log(1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 323.1°K (231)			
0.0	0.03341	1.4761	0.1827
.02542	.02095	1.4114	.3112
.05076	.01591	1.3643	.4100

* From (1075) corrected by (175).

B = $TlNO_3$; T = 298.1°K (231)

0.0	0.01612	1.7926	0.1268
.05035	.00619	1.7284	.237
.10075	.00416	1.6851	.324
.20284	.00304	1.6017	.453

$TlCl$.—(*Continued*)

B = $TlNO_3$.—(*Continued*)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{1/2}$
T = 298.1°K (1075) *corrected by* (175)			
0.0	0.01607	1.7940	0.1266
.0283	.00828	1.7584	.1905
.0560	.00570	1.7269	.248
.1468	.00331	1.6519	.387

m_B	S_A	$\log (1/m_\pm)$	$\mu^{1/2}$
T = 298.1°K (1076) *corrected by* (175)			
0.0	0.01607	1.7940	0.1265
.025	.0088	1.7633	.1838
.05	.00624	1.7274	.2371
.1	.00422	1.6783	.3228
T = 323.1°K (231)			
0.0	0.03341	1.4761	0.1827
.10167	.01404	1.3947	.340
.20481	.01034	1.3264	.463

B = $TlCNS$

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{1/2}$
T = 298.1°K (1075)			
0.0	0.01607	1.7940	0.1265
.0107	.0119	1.7844	.1503
T = 312.84°K (1077)			
0.02149	0.01807	1.7430	0.1989

B = $ZnCl_2$; T = 298.1°K (1076) *corrected by* (175)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.01607	1.7940	0.1265
.0125	.00896	1.7584	.215
.025	.00625	1.7270	.285
.05	.00411	1.6844	.392
.1	.00280	1.6229	.550

B = $ZnSO_4$

m_B	S_A	$\log (1/m_\pm)$	$\mu^{1/2}$
T = 273.1°K (231)			
0.0	0.006701	2.1739	0.0819
.04997	.008746	2.0582	.457
.1	.009786	2.0094	.639
.2998	.01213	1.9161	1.100
5986	.01421	1.8474	1.552
T = 298.1°K (231)			
0.0	0.01612	1.7926	0.1268
.05013	.02065	1.6851	.470
.10021	.02284	1.6413	.650
.30045	.02773	1.5571	1.108
.60062	.03209	1.4936	1.559
T = 323.1°K (231)			
0.0		1.4761	0.1827
.05066	0.04081	1.3892	.4935
.10142	.04520	1.3448	.6712
.3047	.05432	1.2650	1.1285
.6093	.06265	1.2031	1.5810

B = $CdCl_2$; T = 298.1°K (1076) *corrected by* (175)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.01607	1.1940	0.1265
.0125	.01037	1.7178	.218
.025	.00778	1.6736	.287
.05	.00576	1.6076	.394
.1	.00426	1.5302	.551

B = $CdSO_4$; T = 298.1°K (1075) *corrected by* (175)

0.015	0.0206	1.5665	0.1887
.03935	.0254	1.3912	.2545
.0787	.0309	1.2343	.3311

B = $CuCl_2$; T = 298.1°K (1076) *corrected by* (175)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.01607	1.7940	0.1268
.0125	.00903	1.7562	.215
.025	.00612	1.7321	.285
.05	.00421	1.6789	.392
.1	.00290	1.6144	.550

B = $MnCl_2$; T = 298.1°K (1076) *corrected by* (175)

0.0	0.01607	1.7940	0.1268
.0125	.00895	1.7587	.215
.025	.00615	1.7309	.285
.05	.00411	1.6894	.392
.1	.00285	1.6189	.550

B = $FeCl_2$; T = 298.1°K (569)

(569) states same solubility as in $BaCl_2$ (175)

B = $La_2(SO_4)_3$

m_B	S_A	$\log (1/m_\pm)$	$\mu^{1/2}$
T = 273.1°K (231)			
0.0	0.00670	2.1739	0.0819
.01001	.00747	2.1267	.3965
.01502	.00806	2.0937	.482
.02005	.00830	2.0809	.555
.02507	.00847	2.0721	.620
T = 298.1°K (231)			
0.0	0.01612	1.7926	0.1268
.01004	.01809	1.7433	.410
.01508	.01845	1.7352	.484
.02012	.01925	1.7176	.566
.02516	.01950	1.7120	.630

B = $La(NO_3)_3$; T = 298.1°K (1174)

m_B	S_A	$\log (1/m_\pm)$	$\mu^{1/2}$
0.0	0.01611	1.7929	0.1269
.005215	.01740	1.7594	.2224
.008808	.01778	1.7500	.2657
.02024	.01946	1.7109	.3754
.04180	.02129	1.6718	.5216
.08166	.02433	1.6138	.7171
.1970	.02697	1.5692	1.100

B = $MgCl_2$; T = 298.1°K (1076) *corrected by* (175)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.01607	1.7940	0.1265
.0125	.00901	1.7559	.147
.025	.00616	1.7297	.176
.05	.00412	1.6882	.233
.10	.00274	1.6268	.320

B = $MgSO_4$; T = 298.1°K (1174)

m_B	S_A	$\log (1/m_\pm)$	$\mu^{1/2}$
0.0	0.01611	1.7929	0.1269
.01708	.01920	1.7127	.2958
.03364	.02042	1.6899	.3937
.04384	.02106	1.6765	.4454
.06259	.02214	1.6548	.5220
.1291	.02504	1.6014	.7358
.1994	.02641	1.5782	.9078
.3529	.02878	1.5409	1.2002

B = $CaCl_2$; T = 298.1°K (1076) *corrected by* (175)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.01607	1.7940	0.1265
.0125	.00893	1.7593	.215
.025	.00622	1.7281	.285
.05	.00416	1.6867	.392
.1	.00283	1.6206	.550

B = **$BaCl_2$**; T = 298.1°K (1076) *corrected by* (175)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.01607	1.7940	0.1265
.01415*	.00855	1.7508	.226
.025	.00618	1.7297	.285
.05	.00424	1.6772	.393
.0734*	.00322	1.6580	.472

* (1075).

B = **$LiNO_3$**; T = 298.1°K (468)

0.0	0.01606	1.7943	0.1265
.5	.02542	1.5948	.7249
1	.03035	1.5178	1.015
2	.03785	1.4219	1.427
3	.04438	1.3528	1.744

B = **NaCl**; T = 298.1°K (1076) *corrected by* (175)

0.0	0.01607	1.7940	0.1265
.025	.00867	1.7669	.1835
.05	.00590	1.7408	.236
.1	.00394	1.6989	.322
.2	.00270	1.6308	.450

B = **$NaClO_3$**; T = 298.1°K (468)

0.0	0.01606	1.7943	0.1265
.5	.02320	1.6345	.7233
1	.02687	1.5707	1.1425
2	.03060	1.5142	1.425
3	.03303	1.4810	1.7415
4	.03850	1.4145	2.01

B = **$NaNO_3$**; T = 298.1°K (468)

0.0	0.01606	1.7943	0.1265
.5	.02564	1.5910	.725
1	.03054	1.5151	1.014
2	.03851	1.4144	1.428
3	.04544	1.3425	1.745
4	.05128	1.2900	2.013

B = **$NaC_2H_3O_2$**, Acetate; T = 298.1°K (1075) *corrected by* (175)

0.0	0.01607	1.7940	0.1265
.0150	.0163	1.7878	.177
.0300	.0169	1.7721	216
.0787	.0181	1.7423	311
.1574	.0192	1.7167	.420

B = **KCl**; T = 298.1°K (231)

m_B	S_A	log $(1/m_\pm)$	$\mu^{\frac{1}{2}}$
0.0	0.01612	1.7926	0.1265
.05025	.00589	1.7403	.237
.10051	.00389	1.6957	.322
.20190	.00260	1.6372	.451
.50911	.00179	1.5194	.714

T = 298.1°K (1075) *corrected by* (175); *cf.* (199)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.01607	1.7940	0.1265
.025	.00869	1.7667	.1835
.05	.00590	1.7408	.2364
.1	.00396	1.6927	.3224
.2	.00268	1.6325	.4502
.8	.00170	1.4237	.8954

T = 323.1°K (231)

m_B	S_A	log $(1/m_\pm)$	$\mu^{\frac{1}{2}}$
0.0	0.033412	1.4761	0.1827
.05071	.01861	1.4448	.2633
.10151	.01300	1.4136	.3384
.2036	.00909	1.3568	.4612
.5140	.00623	1.2447	.7211

B = **$KClO_3$**; T = 298.1°K (468)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.5	0.5237	1.6252	0.7237

B = **K_2SO_4**; T = 298.1°K (175)

m_B	S_A	log $(1/m_\pm)$	$\mu^{\frac{1}{2}}$
0.0	0.01615	1.7918	0.1271
.01006	.01787	1.7479	.2002
.02511	.01953	1.7093	.314
.05028	.02151	1.6674	.415
.1515	.02628	1.5814	.686
.5133	.03512	1.4544	1.255

B = **KNO_3**

T = 273.1°K (231)

0.0	0.006701	2.1739	0.0819
.0501	.007894	2.1027	.2405
.2015	.009623	2.0167	.459
.5094	.01206	1.9191	.721
1.0401	.015310	1.8150	1.025

T = 298.1°K (231)

0.0	0.01612	1.7926	0.1268
.05028	.01836	1.7361	.262
.20234	.02176	1.6623	.473
.51228	.02619	1.5819	.733
1.0487	.03178	1.4979	1.040

T = 298.1°K (175); *cf.* (199)

0.0	0.01615	1.7918	0.127
.0201	.01725	1.7632	.193
.0503	.01838	1.7467	.262
.1008	.01977	1.7040	.347
.3080	.02375	1.6243	.575
1.047	.03217	1.4925	1.037

T = 298.1°K (468)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.01606	1.7943	0.1265
.5	.02566	1.5907	.725
1.0	.03077	1.5119	1.019
2	.03904	1.4085	1.428

T = 298.1°K (1075) *corrected by* (175)

0.015	0.0170	1.7695	0.1789
.03	.0179	1.7471	.2189
.0787	.0192	1.7167	.3129
.1574	.0212	1.6736	.4226

T = 323.1°K (231)

m_B	S_A	log $(1/m_\pm)$	$\mu^{\frac{1}{2}}$
0.0	0.03341	1.4761	0.1827
.05075	.03652	1.4375	.295
.20435	.04226	1.3741	.495
.51797	.04966	1.3040	.753
1.06067	.05859	1.2322	1.052

$TlClO_3$ (s) = $Tl^+ + ClO_3^-$

B = **Tl_2SO_4**; T = 293.1°K (1078)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.1340	0.8729	0.3611
.0683	.1058	.5889	.5574

$TlBr(s) = Tl^+ + Br^-$

B = $TlNO_3$; T = 341.6°K (1075)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.00869	2.0609	0.09311
.0163	.00410	2.0387	.1428
.0294	.00289	2.0150	.1797
.0995	.00148	1.9127	.3178

$TlBrO_3(s) = Tl^+ + BrO_3^-$

B = TlCl; T = 312.85°K (1077)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.02216	1.6544	0.1489
0.01952*	0.01567	1.6292	0.1876

* TlCl(s) present.

B = TlCNS; T = 312.85°K (1077)

0.02210*	0.01496	1.6280	0.1925

* TlCNS (s) present.

$TlCNS(s) = Tl^+ + CNS^-$

B = TlCl

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
T = 298.1°K (1075)			
0	0.0149	1.8286	0.1221
0.0119*	.0107	1.8082	.1503
T = 312.85°K (1077)			
0.0	0.02773	1.5570	0.1665
.01807*	0.03956	1.5452	.1989

* TlCl(s) present.

B = $TlBrO_3$; T = 312.85°K (1077)

$0.01496_{\text{satd.}}$	0.03706*	1.5433	0.1925

* $TlBrO_3$(s) present.

B = $TlNO_3$; T = 298.1°K (1075)

0.0	0.0149	1.8286	0.1221
.0227	.00852	1.7875	.1767
.0822	.00406	1.7278	.2937

B = KCNS; T = 298.1°K (1075)

0.0227	0.0083	1.7947	0.1761

$Tl_2SO_4(s) = 2Tl^+ + SO_4^{--}$

B = H_2SO_4; T = 298.1°K (1078)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.1083	0.7646	0.570
.0247	.1172	.7027	.652
.04935	.1249	.6545	.723

B = $TlClO_3$; T = 293.1°K (1078)

0.0	0.0964	0.8152	0.538
.1058	.0683	.7988	.558

B = $TlNO_3$; T = 298.1°K (1078)

0.0996	0.08365	0.7416	0.593

B = $NaHSO_4$; T = 298.1°K (1078)

0.0505	0.1161	0.6821	0.707

B = Na_2SO_4; T = 298.1°K (1078)

0.02485	0.1080	0.7359	0.632

$Tl_2C_2O_4(s)$, Oxalate $= 2Tl^+ + C_2O_4^{--}$

B = $TlNO_3$; T = 298.1°K (9)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.03768	1.2232	0.336
.04114	.0264	1.2108	.347
.0799	.0195	1.1865	.372
.1597	.01235	1.1256	.444

B = $K_2C_2O_4$; T = 298.1°K (9)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.0498	0.0351	1.1261	0.505
.0996	.03565	1.0541	.637
.2467	.0390	0.9199	.926
.4886	.04506	.7877	1.262
.9785	.05536	.6324	1.763

$AgCl\ (s) = Ag^+ + Cl^-$

B = HCl, B = HNO_3 and B = Various salts; *see* p. 266

$AgBr\ (s) = Ag^+ + Br^-$

B = $Hg(NO_3)_2$ and B = KBr; *see* p. 267

$AgBrO_3\ (s) = Ag^+ + BrO_3^-$

$\log 1/m^\circ_\pm = 2.142 \pm 0.003$

B = $C_2H_4O_2$, Acetic acid; T = 298.1°K (626)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.008267	2.0827	0.09092
.0498	.008240	2.0840	
.0997	.008219	2.0851	
.1995	.008145	2.0891	
.4988	.007904	2.1022	
.9975	.007639	2.1169	
1.8721	.006861	2.1636	

B = $CdSO_4$; T = 298.1°K (317)

0.0	0.008062	2.0937	0.0898
.1	.01041	1.9828	.6406
.5	.01335	1.8745	1.419

B = $AgNO_3$; T = 297.6°K (1075)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.00810	2.0915	0.0900
.00850	.00510	2.0794	.1167
.0346	.00216	2.0500	.1917

B = $Ce(NO_3)_3$; T = 298.1°K (317)

0.0125	0.008888	2.0512	0.2835
.025	.009336	2.0298	.3992

B = $MgSO_4$; T = 298.1°K (317)

0.02	0.00892	2.0497	0.2212
.051	.00967	2.0143	.4622
.1	.0103	1.9872	.6406
.1988	.01138	1.9439	.8981

B = $Mg(NO_3)_2$; T = 298.1°K (317)

0.025	0.008935	2.0489	0.2897
.05	.009414	2.0263	.3983
.10	.01009	1.9961	.5576

B = $Ba(NO_3)_2$; T = 298.1°K (317)

0.025	0.009088	2.0415	0.2900
.05	.009655	2.0153	.3995
.10	.010373	1.9841	.5571

B = Na_2SO_4; T = 298.1°K (317)

0.05	0.009965	2.0015	0.400
.10	.01097	1.9597	.5706
1.00	.01862	1.7300	1.737

B = $KClO_4$; T = 298.1°K (317)

0.025	0.008716	2.0596	0.1836
.05	.009190	2.0367	.2433
.10	.009706	2.0129	.3312

B = $KBrO_3$; T = 297.6°K (1075)

0.00850	0.00519	2.0742	0.117
.0346	.00227	2.0386	.192

B = K_2SO_4; T = 298.1°K (317)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.025	0.00929	2.0159	0.2903
.05	.01002	1.9994	.400
.1	.01109	1.955	.5577
B = KNO_3; T = 298.1°K (317)			
0.040	0.00912	2.0400	0.2221
.100	.00992	2.0035	.3303
.200	.01106	1.9562	.4594
.394	.01266	1.8976	.6377

AgI (s) = $Ag^+ + I^-$

B = $Hg(NO_3)_2$ and B = $AgNO_3$; *see* p. 268

$AgIO_3$(s) = $Ag^+ + IO_3^-$

$s_A = 1.89 \times 10^{-4}$ (1084)

log $(1/m^\circ_\pm)(298.1) = 3.762 \pm 0.003$; $K_{298.1} = 5.29 \times 10^{-8}$

B = HNO_3; T = 298.1°K (629, 630)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.000178	3.7496	0.01334
.125	.000304	3.5171	.354
.25	.000379	3.4214	.5004
.5	.000499	3.302	.7075
1.0	.000731	3.136	1.001
2.0	.001174	2.930	1.415
4.0	.002469	2.6075	2.000
8.0	.005608	2.2511	2.829

$AgNO_2$ (s) = $Ag^+ + NO_2^-$

log $(1/m^\circ_\pm)(298.1) = 1.850$ from $K_{298.1} = 2.0 \times 10^{-4}$ (6) *from* (5, 892, 1049, 1050)

B = $AgNO_3$

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
T = 298.1°K (313)			
0.0	0.0269	1.5702	0.164
.00258	.0260	1.5644	.169
.00588	.0244	1.5657	.174
.01177	.0224	1.558	.185
.02355	.0192	1.542	.207
.04710	.0164	1.4913	.252
T = 291.1°K (1049)			
0.0	0.02067	1.6846	0.1438
.00258	.01975	1.6777	.1494
.00517	.01900	1.6689	.1555
.01033	.01689	1.6687	.1650
.02067	.01435	1.6494	.1871
04134	.01168	1.6040	.2303
.08268	.00961	1.5270	.3038
B = KNO_2; T = 298.1°K (313)			
0.00258	0.0259	1.5660	0.1688
.00588	.0249	1.5577	.1754
.01177	.0232	1.5454	.187
.02355	.0203	1.5252	.2094
.04710	.0181	1.4640	.2552

$AgC_2H_3O_2$, Acetate = $Ag^+ + C_2H_3O_2^-$

B = $C_2H_4O_2$, Acetic acid; T = 298.1°K (769)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
0.0	0.06635	1.1782	0.2576
1	.0643	0.5823	
2	.0618	.4474	
2.98	.0598	.3702	
4.19	.0570	.3089	
5.99	.0532	.2464	

B = $C_2H_4O_2$.—(*Continued*)

c_B	s_A	log $(1/c_\pm)$	$\mu_c^{1/2}$
8.01	0.0463	0.2140	
9.96	.0406	.1956	
12.32	.0319	.2022	
13.97	.0257	.2221	
14.96	.0206	.2558	
15.93	.0149	.3127	
17.28	.00653	.4736	
B = $Pb(C_2H_3O_2)_2$, Acetate; T = 298.1°K (677)			
0.0	0.0667	1.1759	0.2583
.01	.06403	1.1346	.3067
.05	.0566	1.0262	.4545
.1	.04995	0.9518	.5916
.5	.04349	.6715	1.242
1.0	.03587	.5711	1.743
B = $Cd(C_2H_3O_2)_2$, Acetate; T = 298.1°K (677)			
0.01	0.06224	1.1454	0.3037
.05	.04852	1.0711	.4455
.1	.04021	1.0075	.583
.5	.02592	0.7876	1.235
1.0	.02363	.6601	1.739
B = $AgNO_3$			
T = 289.1°K (1051)			
0.0	0.0603	1.2196	0.2484
.061	.0417	1.1841	.3205
.119	.0341	1.1411	.3913
.230	.0195	1.1564	.4995
T = 292.9°K (26)			
0.0	0.0590	1.2291	0.2429
.0533	.0411	1.2056	.3072
.1	.0311	1.1948	.3621
T = 298.1°K (677)			
0.01634	0.0595	1.1728	0.2754
.03268	.0540	1.1648	.2944
.06535	.0444	1.1561	.3312
.1307	.0348	1.1199	.4063
B = $NaC_2H_3O_2$, Acetate; T = 289.1°K (1051)			
0.061	0.0392	1.2029	0.3597
.119	.0280	1.1927	.3834
.230	.0208	1.1412	.5010
T = 289.1°K (1049)			
0.0	0.0569	1.2448	0.2385
.0569	.03748	1.2256	.3072
.1138	.02787	1.2018	.3764
.2276	.01973	1.1558	.4973
T = 291.7°K (26)			
0.0	0.0593	1.2269	0.2435
.0333	.0474	1.2087	.2841
.0667	.0384	1.1970	.3242
.1333	.0282	1.1708	.4018
.2667	.0203	1.1173	.5357
.5000	.0147	1.0605	.7173
T = 298.1°K (677)			
0.0240	0.05557	1.1771	0.2821
.2403	.02519	1.0874	.5153
1.201	.01396	0.8853	1.102
2.403	.01239	.7620	1.554
B = $KC_2H_3O_2$, Acetate; T = 298.1°K (677)			
0.0226	0.0575	1.1973	0.2648
.2262	.02653	1.0868	.5027
1.131	.01442	0.8911	1.070
2.262	.01305	.7637	1.510

$AgC_2H_2ClO_2(s)$, Chloroacetate = $Ag^+ + C_2H_2ClO_2^-$

B = HNO_3; T = 298.1°K (629, 630)

c_B	s_A	d	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.0737	1.0095	1.1325	0.2715
.2405	.2546	1.0426	0.5941	.7036
.4738	.4560	1.0791	0.3410	.9642
.9525	.8309	1.1473	0.0904	1.335
1.751	1.543	1.2716	−0.1884	1.815
3.271	2.726	1.4749	−0.4355	2.449
3.918	3.273	1.5673	−0.5149	2.644

B = $AgNO_3$; T = 290.0°K (26)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.0644	1.1911	0.2538
.0533	.0449	1.1567	.329
.1	.0373	1.1453	.3705
B = $NaC_2H_2ClO_2$, Chloroacetate; T = 290.0°K (26)			
0.0333	0.0499	1.1909	0.2885
.0667	.0405	1.1812	.3274
.1333	.0299	1.1557	.404
.2667	.0208	1.1112	.5362
.5	.0162	1.0388	.7185

$AgC_3H_5O_2(s)$, Propionate = $Ag^+ + C_3H_5O_2^-$

B = $C_3H_6O_2$, Propionic acid; T = 298.1°K (769)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0	0.04782	1.3203	0.2187
1	.04539	0.6618	1.022
2	.04237	.5313	1.429
2.97	.04020	.4586	1.735
4.95	.03587	.3738	2.233
6.97	.03057	.3347	2.646
8.56	.02623	.3240	2.929
11.40	.01671	.3597	3.380
13.03	.01148	.4154	3.611
B = $AgNO_3$; T = 292.8°K (26)			
0.0	0.0462	1.3353	0.2150
.0167	.0393	1.3286	.2366
.0333	.0345	1.3154	.2604
.0667	.0258	1.3064	.3074
.1333	.0191	1.2679	.3904
.2667	.0131	1.2179	.5290
.5000	.0101	1.1440	.7142
B = $NaC_3H_5O_2$, Propionate; T = 291.1°K (26)			
0.0	0.0471	1.3269	0.217
.0133	.0415	1.3653	.2117
.0267	.0379	1.3056	.2542
.0533	.0307	1.2943	.2898
.1	.0222	1.2832	.3496

$AgC_4H_7O_2$, Butyrate = $Ag^+ + C_4H_7O_2^-$

B = $AgNO_3$; T = 291.9°K (26)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.0228	1.6420	0.151
.0667	.0078	1.6179	.273
.1	.0062	1.5907	.3257
B = $AgC_2H_3O_2$, Acetate; T = 290.9°K (26)			
0.0	0.0221	1.6556	0.1486
.0270	.0139	1.6226	.2022
.0506	.0103	1.6013	.2468

B = $NaC_4H_7O_2$, Butyrate; T = 291.3°K (26)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.0224	1.6497	0.1497
.0066	.0199	1.6389	.1628
.0164	.0169	1.6252	.1825
.0329	.0131	1.6099	.2145
.0658	.0091	1.5832	.2675
.1315	.0060	1.5417	.3708
.263	.0040	1.4857	.5167
.493	.0027	1.4367	.6953

$AgC_5H_9O_2$, Valerate = $Ag^+ + C_5H_9O_2^-$

B = $AgNO_3$; T = 289.6°K (26)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.0094	2.0268	0.0969
.0067	.0068	2.0185	.1162
.01333	.0051	2.0134	.1358
.0267	.0031	2.0171	.1726
0.1	.0012	1.9578	.3181
B = $AgC_2H_3O_2$, Acetate; T = 290.9°K (26)			
0.0	0.0094	2.0268	0.0969
.0067	.0070	2.0091	.1170
.0135	.0057	1.9804	.1386
.0270	.0037	1.9723	.1752
.0505	.00265	1.9257	.2305
B = $NaC_5H_9O_2$, Valerate; T = 291.7°K (26)			
0.0	0.0095	2.0223	0.0975
.0175	.0047	1.9908	.1486
.0349	.0030	1.9721	.1947
.0698	.0018	1.9448	.2676
.1395	.0015	1.9373	.3755

$AgC_7H_5O_2$, Benzoate = $Ag^+ + C_7H_5O_2^-$

B = HNO_3; T = 298.1°K (1086)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.01144	1.9416	0.1070
.004435	.01395	1.8557	.1356
.00887	.01698	1.7700	.1608
.008915	.01715	1.7657	.1614
.01774	.02324	1.6337	.2024
.01783	.02351	1.6287	.2034
.02674	.03071	1.5127	.2397
B = $C_2H_3ClO_2$, Chloroacetic acid; T = 298.1°K (1086)			
0.003935	0.01385	1.8585	
.00785	.01612	1.7926	
.01574	.02093	1.6792	

$Ag_2SO_4(s) = 2Ag^+ + SO_4^{--}$

B = H_2SO_4; T = 298.1°K (1415); *cf.* (354)

c_B	s_A	$\log(1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.0	0.02699	1.3681	0.2949
.01451	.02744	1.2995	.3389
.02901	.02782	1.2515	.4365
.05263	.02841	1.1941	.4930
B = HNO_3; T = 298.1°K (1415)			
0.01589	0.02993	1.3233	0.3251
.03178	.3266	1.2853	.3603
.06357	.3795	1.2201	.4212

m_B	S_A	d	$\log(1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 298.1°K (629, 630)				
0.0	0.02684	1.0054	1.3705	0.2838
1.043	.1138	1.0610	0.7432	1.177
2.163	.1688	1.1069	.5718	1.634

B = **HNO_3**.—(*Continued*)

m_B	S_A	d	log (1/$m_\pm$)	$\mu^{\frac{1}{2}}$
4.568	0.2633	1.1871	0.3788	2.315
4.861	.2754	1.1956	.3593	2.385
6.764	.3317	1.2456	.2786	2.785
10.423	.3803	1.3326	.2191	3.400
15.311	.4515	1.3676	.1446	4.082

B = **$(NH_4)_2SO_4$**

m_B	S_A	log (1/$m_\pm$)	$\mu^{\frac{1}{2}}$
T = 289.6°K (53)			
0.7522	0.02851	0.8651	1.530
1.468	.03492	.7929	2.124
2.206	.03903	.6213	2.595
2.944	.040825	.5670	2.994
3.634	.04162	.5313	3.320
4.26	.04137	.5103	3.592
5.0386	.04015	.4949	3.903
5.51	.03919	.4821	4.080
T = 304.1°K (53)			
0.0	0.02941	1.3307	0.2970
.7438	.03531	0.8035	1.529
1.46	.04269	.6534	2.123
2.204	.04811	.5603	2.599
2.898	.05083	.5053	2.974
3.448	.05192	.4744	3.391
4.344	.05218	.4406	3.623
5.066	.05131	.4228	
5.922	.04993	.4083	4.233
T = 324.1°K (53)			
0.0	0.03441	1.2626	0.3212
.7505	.04369	0.7391	1.543
1.5007	.05388	.5811	2.160
2.243	.06052	.4906	2.628
3.006	.0635	.4350	3.035
3.689	.0661	.3942	3.357
3.829	.06719	.3805	3.463
5.015	.06677	.3475	3.905
5.769	.06590	.3313	4.184
6.442	.06497	.3196	4.418
T = 348.1°K (53)			
0.0	0.04018	1.1953	0.3471
.7316	.06193	0.6382	1.540
1.395	.08364	.4609	2.106
2.244	.1062	.3250	2.650
3.098	.127	.2252	3.110
3.715	.1389	.1755	3.400
5.109	.1615	.0866	3.976
6.644	.182	.0145	4.525
6.943	.1838	.0054	4.624
T = 373.1°K (53)			
0.0	0.04531	1.1607	0.3612
0.7885	.08043	0.5484	1.615
1.378	.1022	.4230	2.098
2.223	.1316	.2628	2.658
2.933	.153	.1797	3.043
4.299	.1912	.0609	3.670
5.091	.2102	.0094	3.987
6.425	.2377	−0.0592	4.471
7.28	.2505	−0.0921	4.754

B = **$AgNO_3$**; *T* = 298.1°K (570)

m_B	S_A	log (1/$m_\pm$)	$\mu^{\frac{1}{2}}$
0.0	0.02684	1.3705	0.2838
.02501	.01958	1.3645	.2894
.05009	.01429	1.3511	.3049
.1002	.00853	1.3102	.3546

B = **$MgSO_4$**; *T* = 298.1°K (570)

m_B	S_A	log (1/$m_\pm$)	$\mu^{\frac{1}{2}}$
0.01004	0.02619	1.3341	0.3587
.02511	.02555	1.2927	.4208
.05019	02506	1.2412	.5253
.10027	.02489	1.1722	.6897

B = **$Mg(NO_3)_2$**; *T* = 298.1°K (570)

m_B	S_A	log (1/$m_\pm$)	$\mu^{\frac{1}{2}}$
0.01245	0.02989	1.3237	0.3564
.02500	.03243	1.2883	.4151
.05038	.03683	1.2331	.5115

B = **Na_2SO_4**

m_B	S_A	log (1/$m_\pm$)	$\mu^{\frac{1}{2}}$
T = 287.6°K (51)			
0.0	0.02358	1.4267	0.2660
.3715	.02376	1.0164	1.089
.7112	.02899	0.8680	1.490
.9183	.03217	.8017	1.689
T = 291.1°K (53)			
0.0	0.02456	1.4091	0.2714
.0176	.02283	1.3580	.3483
.0359	.02187	1.3188	.4163
.05209	.02165	1.2865	.4703
.07039	.02133	1.2591	.5246
.1042	.02149	1.2113	.6140
.176	.02210	1.1374	.7709
.214	.02254	1.1061	.8423
.3513	.02463	1.0132	1.061
.711	.02989	0.8590	1.491
.9179	.03297	.7945	1.689
T = 304.1°K (53)			
0.0176	0.02761	1.2868	0.3682
.0359	.02678	1.2484	.4343
.05279	.02646	1.2179	.4876
.1056	.02629	1.1461	.6290
.1746	.02723	1.0743	.7780
.3759	.03117	0.9002	1.105
.7075	.03688	.7975	1.494
1.0686	.04233	.6996	1.826
1.789	.04964	.5806	2.349
2.776	.04689	.5350	2.770
3.307	.02989	.6460	3.164
T = 324.1°K (53)			
0.0176	0.0331	1.2495	0.3494
.03449	.03239	1.1839	.4479
.04787	.03207	1.1609	.4897
.0718	.03191	1.1247	.5578
.1063	.03213	1.0809	.6381
.1732	.03316	1.0041	.7867
.2780	.03537	0.9348	.9696
.7117	.04422	.7427	1.506
1.773	.05731	.5396	2.343
2.473	.05538	.5049	2.734
3.130	.02828	.6651	3.078
T = 348.1°K (53)			
0.01408	0.03896	1.166	0.3989
.03308	.03874	1.1217	.4642
.0563	.03868	1.0851	.5337
.06899	.03880	1.0625	.5687
.107	.03919	1.0155	.6623

Ag_2SO_4.—(*Continued*)

B = Na_2SO_4.—(*Continued*)

m_B	S_A	$\log (1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 348.1°K.—(*Continued*)			
0.176	0.04069	0.9476	0.8063
.378	.04676	.8100	1.129
.6906	.05442	.6847	1.495
1.406	.06202	.5487	2.099
1.799	.06933	.4813	2.367
2.911	.03707	.5968	2.974
T = 373.1°K (53)			
0.0352	0.04300	1.0792	0.4843
.0711	.04371	1.0189	.5869
.1014	.04432	0.9804	.6611
.1366	.04547	.9407	.7391
.2126	.04791	.8727	.8840
.3752	.05295	.7425	1.259
.7145	.06452	.6289	1.529
1.093	.07414	.5302	1.871
1.792	.0754	.4574	2.367
2.091	.07248	.4475	2.547
2.827	.03714	.2671	2.941

B = KNO_3; T = 298.1°K (570)

m_B	S_A	$\log (1/m_\pm)$	$\mu^{\frac{1}{2}}$
0.02502	0.02898	1.3372	0.3450
.05006	.03075	1.3115	.3772
.1016	.03456	1.2609	.4531

B = $KHSO_4$; T = 298.1°K (1415)

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
0.02632	0.02609	1.2818	0.3964
.05263	.02588	1.2238	.4853

B = K_2SO_4

m_B	S_A	$\log (1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 287.6°K (53)			
0.1911	0.02203	1.1277	0.7996
.3460	.02511	1.0096	1.055
.5251	.02877	0.9122	1.289
.5939	.03037	.8792	1.369
T = 298.1°K (570)			
0.01256	0.02543	1.3359	0.3375
.02513	.02478	1.3041	.3865
.05025	.02414	1.2537	.4725
.1007	.02432	1.1763	.6124

c_B	s_A	$\log (1/c_\pm)$	$\mu_c^{\frac{1}{2}}$
T = 298.1°K (1415)			
0.01359	0.02545	1.3316	0.3424
.02717	.02465	1.2999	.3943

m_B	S_A	$\log (1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 304.1°K (53)			
0.1926	0.02885	1.0440	0.4416
.3451	.03226	0.9346	1.064
.5302	.03701	.8358	1.304
.6749	.04047	.7762	1.465
.7776	.04336	.7365	1.569
T = 324.1°K (53)			
0.1957	0.03499	0.9823	0.8319
.3451	.03874	.8691	1.073
.5335	.04426	.7813	1.316
.6839	.04875	.7184	1.486
.8843	.05445	.6511	1.678
.9801	.05811	.6177	1.765

B = K_2SO_4.—(*Continued*)

m_B	S_A	$\log (1/m_\pm)$	$\mu^{\frac{1}{2}}$
T = 348.1°K (53)			
0.1873	0.04270	0.9550	0.758
.3540	.04855	.8079	1.099
.5371	.05535	.7130	1.333
.6892	.06080	.6517	1.500
.8889	.06821	.5830	1.695
1.0364	.07559	.5470	1.826
1.210	.08011	.4933	1.967
T = 373.1°K (53)			
0.1945	0.05009	0.8700	0.8566
.3466	.05791	.7552	1.102
.5408	.0676	.6512	1.351
.7483	.07831	.5642	1.575
.9342	.08758	.5014	1.751
1.048	.09364	.4659	1.850
1.257	.1037	.4118	2.020
1.354	.109	.3859	2.095

$Ag_2C_2O_4$(s), Oxalate = $2Ag^+ + C_2O_4^{--}$

B = HNO_3; T = 298.1°K (629, 630)

c_B	s_A	$d_{298.1}$
0.2513	0.008853	1.008
.5025	.01411	1.0186
.9608	.02449	1.0339
1.925	.04720	1.0647
3.986	.1192	1.1415
5.534	.1998	1.1996
5.829	.2230	1.2162

$Ag_2S.AgNO_3$(s) = $3Ag^+ + S^{--} + NO_3^-$

B = $AgNO_3$; *see* p. 273

AuI (s) = $Au^+ + I^-$

B = KI; *see* p. 273

$MnC_2O_4.2H_2O$(s), Oxalate = $Mn^{++} + C_2O_4^{--} + 2H_2O$(l)

B = H_2SO_4; T = 298.1°K (593)

m_B	S_A	$\log (1/m_\pm)$	$\mu^{\frac{1}{2}}$
0.0125	0.0128	1.8928	0.2978
.025	.0195	1.7099	.3912
.050	.0317	1.4989	.5261
.124	.0619	1.2083	.7872
.245	.1048	0.9796	1.074
.478	.1815	.7411	1.470
.696	.2482	.6052	1.726
.884	.3080	.5114	1.971
.989	.3376	.4716	2.078
1.079	.3572	.4470	2.160
B = $H_2C_2O_4$, Oxalic acid; T = 298.1°K (593)			
0.0125	0.00530	2.0126	0.2423
.025	.0065	1.8443	.3178
.05	.00755	1.6810	.4245
.125	.00976	1.4405	.6426
.25	.0119	1.2524	.8931
.49	.0145	1.0679	1.236
B = $(NH_4)_2C_2O_4$, Oxalate; T = 298.1°K (593)			
0.005	0.00237	2.3788	0.1565
.025	.00335	2.0089	.2973
.05	.00562	1.7525	.4153
.125	.0125	1.3823	.6519

and Streicher, *25*, **46**: 1577; 13. (1544) Wöhler and Streicher, *25*, **46**: 1591; 13. (1544.5) Wörmann, *8*, **18**: 775; 05. (1545) Wohl, *7*, **110**: 166; 24. (1546) Wohl, *9*, **30**: 36; 24. (1547) Wohl, *9*, **30**: 49; 24. (1548) Wolff, *9*, **20**: 19; 14. (1549) Wolffenstein, *25*, **27**: 3307; 94.
(1550) Wood, *4*, **93**: 411; 08. (1551) Wood, *4*, **97**: 878; 10. (1552) Worthing, *2*, **10**: 377; 17. (1553) Wourtzel, *34*, **169**: 1397; 19. (1554) Wroblewski, *34*, **94**: 212; 82. (1555) Wüst and Durrer, *414*, No. **241**; 21. (1556) Wüst, Meuthen and Durrer, *243*, **39**: 294; 19. *414*, No. **204**; 18. (1557) Wuite, *7*, **86**: 349; 14. (1558) Wuth, *25*, **35**: 2415; 02. (1559) Yoshida, *41*, **48**: 435; 27.
(1560) Zavriev, *42*, **7**: 31; 09. (1561) von Zawidzki, *25*, **36**: 1427; 03. (1562) von Zawidzki, *25*, **37**: 153; 14. (1563) von Zawidzki, *25*, **37**: 2289; 14.

OPTICAL ROTATORY POWER OF SOLID CRYSTALS

W. T. ASTBURY

Optically active crystals exist in two enantiomorphous forms having equal and opposite rotatory powers for light of a given wave-length. No isotropic substances (cubic crystals) exhibit optical rotation when in solution, but some do when in crystal form. Rotatory power = θ/l where θ is the angle through which the plane of polarization is rotated while plane polarized light is passing a distance l through the crystal in the direction of an optic axis. In some cases the variation of θ/l with the wave-length (λ) can be represented by an empirical Drude equation $\theta/l = k/(\lambda^2 - \lambda_0^2)$. Temperature is stated whenever it is given in the published paper, in other cases it is presumably room temperature. $t[T]$ = centigrade (°C) [absolute (°K)] temperature. Iso = isotropic (cubic crystal), Uni = uniaxial, Bi = biaxial, *d*- [*l*-] = dextro- [levo-] rotatory. "*d*-solutions → *l*-crystals" means that levorotatory crystals form from a solution which is dextrorotatory. Yes [No] means that solutions of the substance are [are not] active. A = accuracy; example: For HIO_3, $\lambda = 0.436$, $\theta/l = (74.5 \pm 0.7)$ degrees per mm.

𝔅-TABLE, STANDARD ARRANGEMENT

Unit of θ/l and of A = 1° per mm; of $\lambda = 1\mu = 10^4$ Å $= 10^{-4}$ cm

HIO_3 Iodic acid (12), Bi, No, dimorphous, both forms are orthorhombic bisphenoidal; prism angle of specimen = 86°23′

λ	θ/l	A
0.436	74.5	0.7
0.546	58.7	0.6
0.579	50.5	0.5

$N_2H_4.H_2SO_4$, Hydrazine sulfate (12), Bi, No

0.436	4.00	0.08
0.546	3.05	0.06
0.579	2.80	0.06

C-Compounds, *v.* p. 354

SiO_2, *v.* Vol. VI, p. 342

$PbS_2O_6.4H_2O$, Lead dithionate (18, 19), Uni, No, 20°C

0.5461	6.57	0.03
0.5893	5.46	0.03

If $0.4047 < \lambda < 0.7188$, $k = 1.601$, $\lambda_0^2 = 0.0541$, A = 1% of k

$Pb(CHO_2)_2$, Lead formate (12), Bi, No

0.436	39.4	2.0
0.546	18.0	0.9
0.579	15.6	0.8

$ZnSO_4.7H_2O$, Zinc sulfate (12), Bi, No

λ	θ/l	A
0.436	4.05	0.08
0.546	2.72	0.05
0.579	2.41	0.04

$Zn(C_4H_5O_5)_2.2H_2O$, Zinc malate (25), Uni, Yes, *l*-crystals→*l*-solutions

0.5893	3.0	0.2

HgS, Cinnabar* (17, 19), Uni, No, 20°C

0.5893	560	10
0.6022	480	8
0.7188	140	5

If $0.6103 < \lambda < 0.6870$, $k = 33.65$, $\lambda_0^2 = 0.2915$, A = 1% of k

* For $\lambda = 0.6438$, $(\theta/l)_T = 237.5 \times (1.00421 - 0.00056T + 0.00000355 T^2)$, $A = 0.5$ %, $87°K < T < 277°K$; and $(\theta/l)_t = 264(1 + 0.001t)$, $A = 1$ %, $4°C < t < 22°C$. For $\lambda = 0.6708$, $t = -184.5°C$, $\theta/l = 190 \pm 1$; for $\lambda = 0.5893$, $t = -187.4°C$, $\theta/l = 142 \pm 1$. *See* (17, 19).

$NiSO_4.7H_2O$, Nickel sulfate (12), Bi, No

λ	θ/l	A
0.546	6.30	0.31
0.579	6.10	0.30

$(MoO_4)_2C_4H_6O_5(NH_4)_2.2H_2O$, Ammonium molybdomalate (12), Bi, Yes, *d*-solutions → *l*-crystals

0.436	72.87	0.73
0.546	37.2	0.4
0.579	32.3	0.3
0.5893	30.8	0.3

$MgSO_4.7H_2O$, Magnesium sulfate (12), Bi, No

0.436	3.18	0.03
0.546	2.30	0.02
0.579	1.98	0.02

$MgCrO_4.7H_2O$, Magnesium chromate (12), Bi, No

0.436	8.13	0.08
0.546	6.74	0.07
0.579	5.59	0.06

$CaS_2O_6.4H_2O$, Calcium dithionate (19), Uni, No, 20°C

0.5461	2.74	0.05
0.5893	2.10	0.04

If $0.4047 < \lambda < 0.7188$, $k = 0.702$, $\lambda_0^2 = 0.0133$, A = 2% of k

$SrS_2O_6.4H_2O$, Strontium dithionate (19), Uni, No, 20°C

0.5461	3.27	0.03
0.5893	2.78	0.03

If $0.4047 < \lambda < 0.6868$, $k = 0.894$, $\lambda_0^2 = 0.025$, A = 1% of k

$Sr(CHO_2)_2.2H_2O$, Strontium formate (12), Bi, No

0.436	2.0	0.2
0.546	1.0	0.1
0.579	0.75	0.08

$Ba(MoO_4)_2C_4H_6O_5.2H_2O$, Barium molybdomalate (12), Bi, Yes

0.436	78.3	0.8
0.546	41.5	0.4
0.579	33.96	0.34
0.5893	31.68	0.32

$NaClO_3$, Sodium chlorate* (8, 21, 26), Iso, No, 20°C

λ	θ/l	A
0.5461	3.69	0.02
0.5893	3.16	0.01

If $0.3184 < \lambda < 0.7188$, $k = 1.078$, $\lambda_0^2 = 0.0062$, A = 0.5% of k

* $(\theta/l)_t = (\theta/l)_0 \{1 + \beta t(10)^{-5}\}$; Guye (8) found $\beta = 59 \pm 1$ if $0°C < t < 31°C$ and $0.3821 < \lambda < 0.5893$; Sohncke (21) found $\beta = 61 \pm 6$ if $16°C < t < 148°C$ and $0.4862 < \lambda < 0.5893$.

$NaBrO_3$, Sodium bromate (19, 22), Iso, No, 20°C

0.4047	7.2	0.1
0.5461	2.62	0.02
0.5893	2.13	0.02
0.7188	1.39	0.04

If $0.4102 < \lambda < 0.6867$, $k = 0.541$, $\lambda_0^2 = 0.092$, A = 1% of k

$NaIO_4.3H_2O$, Sodium periodate (7), Uni, No

0.4308	47.1	0.7
0.4862	34.2	0.2
0.5270	28.5	0.4
0.5893	23.3	0.1
0.6563	19.4	0.5

$NaH_2PO_4.2H_2O$, Sodium dihydrogen phosphate (6), Bi, No

0.5893	4.5	0.4

$Na_3SbS_4.9H_2O$, Sodium sulfantimoniate (16), Iso, No

0.556	2.7	0.3

$NaNH_4C_4H_4O_6.4H_2O$, Sodium ammonium tartrate (6), Bi, Yes, *d*-solutions → *l*-crystals

0.5893	1.55	0.15

$NaUO_2(C_2H_3O_2)_3$, Sodium uranyl acetate (22), Iso, No

0.5893	1.48	0.05

$K_2S_2O_6$, Potassium dithionate (18, 19), Uni, No, 20°C

0.5461	9.67	0.05
0.5893	8.20	0.04

If $0.4047 < \lambda < 0.7188$, $k = 2.664$, $\lambda_0 = 0.0225$, A = 1% of k

$K_3Ir(C_2O_4)_3.H_2O$, Potassium iridium trioxalate (15), Uni, Yes

0.579	12.0	.0.6

$K_3Rh(C_2O_4)_3 \cdot H_2O$, Potassium rhodium trioxalate (14), Uni, Yes, solution has similar dispersion of rotation, but inversion is at λ = 0.597 instead of 0.519

λ	θ/l	A
0.490	+5.1	0.1
0.500	+2.8	0.06
0.520	−1.0	0.02
0.540	−2.6	0.05
0.560	−4.8	0.1
0.580	−6.4	0.1
0.600	−7.4	0.1
0.620	−8.4	0.2
0.640	−8.9	0.2
0.660	−9.1	0.2
0.680	−8.8	0.2
0.700	−8.4	0.2

$K_4Mo_{12}SiO_{40} \cdot 18H_2O$, Potassium silicomolybdate (4), Uni, No

0.5893	17.2	0.3

$K_4W_{12}SiO_{40} \cdot 18H_2O$, Potassium silicotungstate (30), Uni, No

λ	θ/l	A
0.5893	14.4	0.2

$LiKSO_4$, Lithium potassium sulfate (23), Uni, No

0.5893	3.5	0.2

$K_2SO_4 \cdot Li_2CrO_4$, Potassium lithium sulfochromate (23), Uni, No

0.5893	1.9	0.2

$KNaC_4H_4O_6 \cdot 4H_2O$, Rochelle salt (6), Bi, Yes, *d*-solutions → *d*-crystals

0.5893	1.35	0.15

$Rb_2C_4H_4O_6$, Rubidium tartrate (24, 29), Uni, Yes, *d*-solutions → *l*-crystals

0.5893	10.4	0.2

$Cs_2C_4H_4O_6$, Cesium tartrate (24), Uni, Yes, *d*-solutions → *l*-crystals

0.5893	17	3

𝕮-TABLE, STANDARD ARRANGEMENT

v. Vol. III, p. viii

$(COONH_4)_2 \cdot H_2O$, Ammonium oxalate (12), Bi, No

λ	θ/l	A
0.436	20.0	0.4
0.546	13.7	0.3
0.579	12.0	0.2

$C_2H_4(NH_2)_2 \cdot H_2SO_4$, Ethylenediamine sulfate (11), Uni, No

0.5893	15.5	0.3

$(CH_5N_3)_2 \cdot H_2CO_3$, Guanidine carbonate (2), Uni, No

0.5351	17.1	0.2
0.5893	14.6	0.3
0.6708	12.6	0.1

$C_4H_4O_6$, Tartaric acid (13), Bi, Yes, *d*-solutions (aqueous) → *l*-crystals

0.436	24.0	0.2
0.546	13.0	0.1
0.589	10.7	0.1
0.650	9.1	0.1

If $0.480 < \lambda < 0.600$, $k = 2.80$, $\lambda_0^2 = 0.0839$, $A = 1\%$ of k

$C_4H_4O_6(NH_4)_2$, Ammonium tartrate (12), Bi, Yes

λ	θ/l	A
0.436	16.0	0.3
0.546	14.0	0.3
0.579	8.9	0.2
0.5893	8.8	0.2

$C_4H_4O_6(SbO)NH_4 \cdot H_2O$, Ammonium antimonyl tartrate (27), Bi, Yes

0.491	24.9	0.6
0.536	18.5	0.4
0.570	16.8	0.4
0.620	13.9	0.3

$C_4H_8N_2O_3 \cdot H_2O$, Asparagine (12), Bi, Yes, *l*-solutions → *l*-crystals

0.436	9.7	0.2
0.546	7.2	0.1
0.579	6.2	0.1
0.5893	5.9	0.1

$C_6H_{12}O_5$, Quercitol (10), Bi, Yes

"Weak" axis

0.5461	4.5	0.2
0.5893	3.7	0.2

If $0.4862 < \lambda < 0.6868$, $k = 1.04$, $\lambda_0^2 = 0.067$, $A = 4\%$ of k

"Strong" axis

0.5270	6.4	0.4
0.5550	5.9	0.3
0.5893	4.6	0.3
0.6563	3.9	0.3

$C_7H_{14}O_6$, *d*-Methyl-α-glucoside (6), Bi, Yes, *d*-solution → *d*-crystals

λ	θ/l	A
0.5893	4.4	0.3

$C_{10}H_{16}O$, Camphor (common, Laurus) (20), Uni, Yes

0.4308	1.82	0.02
0.5893	0.65	0.01
0.6868	0.46	0.01

$C_{12}H_{20}O$, Matico camphor (9, 24), Uni, Yes

0.5351	2.47	0.05
0.5893	1.98	0.06
0.6708	1.68	0.05

$C_{14}H_{10}O_2$, Benzil (5), Uni, No

0.5893	25.0	0.3

$C_{15}H_{26}O$, Patchouli camphor (24), Uni, Yes. All crystals seen were levo

0.5893	1.33	0.02

$C_{17}H_{20}O$, Benzylidenecamphor (12), Bi, Yes, *d*-solutions → *d*-crystals

0.436	20.2	0.4
0.546	10.0	0.2
0.579	8.6	0.2
0.5893	8.18	0.16

$C_{18}H_{22}O_2$, Anisalcamphor (12), Bi, Yes, *d*-solutions → *l*-crystals

λ	θ/l	A
0.436	82.0	0.8
0.546	44.0	0.4
0.579	38.0	0.4
0.5893	36.2	0.4

$C_{20}H_{23}NO_4$, *d*-Corydine (1), Uni, Yes

0.5351	14.6	0.2
0.5893	13.2	0.2
0.6708	10.5	0.2

$C_{24}H_{18}O_6$, Diacetylphenolphthalein (3), Uni, No

0.5351	23.8	0.2
0.5893	19.8	0.1
0.6708	17.1	0.2

$(C_{19}H_{24}N_2O)_2 \cdot H_2SO_4 \cdot 11H_2O$, Hydrocinchonine sulfate (31), Uni, Yes, all crystals are dextro

0.5893	12.8	0.1

$(C_{21}H_{22}N_2O_2)_2 \cdot H_2SO_4 \cdot 6H_2O$, Strychnine sulfate (22, 31), Uni, Yes, *l*-crystals→ *l*-solutions

0.5893	13.25	(?)
0.5893	10.9	(?)

$(C_{19}H_{24}N_2O)_2(SbO)_2C_4H_4O_6 \cdot 5H_2O$, Cinchonine antimonyl tartrate (25), Uni, Yes, *d*-solution → *d*-crystals

0.5893	9.8	0.1

$(C_{19}H_{22}N_2O)_2 \cdot C_4H_6O_4 \cdot 6H_2O$, Apocinchonine succinate (28), Uni, Yes

0.5893	3.5	0.5

LITERATURE

(For a key to the periodicals see end of volume)

(1) Blass, *94*, **48**: 20; 11. (2) Bodewig, *8*, **157**: 122; 76. (3) Bodewig, *94*, **1**: 72; 77. (4) Copaux, *6*, **7**: 118; 06. (5) Des Cloizeaux, *34*, **68**: 308; 69. **70**: 1209; 70. (6) Dufet, *51*, **3**: 757; 04. (7) Groth, *8*, **137**: 433; 69. (8) Guye, *149*, **22**: 130; 89. (9) Hintze, *8*, **157**: 127; 76.

(10) Karandyeev, *134*, **9**: 1285; 15. (11) von Lang, *75*, **65 II**: 30; 72. (12) Longchambon, *191*, **45**: 161; 22. *34*, **172**: 1187; 21. **173**: 89; 21. **175**: 174; 22. *Thesis*, Paris, 1923. (13) Longchambon, *34*, **178**: 951; 24. (14) Longchambon, *34*, **178**: 1828; 24. (15) Longchambon, Univ. Nancy, *0*. (16) Marbach, *8*, **99**: 451; 56. (17) Molby, *2*, **31**: 291; 10. (18) Pape, *8*, **139**: 224; 70. (19) Rose, *190B*, **29**: 53; 10.

(20) von Seherr-Thoss, *in* Traube, *94*, **23**: 577; 94. (21) Sohncke, *8*, **3**: 516; 78. (22) Traube, *B3*, 2nd ed., 1894; p. 459, 460. (23) Traube, *190*, **1**: 171; 94. (24) Traube, *76*, **1895**: 195. (25) Traube, *190B*, **11**: 623; 97. (26) Voigt, *63*, **9**: 585; 08. (27) Wallerant, *34*, **158**: 91; 14. (28) Wyrouboff, *6*, **1**: 5; 94. (29) Wyrouboff, *51*, **3**: 451; 94.

(30) Wyrouboff, *191*, **19**: 219; 96. (31) Wyrouboff, *191*, **24**: 76; 01.

OPTICAL ROTATORY POWER OF LIQUIDS AND SOLUTIONS[1]

THOMAS MARTIN LOWRY

ARRANGEMENT

Arrangement is by classes defined as follows:

Carbon Compounds*

I. None of the asymmetric carbon atoms forms part of a ring.

II. At least one asymmetric carbon atom forms part of a ring.

III. The compound contains no asymmetric carbon atom or contains at least one asymmetric or dissymmetric atom other than carbon.

IV. Substances of unknown, doubtful or complex structure.

Classes I to IV are subdivided according to the number and nature of the asymmetric atoms as follows:

A_n The molecule contains *n* asymmetric atoms which are attached each to only one other carbon atom.

B_n The molecule contains *n* asymmetric atoms which are attached each to two other carbon atoms.

C_n The molecule contains *n* asymmetric atoms which are attached each to three other carbon atoms.

D_n The molecule contains *n* asymmetric atoms which are attached each to four other carbon atoms.

For substances which fall within two or more of the above subdivisions the higher (in the order D, C, B, A) division receives preference in deciding the arrangement. Within a subdivision the arrangement is in accordance with the value of *n* in the order 1, 2, 3, etc.

SYMBOLS AND ABBREVIATIONS

t	Temperature in degrees centigrade (°C).
λ	Wave length of light expressed in Ångstrom units, *i.e.*, in tenths of a millimicron ($\frac{1}{10}\mu\mu$) unless otherwise indicated.
D	A wave length of 5893 Å.
α_λ^t	Observed rotation at the given values for t.
$[\alpha]_\lambda^t$	Specific rotation at the given values for t.
$[M]_\lambda^t$	Molecular rotation at the given values for $t (= M \times [\alpha]_\lambda^t/100)$.
C	Concentration in grams per 100 cm³ of solution.
%	Concentration in grams per 100 grams of solution (= Wt. %). (Values in italics.)
d	d_4^t = density at the given value for t referred to water at 4°C, unless otherwise indicated.
2% NaOH (etc.)	2% of solution of NaOH in water.
2% NaOH MeOH	2% of solution of NaOH in methyl alcohol.
M	Moles.
N NaOH	Normal aqueous solution of NaOH (= 1 equivalent/liter).

ARRANGEMENT

Arrangement par classes, définies comme suit:

Composés du carbone

I. Aucun des atomes de carbone asymétriques ne fait partie d'une chaine cyclique.

II. Un atome de carbone asymétrique au moins fait partie d'une chaine cyclique.

III. Le composé ne contient aucun atome de carbone ou contient au moins un atome asymétrique ou dyssymétrique autre que carbone.

IV. Substances de structure inconnue, douteuse ou complexe.

Les classes I–IV sont subdivisées comme suit, en accord avec le nombre et la nature des atomes asymétriques:

A_n La molécule contient *n* atomes asymétriques, chacun de ceux-ci étant seulement relié à un autre atome de carbone.

B_n La molécule contient *n* atomes asymétriques, chacun de ceux-ci étant relié à deux autres atomes de carbone.

C_n La molécule contient *n* atomes asymétriques, chacun de ceux-ci étant relié à trois autres atomes de carbone.

D_n La molécule contient *n* atomes asymétriques, chacun de ceux-ci étant relié à quatre autres atomes de carbone.

Lorsqu'une substance est comprise dans deux ou plusieurs subdivisions ci-dessus, on donnera la préférence à la division supérieure (dans l'ordre D, C, B, A) pour décider de l'arrangement. Dans une subdivision, l'arrangement est réalisé en accord avec les valeurs de *n*, dans l'ordre 1, 2, 3, etc.

SYMBOLES ET ABRÉVIATIONS

t	Température en degrés centigrades (°C).
λ	Longueur d'onde de la lumière exprimée en unités Ångstrom, *i.e.*, en dixièmes de millimicron ($\frac{1}{10}\mu\mu$) à moins d'une autre indication.
D	Une longueur d'onde de 5893 Å.
α_λ^t	Rotation observée pour les valeurs données de t.
$[\alpha]_\lambda^t$	Rotation spécifique pour les valeurs données de t.
$[M]_\lambda^t$	Rotation moléculaire pour les valeurs données de $t (= M \times [\alpha]_\lambda^t/100)$.
C	Concentration en grammes pour 100 cm³ de solution.
%	Concentration en grammes pour 100 grammes de solution (= Pds. %). (Valeurs en italique.)
d	d_4^t = densité pour la valeur donnée de t par rapport à l'eau à 4°C, à moins d'une autre indication.
2% NaOH (etc.)	Solution de NaOH dans l'eau, à 2%.
2% NaOH MeOH	Solution à 2% de NaOH dans l'alcool méthylique.
M	Molécule-gramme ou mole.
N NaOH	Solution aqueuse normale de NaOH (= 1 équivalent/litre).

Symbols for Solvents

A ≡ The acid radical under which it is used.
Ac ≡ (CH_3CO) Acetyl.
Bu ≡ (C_3H_7) Butyl.
En ≡ ($C_2H_8N_2$) α, β-Ethylenediamine.
Et ≡ (C_2H_5) Ethyl.
Me ≡ (CH_3) Methyl.
Ph ≡ (C_6H_5) Phenyl.
Pn ≡ ($C_3H_{10}N_2$) α, β-Propylenediamine.
Py ≡ (C_5H_5N) Pyridine.
Tr ≡ ($C_3H_{10}N_2$) α, γ-Diaminopropane.

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[1] This section includes data and bibliography to January 1, 1924.

* Sugars and their derivatives (*see also* Vol. II, p. 334, 353) are classed as open chain compounds. In general, derivatives are listed under the parent compound, even when they contain additional asymmetric atoms.

ANORDNUNG

Die Anordnung erfolgt nach Klassen, die folgendermassen bestimmt sind:

Kohlenstoffverbindungen

I. Keines der asymmetrische Kohlenstoffatome bildet einen Teil eines Ringes.

II. Wenigstens ein asymmetrisches Kohlenstoffatom bildet einen Teil eines Ringes.

III. Die Verbindung enthält kein asymmetrisches Kohlenstoffatom oder enthält wenigstens ein asymmetrisches oder dissymmetrisches Atom von anderer Natur als Kohlenstoff.

IV. Stoffe unbekannter, zweifelhaftiger oder komplexer Struktur.

Die Klassen I–IV werden weiter geteilt nach der Zahl und Natur der asymmetrischen Atome wie folgt:

A_n Das Molekül enthält *n* asymmetrische Atome, von denen jedes an nur ein anderes Kohlenstoffatom gebunden ist.
B_n Das Molekül enthält *n* asymmetrische Atome, von denen jedes an zwei andere Kohlenstoffatome gebunden ist.
C_n Das Molekül enthält *n* asymmetrische Atome, von denen jedes an drei andere Kohlenstoffatome gebunden ist.
D_n Das Molekül enthält *n* asymmetrische Atome, von denen jedes an vier andere Kohlenstoffatome gebunden ist.

Für Stoffe die in zwei oder mehr der obigen Unterabteilungen fallen, erhält die höhere Abteilung (in der Reihenfolge D, C, B, A) bei der Entscheidung der Anordnung den Vorzug. Innerhalb einer Unterabteilung erfolgt die Anordnung entsprechend dem Werte von *n* in der Reihenfolge 1, 2, 3, usw.

ZEICHEN UND ABKÜRZUNGEN

t	Temperatur in Celsiusgraden (°C).
λ	Lichtwellenlänge ausgedrückt in Ångstrom Einheiten, d.h., in Zehnteln eines Millimikrons ($^1\!/_{10}\mu\mu$), wenn nicht anders angegeben.
D	Wellenlänge 5893 Å.
α_λ^t	Beobachtete Drehung bei den gegebenen Werten für *t*.
$[\alpha]_\lambda^t$	Spezifische Drehung bei den gegebenen Werten für *t*.
$[M]_\lambda^t$	Molekulare Drehung bei den gegebenen Werten für *t*($= M \times [\alpha]_\lambda^t/100$).
C	Konzentration in Gramm pro 100 cm^3 Lösung.
%	Konzentration in Gramm pro 100 Gramm Lösung (= Gew. %). (Werte in Kursivschrift.)
d	d_4^t = Dichte bei dem gegebenen Wert für *t* (bezogen auf Wasser bei 4°C, wenn nicht anders angegeben).
2% NaOH (usw.)	2%-ige Lösung von NaOH in Wasser.
2% NaOH MeOH	2%-ige Lösung von NaOH in Methylalkohol.
M	Mole
N NaOH	Normale wässerige Lösung von NaOH (= 1 Äquivalent/Liter).

DISPOSIZIONE

La disposizione è fatta secondo classi definite come segue:

Composti del carbonio

I. Nessuno degli atomi di carbonio asimmetrici fa parte di un anello.

II. Almeno un atomo di carbonio asimmetrico fa parte di un anello.

III. Il composto contiene nessuno atomo asimmetrico di carbonio o contiene almeno un atomo asimmetrico o dissimmetrico diverso dal carbonio.

IV. Sostanze di struttura sconosciuta, incerta o complessa.

Le classi I–IV sono suddivise secondo il numero e la natura degli atomi asimmetrici nella maniera seguente:

A_n La molecola contiene *n* atomi asimmetrici i quali sono attaccati ciascuno a un altro atomo di carbonio soltanto.
B_n La molecola contiene *n* atomi asimmetrici i quali sono attaccati ciascuno a due altri atomi di carbonio.
C_n La molecola contiene *n* atomi asimmetrici i quali sono attaccati ciascuno a tre altri atomi di carbonio.
D_n La molecola contiene *n* atomi asimmetrici che sono attaccati ciascuno a quattro atomi di carbonio.

Per le sostanze che rientrano in due o più delle suddivisioni indicate, la divisione più alta (nell'ordine D, C, B, A) ha la preferenza nel decidere la disposizione. Entro ciascuna suddivisione la disposizione è d'accordo con il valore di *n* nell'ordine 1, 2, 3, ecc.

SIMBOLI ED ABBREVIAZIONI

t	Temperatura in gradi centigradi (°C).
λ	Lunghezza d'onda della luce espressa in unità Ångstrom, *i.e.*, in decimi di millimicron ($^1\!/_{10}\mu\mu$) tranne che non sia altrimenti indicato.
D	Una lunghezza d'onda di 5893 Å.
α_λ^t	Rotazione osservata ai valori di *t* indicati.
$[\alpha]_\lambda^t$	Rotazione specifica ai valori di *t* indicati.
$[M]_\lambda^t$	Rotazione molecolare ai valori dati per *t* ($= M \times [\alpha]_\lambda^t/100$).
C	Concentrazione in grammi per 100 cm^3 di soluzione.
%	Concentrazione in grammi per 100 grammi di soluzione (= % in peso). (Valori scritti in caratteri italici.)
d	d_4^t = densità al valore di *t* indicato, riferita all'acqua a 4°C salvo che non sia indicato altrimenti.
2% NaOH (ecc.)	2% di soluzione di NaOH in acqua.
2% NaOH MeOH	2% di soluzione di NaOH in alcool metilico.
M	Moli.
N NaOH	Soluzione acquosa normale di NaOH (=1 equivalente/litro).

CONTENTS

Class I. Organic Substances, the Asymmetric Carbon Atoms of Which Do Not Form Part of a Ring

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* For further data on these compounds at various temperatures, with other wave lengths, and in various solvents, *see* the forthcoming article by Professor Lowry, Miscellaneous Publications, Bureau of Standards, No. 118, 1931.

CONTENTS.—(*Continued*)

Simple dicarboxylic acids.

Monohydroxydicarboxylic acids.

Monoaminomonocarboxylic acids.

Monoaminodicarboxylic acids.

IB$_2$. *The molecule contains two asymmetric carbon atoms which are attached each to two other carbon atoms.*

Alcohols and amines.

Carboxylic acids.

Dihydroxydicarboxylic acids.

Carbohydrates and related compounds.

Sugars containing 5 carbon atoms.

Pentahydric and hexahydric alcohols.

Sugars containing 6 carbon atoms.

Nitrogen derivatives of glucose.

Sugar acids containing 6 carbon atoms.

Sugars, etc., containing 7 carbon atoms.

Sugars, etc., containing 12 carbon atoms.

IC$_1$. *The molecule contains one asymmetric atom attached to three other carbon atoms.*

Alcohols and their derivatives.

Acids and derivatives.

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* For further data on these compounds at various temperatures, with other wave lengths, and in various solvents, *see* the forthcoming article by Professor Lowry, Miscellaneous Publications, Bureau of Standards, No. 118, 1931.

CONTENTS.—(*Continued*)

ID. The molecule contains one asymmetric atom attached to four other carbon atoms.

Class II. Organic Substances, at Least One Asymmetric Carbon Atom of Which Forms Part of a Ring

IIB. The molecule contains asymmetric atoms attached to two other carbon atoms.

IIC. The molecule contains asymmetric atoms attached each to three other carbon atoms.

IICB. The molecule contains two or more asymmetric atoms attached respectively to two and three other carbon atoms.

IID. The molecule contains an asymmetric atom forming part of a ring and attached to four other carbon atoms.

IIDB. The molecule contains two or more asymmetric atoms attached respectively to two and four other carbon atoms.

IIDC. The molecule contains two or more asymmetric atoms attached respectively to three and four other carbon atoms.

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* For further data on these compounds at various temperatures, with other wave lengths, and in various solvents, *see* the forthcoming article by Professor Lowry, Miscellaneous Publications, Bureau of Standards, No. 118, 1931.

CONTENTS.—(*Continued*)

Class III. Compounds Containing No Asymmetric Carbon Atom or Containing an Asymmetric or Dissymmetric Atom of Some Other Element*

Class IV. Substances of Unknown, Doubtful or Complex Structure

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* For further data on these compounds at various temperatures, with other wave lengths, and in various solvents, *see* the forthcoming article by Professor Lowry, Miscellaneous Publications, Bureau of Standards, No. 118, 1931.

Class I. ORGANIC SUBSTANCES, THE ASYMMETRIC CARBON ATOMS OF WHICH DO NOT FORM PART OF A RING

IB_1. The Molecule Contains One Asymmetric Atom Attached to Two Other Carbon Atoms

SIMPLE HALIDES

Formula	Name	d_4^{20}	t, °C	$[\alpha]_D$	Lit.
C_4H_9I	*l*-β-Iodobutane	1.5970	17	−31.98	(1619)
$C_5H_{11}I$	*l*-β-Iodopentane	1.5067	17	−37.15	(1619)
$C_6H_{13}I$	*l*-β-Iodohexane	1.4354	17	−38.35	(1619)
C_8H_9Cl	*l*-α-Chloroethylbenzene	1.0642	17	−5.80	(1619)
$C_8H_{17}Br$	*d*-β-Bromooctane	1.0895	17	+27.53	(1619)
	l-β-Bromooctane		4	−31.07	(1619)
		$1.0927_4^{13.8}$	13.1	−30.33	
		1.0914_4^{17}	17	−27.47	
		1.0805_4^{26}	30	−29.05	
		1.0688_4^{37}	37	−28.62	
		1.0532_4^{53}	50	−27.81	
			92	−25.18	
$C_8H_{17}Cl$	*l*-β-Chlorooctane	0.8628	17	−20.44	(1619)
	d-β-Chlorooctane	0.8658	17	+20.40	(1619)
$C_8H_{17}I$	*l*-β-Iodooctane	1.3299	17	−40.56	(1619)
	d-β-Iodooctane	1.3314	17	+39.82	(1619)
$C_9H_{11}Cl$	*l*-α-Chloropropylbenzene	1.0430	17	−3.87	(1619)
	d-α-Chloropropylbenzene	1.0429	17	+3.79	(1619)
$C_9H_{19}Br$	*l*-γ-Bromononane	1.0897	17	−13.39	(1619)
	d-γ-Bromononane	1.0900	17	+12.90	(1619)
$C_9H_{19}Cl$	*l*-γ-Chlorononane	0.8540	17	−8.03	(1619)
	d-γ-Chlorononane	0.8588	17	+7.71	(1619)
$C_9H_{19}I$	*l*-γ-Iodononane	1.2873	17	−17.50	(1619)
	d-γ-Iodononane	1.2940	17	+17.65	(1619)

ALCOHOLS

MONOHYDROXY ALCOHOLS, THIOLS AND THEIR ESTERS

Methyl carbinols, RCH_3CHOH (1619); *cf.* (812)

Formula	R	$[\alpha]_D^{20}$
$C_4H_{10}O$	Ethyl	13.87
$C_5H_{12}O$	*n*-Propyl	13.70
$C_6H_{14}O$	*n*-Butyl	11.57
$C_7H_{16}O$	*n*-Amyl	10.32
$C_8H_{18}O$	*n*-Hexyl	9.76
$C_9H_{20}O$	*n*-Heptyl	8.99
$C_{10}H_{22}O$	*n*-Octyl	8.68
$C_{11}H_{24}O$	*n*-Nonyl	8.13
$C_{12}H_{26}O$	*n*-Decyl	7.78
$C_{13}H_{28}O$	*n*-Undecyl	7.22

Ethyl carbinols, RC_2H_5CHOH (1622); *cf.* (1305)

$C_4H_{10}O$	Methyl	13.87
$C_6H_{14}O$	Propyl	1.97
$C_7H_{16}O$	Butyl	8.13
$C_8H_{18}O$	Amyl	8.22
$C_9H_{20}O$	Hexyl	7.38
$C_{10}H_{22}O$	Heptyl	6.68
$C_{11}H_{24}O$	Octyl	6.25
$C_{12}H_{26}O$	Nonyl	5.97
$C_{13}H_{28}O$	Decyl	6.23
$C_{14}H_{30}O$	Undecyl	5.87
$C_{15}H_{32}O$	Dodecyl	5.53
$C_{16}H_{34}O$	Tridecyl	5.11
$C_{18}H_{38}O$	Pentadecyl	4.77

Isopropyl carbinols, RC_3H_7CHOH (1305, 1620)

Formula	R	$[\alpha]_D^{20}$
$C_5H_{12}O$	Methyl	4.85
$C_6H_{14}O$	Ethyl	15.06
$C_7H_{16}O$	*n*-Propyl	21.25
$C_8H_{18}O$	*n*-Butyl	25.64
$C_9H_{20}O$	*n*-Amyl	22.84
$C_{10}H_{22}O$	*n*-Hexyl	21.46
$C_{12}H_{26}O$	*n*-Octyl	18.55
$C_{14}H_{30}O$	*n*-Decyl	16.15

Other carbinols (1624); *cf.* (1305)

Formula	Name	$[\alpha]_D^{20}$
$C_6H_{14}O$	*d*-Methyl *tert.*-butyl	7.71
$C_8H_{10}O$	*d*-Methyl phenyl	41.77
$C_9H_{12}O$	*l*-Ethyl phenyl	−25.86
$C_9H_{12}O$	*d*-Methyl benzyl	26.55
$C_{10}H_{14}O$	*l*-Methyl β-phenylethyl	−14.74
$C_{12}H_{12}O$	*l*-Methyl α-naphthyl	−14.53
$C_{17}H_{22}O$	*d*-*n*-Hexyl α-naphthyl	− 1.51

Ethers of *d*-Benzylmethyl carbinol, $C_7H_7(CH_3)CHOR$ (1617)

Formula	R	$[\alpha]_D^{20}$
$C_{14}H_{22}O$	*n*-Amyl	22.75
$C_{15}H_{24}O$	*n*-Hexyl	22.83
$C_{18}H_{30}O$	*n*-Nonyl	20.78

Methyl alkyl carbinyl esters (1623, 1625)

d-β-Butyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_5H_{10}O_2$	Formate	18.74
$C_6H_{12}O_2$	Acetate	25.43
$C_7H_{14}O_2$	Propionate	23.85
$C_8H_{16}O_2$	*n*-Butyrate	21.97
$C_9H_{18}O_2$	*n*-Valerate	20.72
$C_{10}H_{20}O_2$	*n*-Hexoate	18.66
$C_{11}H_{22}O_2$	*n*-Heptoate	17.37

d-β-Butyl derivatives.—(Continued)

Formula	Ester	$[\alpha]_D^{20}$
$C_{12}H_{24}O_2$	*n*-Octoate	16.14
$C_{13}H_{26}O_2$	*n*-Nonoate	15.03
$C_{15}H_{30}O_2$	*n*-Undecoate	13.42
$C_{16}H_{32}O_2$	*n*-Dodecoate	12.69
$C_{18}H_{36}O_2$	*n*-Myristate	11.34
$C_{20}H_{40}O_2$	Palmitate	10.25
$C_{22}H_{44}O_2$	Stearate	9.39

d-β-Amyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_7H_{14}O_2$	Acetate	17.16
$C_8H_{16}O_2$	Propionate	16.43
$C_9H_{18}O_2$	*n*-Butyrate	15.77
$C_{10}H_{20}O_2$	*n*-Valerate	16.01
$C_{17}H_{34}O_2$	*n*-Dodecoate	10.44

d-β-Hexyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_8H_{16}O_2$	Acetate	10.13
$C_9H_{18}O_2$	Propionate	9.76
$C_{10}H_{20}O_2$	*n*-Butyrate	10.83
$C_{11}H_{22}O_2$	*n*-Valerate	11.16
$C_{12}H_{24}O_2$	*n*-Hexoate	10.84
$C_{13}H_{26}O_2$	*n*-Heptoate	10.36
$C_{15}H_{30}O_2$	*n*-Nonoate	9.38
$C_{17}H_{34}O_2$	*n*-Undecoate	8.35
$C_{18}H_{36}O_2$	*n*-Dodecoate	7.99
$C_{20}H_{40}O_2$	*n*-Myristate	7.40
$C_{22}H_{44}O_2$	Palmitate	6.87
$C_{24}H_{48}O_2$	Stearate	6.16

d-β-Heptyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_9H_{18}O_2$	Acetate	8.23
$C_{10}H_{20}O_2$	Propionate	8.37
$C_{11}H_{22}O_2$	*n*-Butyrate	10.16
$C_{12}H_{24}O_2$	*n*-Valerate	10.26
$C_{13}H_{26}O_2$	*n*-Hexoate	9.97
$C_{14}H_{28}O_2$	*n*-Heptoate	9.53
$C_{15}H_{30}O_2$	*n*-Octoate	9.07
$C_{16}H_{32}O_2$	*n*-Nonoate	8.70
$C_{18}H_{36}O_2$	*n*-Undecoate	7.96
$C_{19}H_{38}O_2$	*n*-Dodecoate	7.58
$C_{21}H_{42}O_2$	*n*-Myristate	6.91
$C_{23}H_{46}O_2$	Palmitate	6.53
$C_{25}H_{50}O_2$	Stearate	6.06

d-β-Octyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_9H_{18}O_2$	Formate	−4.16
$C_{10}H_{20}O_2$	Acetate	6.84
$C_{11}H_{22}O_2$	Propionate	6.98
$C_{12}H_{24}O_2$	*n*-Butyrate	8.95
$C_{13}H_{26}O_2$	*n*-Valerate	9.16
$C_{14}H_{28}O_2$	*n*-Hexoate	8.96
$C_{15}H_{30}O_2$	*n*-Heptoate	8.59
$C_{16}H_{32}O_2$	*n*-Octoate	8.25
$C_{17}H_{34}O_2$	*n*-Nonoate	7.96
$C_{19}H_{38}O_2$	*n*-Undecoate	7.35
$C_{20}H_{40}O_2$	*n*-Dodecoate	7.00
$C_{22}H_{44}O_2$	*n*-Myristate	6.59
$C_{24}H_{48}O_2$	Palmitate	6.14
$C_{26}H_{52}O_2$	Stearate	5.71

d-β-Nonyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_{11}H_{22}O_2$	Acetate	6.21
$C_{21}H_{42}O_2$	*n*-Dodecoate	6.71

d-β-Decyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_{12}H_{24}O_2$	Acetate	5.64
$C_{22}H_{44}O_2$	*n*-Dodecoate	6.41

d-β-Undecyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_{13}H_{26}O_2$	Acetate	5.27
$C_{14}H_{28}O_2$	Propionate	5.15
$C_{15}H_{30}O_2$	*n*-Butyrate	7.31
$C_{16}H_{32}O_2$	*n*-Valerate	7.46
$C_{17}H_{34}O_2$	*n*-Hexoate	7.37
$C_{18}H_{36}O_2$	*n*-Heptoate	7.17
$C_{20}H_{40}O_2$	*n*-Nonoate	6.81
$C_{22}H_{44}O_2$	*n*-Undecoate	6.30
$C_{23}H_{46}O_2$	*n*-Dodecoate	6.19
$C_{25}H_{50}O_2$	*n*-Myristate	5.72

d-β-Dodecyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_{24}H_{48}O_2$	*n*-Dodecoate	5.99

d-β-Tridecyl derivatives

Formula	Ester	$[\alpha]_D^{20}$
$C_{15}H_{30}O_2$	Acetate	4.63
$C_{25}H_{50}O_2$	*n*-Dodecoate	5.87

d-γ-Nonyl esters (**1051, 1625**)

Formula	Ester	$[\alpha]_D^{20}$
$C_{10}H_{20}O_2$	Formate	−11.28
$C_{11}H_{22}O_2$	Acetate	−5.21
$C_{12}H_{24}O_2$	Propionate	−5.87
$C_{13}H_{26}O_2$	*n*-Butyrate	−3.38
$C_{14}H_{28}O_2$	Valerate	−3.12
$C_{15}H_{30}O_2$	*n*-Hexoate	−2.66
$C_{16}H_{32}O_2$	*n*-Heptoate	−2.36
$C_{17}H_{34}O_2$	*n*-Octoate	−2.10
$C_{18}H_{36}O_2$	*n*-Nonoate	−1.94
$C_{19}H_{38}O_2$	*n*-Decoate	−1.90
$C_{20}H_{40}O_2$	*n*-Undecoate	−1.83
$C_{21}H_{42}O_2$	*n*-Dodecoate	−1.63
$C_{23}H_{46}O_2$	*n*-Myristate	−1.55
$C_{25}H_{50}O_2$	Palmitate	−1.49
$C_{27}H_{54}O_2$	Stearate	−1.49

Acetic acid esters, CH_3COOR (**1051**)

Formula	R	$[\alpha]_D^{20}$
$C_8H_{16}O_2$	*d*-γ-Hexyl	0.55
$C_9H_{18}O_2$	*d*-γ-Heptyl	−4.68
$C_{10}H_{20}O_2$	*d*-γ-Octyl	−4.30
$C_{12}H_{24}O_2$	*l*-γ-Decyl	4.48
$C_{13}H_{26}O_2$	*l*-γ-Undecyl	4.40
$C_{14}H_{28}O_2$	*l*-γ-Dodecyl	3.68
$C_{15}H_{30}O_2$	*l*-γ-Tridecyl	3.83
$C_{16}H_{32}O_2$	*l*-γ-Tetradecyl	3.69
$C_{17}H_{34}O_2$	*l*-γ-Pentadecyl	3.68
$C_{18}H_{36}O_2$	*l*-γ-Hexadecyl	3.19
$C_{20}H_{40}O_2$	*l*-γ-Octadecyl	2.98

Esters of methyl benzyl carbinol (**1052.5**)

Formula	Ester	$[\alpha]_D^{20}$
$C_{11}H_{14}O_2$	Acetate	6.41
$C_{12}H_{16}O_2$	Propionate	4.81
$C_{13}H_{18}O_2$	*n*-Butyrate	8.48
$C_{14}H_{20}O_2$	*n*-Valerate	10.76
$C_{15}H_{22}O_2$	*n*-Hexoate	10.46
$C_{16}H_{24}O_2$	*n*-Heptoate	10.69
$C_{17}H_{26}O_2$	*n*-Octoate	10.67
$C_{18}H_{28}O_2$	*n*-Nonoate	10.50
$C_{19}H_{30}O_2$	*n*-Decoate	10.13
$C_{20}H_{32}O_2$	*n*-Undecoate	9.92
$C_{21}H_{34}O_2$	*n*-Dodecoate	9.66
$C_{24}H_{38}O_2$	Myristate	9.22
$C_{26}H_{42}O_2$	Palmitate	8.44
$C_{28}H_{46}O_2$	Stearate	7.92

ALCOHOLS.—(*Continued*)

Esters of *d*-*α*-naphthyl-*n*-hexyl carbinol (1053)

Formula	Ester	$[\alpha]_D^{20}$
$C_{19}H_{24}O_2$	Acetate	23.85
$C_{20}H_{26}O_2$	Propionate	28.59
$C_{21}H_{28}O_2$	*n*-Butyrate	27.02
$C_{22}H_{30}O_2$	*n*-Valerate	22.23
$C_{23}H_{32}O_2$	*n*-Hexoate	21.12
$C_{24}H_{34}O_2$	*n*-Heptoate	19.63
$C_{25}H_{36}O_2$	*n*-Octoate	21.13
$C_{26}H_{38}O_2$	*n*-Nonoate	19.06
$C_{27}H_{40}O_2$	*n*-Decoate	17.13
$C_{28}H_{42}O_2$	*n*-Undecoate	16.44

Esters of benzoic acid and naphthoic acids with secondary alcohols

Benzoic acid esters (1056)

Formula	Ester	$[\alpha]_D^{20}$
$C_{11}H_{14}O_2$	*d*-*β*-Butyl	39.23
$C_{13}H_{18}O_2$	*d*-*β*-Hexyl	35.38
$C_{15}H_{22}O_2$	*d*-*β*-Octyl	33.27
$C_{16}H_{16}O_2$	*d*-Benzyl methyl carbinyl	65.07
$C_{16}H_{24}O_2$	*d*-*γ*-Nonyl	6.84
$C_{18}H_{28}O_2$	*d*-*β*-Undecyl	27.55

α-Naphthoic acid esters (1056)

Formula	Ester	$[\alpha]_D^{20}$
$C_{15}H_{16}O_2$	*d*-*β*-Butyl	28.40
$C_{17}H_{20}O_2$	*d*-*β*-Hexyl	5.87
$C_{18}H_{22}O_2$	*d*-*β*-Heptyl	3.99
$C_{19}H_{24}O_2$	*d*-*β*-Octyl	1.67
$C_{20}H_{18}O_2$	*d*-Benzyl methyl carbinyl	29.10
$C_{20}H_{26}O_2$	*d*-*γ*-Nonyl	−22.23
$C_{21}H_{28}O_2$	*d*-*β*-Decyl	1.41
$C_{22}H_{30}O_2$	*d*-*β*-Undecyl	1.63

β-Naphthoic acid esters (1056)

Formula	Ester	$[\alpha]_D^{20}$
$C_{15}H_{16}O_2$	*d*-*β*-Butyl	50.04
$C_{17}H_{20}O_2$	*d*-*β*-Hexyl	57.11
$C_{19}H_{24}O_2$	*d*-*β*-Octyl	56.25
$C_{20}H_{18}O_2$	*d*-Benzyl methyl carbinyl	122.83
$C_{20}H_{26}O_2$	*d*-*γ*-Nonyl	19.14
$C_{22}H_{30}O_2$	*d*-*β*-Undecyl	50.03

Formula	Name	Solvent	*d* or *C*	*t*, °C	$[\alpha]_D$	Lit.
$C_4H_{10}O$	*sec.*-Butyl alcohol		0.8034	25	13.11	(2185)
$C_4H_{10}S$	*sec.*-Butylmercaptan	EtOH	20		>12.45	(631)
$C_{13}H_{13}NO$	*l*-*α*-[*β*-Hydroxy-*β*-phenylethyl] pyridine $NC_5H_4.CH_2.CHOH.C_6H_5$	$CHCl_3$	13.2	25	−36.44	(1267)
$C_{17}H_{22}O_2$	*d*-*β*-Octyl *β*-phenylpropiolate				35.08	(908)
		$CHCl_3$	2.5	22	30.88	
		C_6H_6	2.5	22	35.12	
$C_{17}H_{24}O_2$	*d*-*β*-Octyl *β*-cinnamate			22	35.32	(908)
		$CHCl_3$	2.5	22	30.40	
		C_6H_6	2.5	22	33.04	
$C_{17}H_{26}O_2$	*d*-*β*-Octyl *β*-phenylpropionate			22	11.92	(908)
		$CHCl_3$	2.5	22	11.52	
		C_6H_6	2.5	22	6.00	
	KETO ALCOHOLS					
$C_{14}H_{12}O_2$	*d*-Benzoin	Me_2CO	0.413	11.5	120.5	(2214)
	l-Benzoin	Me_2CO	0.923	10.5	−118.6	(1354)
	l-Benzoin	EtOH	0.923	10.5	−118.6	(2214)
$C_{14}H_{13}NO_2$	*l*-Benzoin *α*-oxime	$CHCl_3$	0.858	24	−3.2	(2214)
		EtOH	0.965	23	4.4	
		$C_6H_5CO_2Et$	0.472	23.3	37.0	
		Me_2CO	0.707	15	18.0	
$C_{15}H_{14}O_2$	*l*-Benzoin methyl ether	EtOH	0.586	11	−94.3	(2214)
		$CHCl_3$	2.111	12	−88.2	
		C_7H_{16}	5.65	11.5	147.8	
		C_6H_6	0.643	15	50.9	
$C_{15}H_{14}O_2$	*d*-Benzoylbenzylcarbinol	Me_2CO	1.23	17.5	12.6	(1344)
$C_{16}H_{14}O_3$	Acetyl-*l*-benzoin	$CHCl_3$	0.724	14.5	−217.9	(2214)
$C_{21}H_{17}NO_3$	Carbanilido-*l*-benzoin	C_6H_6	0.802	18	−291.9	(2214)
	$C_6H_5.CO.CH(C_6H_5).O.CO.NH.C_6H_5$	Me_2CO	0.653	21	−214.8	
	POLYHYDROXY ALCOHOLS AND DERIVATIVES					
$C_5H_{11}NO_4$	Pentane-3, 4, 5-triolal oxime(Class IB_2) $(HO.CH_2(CHOH)_2.CH_2.CH{:}NOH)$	H_2O	4.2		10.6	(1067)
	Pentane-1, 4, 5-triol-3-one oxime $(HO.CH_2.CHOH.C(NOH)CH_2.CH_2.OH)$	H_2O	3.28		11.8	(1067)
$C_{20}H_{18}O_2$	*d*-*α*, *β*-Dihydroxy-*α*, *β*, *β*-triphenylethane	$CHCl_3$	1.32		−228	(1338)
$C_{21}H_{20}O_2$	*l*-*β*-Hydroxy-*α*-methoxy-*α*, *β*, *β*-triphenylethane	Me_2CO	5.428	12	−185.3	(1355)
		$CHCl_3$	4.579	13	−235	
		C_6H_6	3.667	9	−294.5	
		EtOH	1.0176	8	−166.3	
$C_{20}H_{20}O_6$	Cubebin $(C_6H_8(OH)_2(C_6H_4{:}O_2{:}CH_2)_2)$	$CHCl_3$		25	−45.45	(1366)

AMINES

MONOAMINES

sec.-Butylamine and derivatives

Formula	Name	Solvent	*d* or *C*	*t*, °C	$[\alpha]_D$	Lit.
$C_4H_{11}N$	*d*-*sec.*-Butylamine		0.724	20	7.44	(2014)
$C_4H_{12}ClN$	*d*-*sec.*-Butylamine hydrochloride	H_2O	14.03	20	−1.13	(2014)
	l-*sec.*-Butylamine hydrochloride	H_2O	13.5	20	+1.12	(2014)
$C_5H_{12}N_2S$	*d*-*sec.*-Butylthiocarbamide		0.943	20	61.88	
$C_9H_{20}N_2O$	*d*-Di-*sec.*-butylcarbamide	EtOH	2.46	20	39.71	(698)
	α-Phenylethylamine and derivatives					
$C_8H_{11}N$	*d*-*α*-Phenylethylamine		0.95	15	40.27	(1282); *cf.* (1380)
	l-*α*-Phenylethylamine		0.952	20	−39.9	(1557); *cf.* (916)
		EtOH	3.25	20	−31.5	
$C_8H_{12}ClN$	*l*-*α*-Phenylethylamine hydrochloride	H_2O	4.55	20	−5.3	(1557)
		EtOH	1.80	20	−5.0	
$C_9H_{12}N_2O$	*d*-*α*-Phenylethylcarbamide	EtOH	4.035		46.2	(1380)
	l-*α*-Phenylethylcarbamide	EtOH	14.06		−43.6	(1282)
			3.72		−52.1	
$C_9H_{13}N$	*d*-*α*-*p*-Tolylethylamine		0.9366	20	36.57	(1985)
		EtOH	2.0	20	32.1	(1986)
		EtOH	1.0	20	32.9	
		AcOEt	2.6	20	36.1	
$C_{10}H_{14}N_2O$	*l*-*p*-Tolylethylcarbamide	EtOH	1.53	20	−35.9	(1986)
		EtOH	0.766	20	−37.5	
		AcOEt	1.67	20	−31.3	
		AcOEt	0.835	20	−30.3	
		Me_2CO	1.73	20	−22.0	(1986)
$C_{10}H_{15}N$	*l*-*p*-Ethylphenylethylamine			20	−31.7	(1986)
		EtOH	2.27	20	−26.0	
		AcOEt	2.00	20	−27.5	
		AcOEt	1.00	20	−28.3	
$C_{10}H_{15}N$	*N*-Ethyl-*l*-*α*-phenylethylamine		0.907	20	−61.2	(1557)
		EtOH	3.91	20	−53.2	
$C_{10}H_{16}BrN$	*N*-Ethyl-*l*-*α*-phenylethylamine hydrobromide	H_2O	2.79	20	−10.3	(1557)
		EtOH	4.50	20	−17.0	
$C_{10}H_{16}ClN$	*N*-Ethyl-*l*-*α*-phenylethylamine hydrochloride	H_2O	2.50	20	−12.2	(1557)
		EtOH	2.82	20	−21.4	
$C_{11}H_{16}N_2O$	*N*-Ethyl-*l*-*α*-phenylethylcarbamide	EtOH	1.53	20	−50.4	(1557)
		EtOH	0.765	20	−51.5	
		AcOEt	1.66	20	−41.8	
		AcOEt	0.834	20	−42.8	
		Me_2CO	2.00	20	−29.2	
		Me_2CO	1.00	20	−30.1	
$C_{11}H_{16}N_2S$	*N*-Dimethyl-*l*-*α*-phenylethylthiocarbamide	EtOH	2.0	20	7.1	(1986)
		AcOEt	1.53	20	31.7	
		AcOEt	0.765	20	32.8	
		Me_2CO	1.66	20	39.6	
$C_{11}H_{17}N$	*N*-Methylethyl-*l*-*α*-phenylethylamine		0.904	20	−39.2	(1557)
		EtOH	2.84	20	−36.7	
$C_{11}H_{17}N$	*N*-Propyl-*l*-*α*-phenylethylamine		0.896	20	−69.1	(1557)
		EtOH	2.76	20	−62.1	
$C_{11}H_{18}BrN$	*N*-Propyl-*l*-*α*-phenylethylamine hydrobromide	H_2O	2.63	20	−20.4	
		EtOH	3.05	20	−26.3	
$C_{11}H_{18}ClN$	*N*-Propyl-*l*-*α*-phenylethylamine hydrochloride	H_2O	1.90	20	−24.3	(1557)
		EtOH	1.90	20	−35.4	
$C_{13}H_{20}N_2S$	*N*-Diethyl-*d*-*α*-phenylethylthiocarbamide	Me_2CO	2.0	20	−44.9	(1986)
			4.0	20	−43.9	
	N-Diethyl-*l*-*α*-phenylethylthiocarbamide	EtOH	2.33	20	7.6	(1986)
		AcOEt	1.67	20	40.7	
		Me_2CO	1.53	20	44.1	
$C_{15}H_{15}NO$	Benzoyl-*l*-*α*-phenylethylamine					(1986)
$C_{15}H_{15}NO_2$	*N*-*p*-Hydroxybenzoyl *d*-*α*-phenylethylamine	$CHCl_3$	0.747		54.6	(1454)
$C_{15}H_{17}N$	*N*-Benzyl-*l*-*α*-phenylethylamine		1.008	20	−40.1	(1557)
		EtOH	3.74	20	−58.4	

AMINES.—(*Continued*)

Formula	Name	Solvent	*d* or *C*	*t*, °C	$[\alpha]_D$	Lit.
$C_{15}H_{18}ClN$	*N*-Benzyl-*l*-α-phenylethylamine hydrochloride	H_2O	2.80	20	−9.1	(1557)
		EtOH	3.48	20	−18.5	
$C_{15}H_{21}NO_5$	*l*-Quinic *l*-α-phenylethylamide	Py	6.692	20	−92.1	(1380)
$C_{17}H_{21}N$	*N*-Ethylbenzyl-*l*-α-phenylethylamine	EtOH	1.87	20	−31.5	(1557)
		EtOH	1.98	20	−12.6	
$C_{17}H_{22}Cl_2N_2S$	*d*-Diphenylethylthiocarbamide dihydrochloride ($CS(NH.CHCH_3.C_6H_5)_2$)	EtOH	*1%*		22.5	(1284)
	l-Diphenylethylthiocarbamide dihydrochloride	EtOH	*1%*		−22.1	(1284)
$C_{18}H_{22}N_2S$	Methyl-*l*-phenylethylimidophenylethylthiocarbamate ($C_6H_5.CHCH_3.N{:}C(SCH_3).NH.CHCH_3.C_6H_5$)	EtOH	4.15		96	(1532)
$C_{18}H_{24}IN$	*d*-Methylethylbenzyl-α-phenylethylammonium iodide	H_2O	4.38	20	24.9	(1557)
$C_{18}H_{25}NO$	*d*-Methylethylbenzyl-α-phenylethylammonium hydroxide	EtOH	4.54		26.0	(1557)
$C_{18}H_{28}N_2O_4S$	*d*-*p*-Tolylethylamine sulfate	H_2O	3.2	20	3.4	(1986)
$C_{20}H_{28}N_2O_4$	*d*-*p*-Tolylethylamine oxalate	H_2O	1.5	20	4.0	(1986)
$C_{20}H_{32}N_2O_4S$	*l*-*p*-Ethylphenylethylamine sulfate	H_2O	3.34	20	−6.3	(1986)
		H_2O	1.67	20	−14.8	
		H_2O	0.80	20	−17.8	
		H_2O	0.41	20	−20.6	
$C_{22}H_{23}N$	*N*-Dibenzyl-*l*-α-phenylethylamine	EtOH	1.76	20	−97.8	(1557)
$C_{22}H_{32}N_2O_4$	*l*-*p*-Ethylphenylethylamine oxalate	H_2O	8.67	20	−14.4	(1986)
		H_2O	4.34	20	−32.7	
		H_2O	2.17	20	−30.8	

d-Aminobenzyl-β-naphthol and derivatives (136, 138, 139, 141)

Formula	Name	Solvent	*d*, *C* or %	*t*, °C	$[\alpha]_D$	$M[_D]$
	$R = HO.C_{10}H_6.CH(C_6H_5).NH_2$					
$C_{17}H_{15}NO$	*d*-Aminobenzyl-β-naphthol (≡R)	C_6H_6	4.76	18	+58.84	
	l-Aminobenzyl-β-naphthol (≡R)	C_6H_6	5		−58.96	
$C_{17}H_{16}ClNO$	*d*-Aminobenzyl-β-naphthol hydrochloride	EtOH		18	+52.89	
	l-Aminobenzyl-β-naphthol hydrochloride	EtOH	4.76	18	−52.51	
$C_{24}H_{17}Br_2NO_2$	3, 5-Dibromo-hydroxybenzylidene-R	C_6H_6	*1.29*	14–15	+92.18	+471.0
$C_{24}H_{17}ClN_2O_3$	2-Chloro-5-nitrobenzylidene-R	C_6H_6	*1.87*	15–18	−98.9	−412.0
$C_{24}H_{17}Cl_2NO$	2, 5-Dichlorobenzylidene-R	C_6H_6	*0.978*	15–18	−59.7	−242.6
$C_{24}H_{18}BrNO_2$	3-Bromo-4-hydroxybenzylidene-R	C_6H_6	*0.885*	14–15	+150.1	+648.0
$C_{24}H_{18}BrNO_2$	5-Bromosalicylidene-R	C_6H_6	*1.31*	14–15	−76.37	−329.9
$C_{24}H_{18}ClNO$	*o*-Chlorobenzylidene-R	C_6H_6	*2.90*	15–18	−34.6	−128.4
	m-Chlorobenzylidene-R	C_6H_6	*0.995*	15–18	+68.9	+255.9
	p-Chlorobenzylidene-R	C_6H_6	*0.932*	15–18	+75.9	+282.2
$C_{24}H_{18}N_2O_3$	*o*-Nitrobenzylidene-R	C_6H_6	*2.09*	14–15	−259.36	−990.7
	m-Nitrobenzylidene-R	C_6H_6	*1.10*	14–15	+43.88	+167.6
	p-Nitrobenzylidene-R	C_6H_6	*1.53*	14–15	+54.29	+207.4
$C_{24}H_{18}N_2O_4$	5-Nitrosalicylidene-R	C_6H_6	*0.187*	14–15	−132.37	−526.8
	3-Nitrosalicylidene-R	C_6H_6	*0.232*	14–15	+38.83	+154.5
$C_{24}H_{19}NO$	Benzylidene-R	C_6H_6	*4.734*	20	110.7	
$C_{24}H_{19}NO_2$	*o*-Hydroxybenzylidene-R	C_6H_6	*6.238*	20	−15.7	
	m-Hydroxybenzylidene-R	C_6H_6	*0.990*	15–18	+102.7	+362.6
	p-Hydroxybenzylidene-R	C_6H_6	*0.985*	20	+297.3	+1049.5
$C_{24}H_{19}NO_3$	3, 4-Dihydroxybenzylidene-R	C_6H_6	*1.105*	20	+159.6	+588.8
$C_{25}H_{19}NO_3$	Piperonylidene-R	C_6H_6	*2.848*	20	+259.6	+989.0
$C_{25}H_{20}BrNO_2$	5-Bromomethylsalicylidene-R	C_6H_6	*4.12*	14–15	+39.45	+175.9
$C_{25}H_{20}N_2O_4$	3-Nitroanisylidene-R	C_6H_6	*0.729*	14–15	+135.83	+559.6
$C_{25}H_{21}NO$	*o*-Methylbenzylidene-R	C_6H_6	*0.906*	15–18	−93.01	−326.5
	m-Methylbenzylidene-R	C_6H_6	*2.127*	15–18	+143.73	+504.5
	p-Methylbenzylidene-R	C_6H_6	*2.004*	15–18	+196.1	+691.4
$C_{25}H_{21}NO_2$	2-Hydroxy-4-methylbenzylidene-R	C_6H_6	*3.05*	15–18	−18.6	−68.3

d-Aminobenzyl-β-naphthol and derivatives (136, 138, 139, 141).—(*Continued*)

Formula	Name	Solvent	*d*, *C* or %	*t*, °C	$[\alpha]_D$	M$[_D]$
$C_{25}H_{21}NO_2$	*o*-Methoxybenzylidene-R	C_6H_6	*6.254*	20	+243.6	+894.0
	m-Methoxybenzylidene-R	C_6H_6	*1.09*	15–18	+139.7	+512.6
	p-Methoxybenzylidene-R	C_6H_6	*7.390*	20	+314.5	+1154.1
$C_{25}H_{21}NO_3$	3, 4-Dihydroxy-5-methylbenzylidene-R	C_6H_6	*4.096*	20	+318.5	
$C_{26}H_{19}ClN_2O_3$	α-Chloro-*o*-nitrocinnamylidene-R	C_6H_6	*1.425*	20	61.5	+272
$C_{26}H_{19}BrN_2O_3$	α-Bromo-*p*-nitrocinnamylidene-R	C_6H_6	*1.310*	10–12	+73.8	+359.0
$C_{26}H_{19}ClN_2O_3$	α-Chloro-*p*-nitrocinnamylidene-R	C_6H_6	*1.472*	10–12	+85.5	+378.0
$C_{26}H_{20}BrNO$	α-Bromocinnamylidene-R	C_6H_6	*1.031*	10–12	+146.0	+645.0
$C_{26}H_{20}ClNO$	α-Chlorocinnamylidene-R	C_6H_6	*0.918*	10–12	+199.5	+793.0
$C_{26}H_{20}N_2O_3$	*o*-Nitrocinnamylidene-R	C_6H_6	*2.380*	10–12	+350.1	+1428.0
	p-Nitrocinnamylidene-R	C_6H_6	*0.720*	10–12	+395.3	+1613.0
$C_{26}H_{21}NO$	Cinnamylidene-R	C_6H_6	*0.572*	10–12	+478.0	+1775.8
$C_{26}H_{23}NO_2$	2-Methoxy-4-methylbenzylidene-R	C_6H_6	*2.00*	15–18	+220.05	+838.4
$C_{26}H_{23}NO_3$	3, 4-Dimethoxybenzylidene-R	C_6H_6	*4.096*	20	+318.5	+1220.0
$C_{26}H_{24}N_2O$	*p*-Dimethylaminobenzylidene-R	C_6H_6	*0.994*	20	+704.2	+2676.0
$C_{27}H_{25}NO$	*p*-Isopropylbenzylidene-R	C_6H_6	*7.360*	20	+197.0	+746.5
$C_{27}H_{25}NO_4$	2, 4, 6-Trimethoxybenzylidene-R	C_6H_6	*0.869*	20	+421.9	+1801.9
$C_{28}H_{21}NO_2$	β-Hydroxynaphthylidene-R	C_6H_6	*1.054*	20	−232.3	−936.3
$C_{29}H_{23}NO_2$	β-Methoxynaphthylidene-R	C_6H_6	*2.585*	20	+133.42	+556.4

DIAMINES

Formula	Name	Solvent	*d*, *C* or %	*t*, °C	$[\alpha]_D$	Lit.
$C_3H_9BrN_2$	*d*-α, β-Diamino-γ-bromopropane	H_2O	*8.67*	18	5.20	(8)
$C_3H_{10}N_2$	*d*-Propylenediamine		0.8588	25	29.70	(322)
	l-Propylenediamine		0.863	25	−28.04	(322)
$C_9H_{30}CoN_6I_3$	Cobalt tri-*l*-propylenediamine iodide	H_2O	*3.38*	25	23.63	(323)
$C_3H_{11}Br_3N_2$	*d*-α, β-Diamino-γ-bromopropane dihydrobromide	H_2O	*7.50*	18	7.27	(8)
$C_3H_{12}Cl_2N_2$	*l*-Propylenediamine dihydrochloride	H_2O	*19.92*	25	−4.04	(322)
$C_4H_{12}N_2O$	*d*-α, β-Diamino-γ-methoxypropane	H_2O	*8.31*	18	8.19	(8)
$C_4H_{14}Br_2N_2O$	*d*-α, β-Diamino-γ-methoxypropane dihydrobromide	H_2O	*8.44*	18	9.04	(8)

HYDROXYAMINES

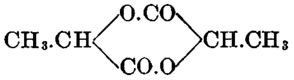
Formula	Name	Solvent	*d*, *C* or %	*t*, °C	$[\alpha]_D$	Lit.
$C_9H_{13}NO_3$	*l*-Adrenaline	0.1*N* H_2SO_4	1	20	−53.3	(128)
	$(C_6H_3(OH)_2.CHOH.CH_2NH.CH_3)$	$CHCl_3$	9.26		−15.12	(689)
	d-Adrenaline	0.32*N* HCl	*3.89*	19.8	51.88	(563)
$C_{21}H_{41}NO_3$	Diacetylhydroxyheptadecylamine	50% $CHCl_3$.MeOH	*18.0*	25	20.44	(1220.5)

CARBOXYLIC ACIDS

MONOHALOGENOMONOCARBOXYLIC ACIDS

Formula	Name	Solvent	*d*, *C* or %	*t*, °C	$[\alpha]_D$	Lit.
$C_3H_5BrO_2$	*l*-α-Bromopropionic acid		1.7084^{20}_{20}	20	−26.7	(554, 555); *cf.* (1764)
			1.705^{20}_{4}	20	−27	(1765)
$C_4H_7BrO_2$	Methyl *d*-α-bromopropionate		1.482^{17}_{4}		42.65	(2102)
$C_4H_7ClO_2$	*d*-β-Chlorobutyric acid	H_2O	*9.89*	20	49.8	(545)
		PhMe	*10.21*	20	46.6	
	Sodium salt	*N* NaOH	*9.10*	20	41.3	(545)
$C_4H_7ClO_2$	Methyl *d*-α-chloropropionate		1.1520^{20}_{4}		19.01	(2091)
$C_5H_9BrO_2$	Ethyl *l*-α-bromopropionate		1.386^{9}_{4}		−31.45	(2102)
$C_5H_9ClO_2$	Ethyl *d*-α-chloropropionate		1.0888^{20}_{4}		12.86	(2091)
$C_6H_{11}BrO_2$	*l*-α-Bromoisohexoic acid		1.358	20	−49.43	(495)
$C_6H_{11}BrO_2$	Propyl *d*-α-bromopropionate		1.315^{14}_{4}		−21.98	(2102)
$C_6H_{11}ClO_2$	Propyl *d*-α-chloropropionate		1.065^{6}_{4}		11.0	(2102)
$C_8H_7BrO_2$	*l*-Phenylbromoacetic acid	C_6H_6	4.10		−147.5	(1349); *cf.* (2090)
$C_8H_7ClO_2$	*l*-Phenylchloroacetic acid	C_6H_6	3.345	12	−191	(1332, 1333)
		$CHCl_3$	1.650	11.2	−159.4	
		EtOH	2.00	18	−155.8	(1346); *cf.* (2090)
$C_8H_{15}BrO_2$	Ethyl *l*-α-bromoisocaproate		1.22	20	−43.1	(1867)
$C_9H_9BrO_2$	*l*-α-Bromohydrocinnamic acid		1.48	20	−8.3	(495)
$C_9H_9ClO_2$	Methyl *l*-phenylchloroacetate		1.213	15	−86.7	(1330)
$C_{10}H_{11}ClO_2$	Ethyl *l*-phenylchloroacetate		1.162	16.4	−64.0	(1330)
$C_{11}H_{13}ClO_2$	*d*-Isopropylphenylchloroacetic acid	C_6H_6	3.0		23.3	(2090)

DIHALOGENOMONOCARBOXYLIC ACIDS AND THEIR DERIVATIVES

Formula	Name	Solvent	*d, C* or %	*t*, °C	$[\alpha]_D$	Lit.
$C_3H_4Br_2O_2$	*d*-*α*, *β*-Dibromopropionic acid	H_2O	*4.94*	18	13.76	(6)
		EtOH	*7.45*	18	6.42	
$C_4H_6Cl_2O_2$	Methyl *α*, *β*-dichloropropionate*			20	1.70	(658)
$C_5H_8Br_2O_2$	Ethyl *d*-*α*, *β*-dibromopropionate	EtOH	*1.08*	18	9.77	(6)
$C_5H_8Cl_2O_2$	Ethyl *α*, *β*-dichloropropionate*			20	−1.79	(658)
$C_7H_{12}Cl_2O_2$	Isobutyl *α*, *β*-dichloropropionate*			20	−3.62	(658)
$C_{10}H_{18}Cl_2O_2$	Heptyl *α*, *β*-dichloropropionate*			20	−1.73	(658)
	MONOHYDROXYMONOCARBOXYLIC ACIDS					
$C_3H_3O_3K$	Potassium *d*-glycidate	H_2O	*6.50*	18	30.16	(6)
	Lactic acid and derivatives (including thio-compounds)					
$C_3H_6O_2S$	*l*-Thiolactic acid		$1.193_{19.2}^{19.2}$	15	−45.47	(1283)
$C_3H_6O_3$	*d*-Lactic acid ($CH_3.CHOH.COOH$)	H_2O	10.46	15	3.82	(1019); *cf.* (924, 2201)
		H_2O	5.022	15	3.33	
		H_2O	2.511	15	2.67	
		H_2O	1.527	15	2.61	
	Calcium salt	H_2O	7.23		−3.87	(2201)
	Lithium salt	H_2O	*5*		−10.95	(924)
		H_2O	*12*		−12.28	(1019); *cf.* (924, 2201)
	Zinc salt + $2H_2O$	H_2O	5.0	15	−6.0	
		H_2O	2.5	15	−8.0	
		H_2O	1.25	15	−11.1	
		H_2O	0.512	15	−13.35	
$C_4H_8O_3$	*l*-Methoxypropionic acid	H_2O	13.47		−71.09	(1737)
	Calcium salt	H_2O	9.53		−38.09	(1737)
	Sodium salt	H_2O	16.53		−49.43	(1737)
$C_5H_{10}O_3$	Ethyl *l*-lactate; *cf.* (646, 1095)		1.030	19	14.52	(2102)
$C_5H_{10}O_3$	*d*-Ethoxypropionic acid	H_2O	29.37		56.96	(1737)
	Calcium salt	H_2O	26.87		38.40	(1737)
	Sodium salt	H_2O	17.96		48.09	(1737)
$C_6H_8O_4$	*d*-Lactide	C_6H_6	1.167	18	−298	(1020)
		C_6H_6	0.583	18	−280	
		C_6H_6	0.292	18	−246	
		H_2O	0.39		−8‡	
$C_6H_{10}O_4S$	*l*-Thiodilactylic acid ($S(CH.CH_3.COOH)_2$)	H_2O			−190	(1283)
$C_6H_{10}O_4S_2$	*d*-Dithiodilactylic acid ($S_2(CH.CH_3.COOH)_2$)	H_2O	6.4	15	429	(1283)
$C_6H_{12}O_3$	Propyl *d*-lactate		1.004	19	−17.06	(2102)
$C_6H_{12}O_3$	*d*-Propoxypropionic acid	H_2O	11.45		55.63	(1737)
	Calcium salt	H_2O	12.01		48.54	(1737)
	Sodium salt	H_2O	30.75		48.94	(1737)
$C_9H_9NO_5$	*l*-*m*-Nitrophenoxypropionic acid	EtOH	0.8	21	−51.87	(617)
	l-*p*-Nitrophenoxypropionic acid	EtOH	0.8	21	−53.7	
$C_{11}H_{11}NO_3$	*l*-Indol-3-lactic acid†	H_2O	*1.391*	20	−5.34	(411)
	β-Hydroxybutyric acid and salts					
$C_4H_8O_3$	*l*-*β*-Hydroxybutyric acid	H_2O	3.26	20	−24.8	(1325); *cf.* (374.5, 775, 1138.5, 1440.5, 1838.6)
		EtOH	8.21	18	−17.5	
	Magnesium salt	H_2O	14.39	13	−17.9	
		H_2O	2.30	13	−15.3	
	Potassium salt	H_2O	4.37	12	−12.3	
		H_2O	1.75	12	−11.9	
	Sodium salt	H_2O	8.52	15	−14.5	
		H_2O	1.36	17	−13.8	
	Zinc salt	H_2O	22.21	18	−17.9	
		H_2O	1.42	18	−14.2	
$C_4H_5Cl_3O_3$	*l*-*γ*, *γ*, *γ*-Trichloro-*β*-hydroxybutyric acid	EtOH	1.553	17	−29.6	(1345)
		EtOH	4.000	15.5	−30.1	
		Me_2CO	1.553	16.5	−22.5	
	Mandelic acid and derivatives					
$C_8H_8O_3$	*d*-Mandelic acid ($C_6H_5.CHOH.COOH$); *cf.* (1242, 1324.5, 1783.5, 2090, 2091)	H_2O	2.01		155.5	(404)

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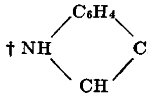
* Prepared from corresponding *l*-glycerates, possibly partly racemized.

†  $C.CH_2.CHOH.COOH$. Compare tryptophane. ‡ Mutarotation.

Mandelic acid and derivatives.—(Continued)

Formula	Name	Solvent	*d*, *C* or %	*t*, °C	$[\alpha]_D$	Lit.
$C_8H_8O_3$	*l*-Mandelic acid	H_2O	1.56		−157.4	(1698)
$C_8H_9NO_2$	*l*-Mandelamide	Me_2CO	1.65		−73.1	(2214)
	d-Mandelamide	Me_2CO	1.65	9	74.7	
$C_8H_{14}O_3$	*d*-Hexahydromandelic acid	AcOH	*10*	23	−26.6*	(667)
		AcOH	*10*	27	−25.8*	
$C_8H_{15}NO_2$	*d*-Hexahydromandelic amide	20% EtOH	*1.26*	25	47.4*	(667)
$C_9H_{10}O_3$	Methyl *l*-mandelate	CS_2	3.33	22	−214.1	(2090)
		CS_2	1.67	22	−217.0	
		Me_2CO	3.33	22	−110.2	
$C_9H_{10}O_3$	*l*-Methoxyphenylacetic acid	EtOH	6.7656	13.5	−150.0	(1355)
$C_9H_{10}O_4$	*d*-*p*-Methoxymandelic acid	H_2O	*2.5*	19	146.14	(1103)
$C_9H_{11}NO_2$	*l*-α-Methoxyphenylacetamide	Me_2CO	3.457	18	−103.6	(1355)
$C_9H_{16}O_3$	Methyl *d*-hexahydromandelate		1.066	25	−4.7*	
$C_{10}H_{10}O_4$	*l*-Acetylmandelic acid	EtOH	2.22		−157.7	(1341)
		Me_2CO	2.08		−153.7	
$C_{10}H_{12}O_3$	Ethyl *l*-mandelate	$CHCl_3$	6.67	22	−128.4	(2090)
		Me_2CO	5.81	22	−90.62	
		CS_2	5.00	22	−180.0	
$C_{10}H_{13}NO_2$	*l*-Mandeloethylamide	EtOH	3.693	16	−34.4	(1344)
$C_{11}H_{12}O_4$	Methyl *l*-acetylmandelate		1.1546		−146.37	(2090); *cf.* (2100)
$C_{12}H_{14}O_4$	Methyl *l*-propionylmandelate		1.1261		−135.5	(2090)
$C_{12}H_{16}O_3$	Isobutyl *l*-mandelate	CS_2	5		−146.6	(2090); *cf.* (2100)
$C_{13}H_{16}O_4$	Ethyl *l*-propionylmandelate		1.0936		−113.7	(2090)
		$CHCl_3$	10.0		−110.8	
$C_{13}H_{18}O_3$	*dl*-Amyl *l*-mandelate		1.0531		−96.46	(2090)
	l-Amyl *l*-mandelate		1.0530		−94.02	
$C_{15}H_{20}O_4$	Ethyl *l*-valerylmandelate		1.0544		−97.06	(2090)
$C_{17}H_{19}NO_3$	*l*-Hydrindamine *d*-mandelate	EtOH	3.73		−55	(1073)
	d-Hydrindamine *l*-mandelate	EtOH	3.37		57	
	d-Hydrindamine *d*-mandelate	EtOH	3.97		53.7	
$C_{20}H_{28}O_4$	*l*-Menthyl *l*-acetylmandelate	EtOH	2.58		−123.1	(1341); *cf.* (2090)
	l-Menthyl *d*-acetylmandelate	EtOH	2.68		8.8	
	l-Menthyl *dl*-acetylmandelate	EtOH	2.53		−57.2	
Homologues of mandelic acid						
$C_9H_{10}O_3$	*d*-α-Hydroxy-β-phenylpropionic acid	H_2O	2.56	13.5	22.8	(1356)
		EtOH	3.53	12	18.5	
	d-β-Hydroxy-β-phenylpropionic acid	EtOH	5.194	10.5	19.2	(1342)
	l-β-Hydroxy-β-phenylpropionic acid	EtOH	5.15	20	−18.9	(1342)
$C_9H_{10}O_4$	*d*-α-Hydroxy-β-*p*-hydroxyphenylpropionic acid	H_2O	*1.13*	20	18.14	(411)
$C_9H_{11}NO_2$	*d*-α-Hydroxy-β-phenylpropionamide	EtOH	2.076	20	81.4	(1344)
	d-β-Hydroxy-β-phenylpropionamide	EtOH	4.43	13	38.4	(1344)
$C_{11}H_{14}O_3$	*l*-Isopropylphenylglycolic acid	EtOH	4.09	17	−135	(452, 453)
$C_{11}H_{14}O_3$	Ethyl *l*-β-hydroxy-β-phenylpropionate	EtOH	4.72	20	−14.1	(1342)
		H_2O	2.16	20	22.22	(411)
$C_{11}H_{15}NO_2$	*l*-β-Hydroxy-β-phenylpropionethylamide	EtOH	3.99	15.5	−26.2	(1344)
Other hydroxymonocarboxylic acids and derivatives						
$C_6H_{12}O_3$	*l*-Leucic acid $((CH_3)_2CHCH_2CH(OH).COOH)$	H_2O	*9.854*	20	−10.4	(1867)
	Sodium salt	H_2O	*9.828*†	20	−27.8	(1867)
$C_8H_{16}O_3$	Ethyl *l*-leucate		0.965	20	−11.07	(1867)
$C_{15}H_{30}O_3$	Convolvulinolic acid $(C_{14}H_{28}(OH).COOH)$	$CHCl_3$	20.869		1.39	(1705); *cf.* (1702)
$C_{16}H_{32}O_3$	Methyl convolvulinolate	$CHCl_3$	10.07		1.57	(1705)
$C_{16}H_{32}O_3$	Hydroxyhexadecylic or jalapinolic acid $(C_{15}H_{30}(OH).COOH)$	$CHCl_3$	17.76		0.79	(1705)
$C_{17}H_{34}O_3$	Methyl hydroxyhexadecylate	$CHCl_3$	14.38		0.98	(1705, 1760)
		$CHCl_3$	18.63		0.94	
$C_{18}H_{32}O_3$	Ricinostearolic acid $(C_{17}H_{30}(OH).COOH)$	Me_2CO	6.4		13.67	(2088)
$C_{18}H_{34}O_3$	Ricinoleic acid $(CH_3.(CH_2)_5.CHOH.CH{:}CH(CH_2)_8.COOH)$	Me_2CO	4.8–21	22	6.25–7.5	(2088)

* λ = 5461. † Mutarotation.

Other hydroxymonocarboxylic acids and derivatives.—(Continued)

Formula	Name	Solvent	*d, C* or %	*t*, °C	$[\alpha]_D$	Lit.
$C_{18}H_{34}O_3$	Ricinelaidic acid	Me_2CO	5		4.8	(2088)
		EtOH	12		6.67	
$C_{19}H_{36}O_3$	Methyl ricinoleate		0.927	15	5.20	(798)
$C_{20}H_{38}O_3$	Ethyl ricinoleate		0.918	15	4.48	(798)
$C_{21}H_{40}O_3$	*n*-Propyl ricinoleate		0.912	15	4.35	(798)
$C_{22}H_{42}O_3$	Isobutyl ricinoleate		0.908	15	4.22	(798)
$C_{25}H_{50}O_3$	Cerebronic acid ($C_{23}H_{47}$.CHOH.COOH)	EtOH	*6.0*	20	3.55	(1239)
	DIHYDROXYMONOCARBOXYLIC ACIDS					
	Glyceric acid and derivatives (including thio-compounds)					
$C_3H_6O_4$	*d*-Glyceric acid: Barium salt	H_2O	*9.89*	20	−10.93	(638)
		H_2O	7.70		−17.38	(1509); *cf.* (632, 640, 649, 1243, 1510)
$C_3H_6O_4$	*l*-Glyceric acid	H_2O	*9.53*	20	12.94	(517)
$C_3H_7NO_3$	Glycerylamide		1.3347	100	−39.98	(664)
			1.3048	136	−38.11	
		MeOH	*2.439*	20	−63.09	
$C_4H_8O_4$	Methyl *d*-glycerate		1.2798	15	−4.80	(649); *cf.* (633, 655)
$C_5H_{10}O_4$	Ethyl *d*-glycerate		1.1921	15	−9.18	
$C_5H_{11}NO_3$	α, β-Dimethoxypropionamide	MeOH	*3.13*	20	−54.55	(642)
		Py	*1.696*	20	−71.60	
$C_6H_{10}O_6S_2$	β-Dithio-α-hydroxypropionic acid ($[S.CH_2.CH(OH).COOH]_2$)	H_2O	3.21		−10.6	(1501)
	Barium salt	H_2O	5.08	22	−19.08	(1501)
$C_6H_{12}O_4$	*n*-Propyl *d*-glycerate		1.1448	17	−12.94	(649); *cf.* (633, 655)
$C_6H_{12}O_4$	Isopropyl *d*-glycerate		1.1303	15	−11.82	(649)
$C_6H_{12}O_4$	Methyl α, β-dimethoxypropionate		1.0634	20	−69.70	(642)
$C_6H_{13}NO_3$	α, β-Dimethoxypropionic methylamide	MeOH	*1.892*	20	−58.72	(642)
$C_7H_{14}O_4$	*n*-Butyl *d*-glycerate		1.1084	17	−13.19	(649); *cf.* (633, 655)
	Isobutyl *d*-glycerate		1.1051	18	−14.23	
	sec.-Butyl *d*-glycerate		1.1052	19	−10.58	
$C_7H_{14}O_4$	Ethyl α, β-dimethoxypropionate		1.0309	20	−69.95	(642)
$C_8H_{16}O_4$	Propyl α, β-dimethoxypropionate		1.0090	20	−69.01	(642)
$C_9H_{18}O_4$	Butyl α, β-dimethoxypropionate		0.9921	20	−64.88	(642)
$C_9H_{11}NO_3$	Glycerylanilide		1.2084	100	−39.98	(664)
			1.1752	139	−36.16	
		MeOH	*2.44*	20	−72.13	
		MeOH	*5.66*	20	−67.29	
$C_{10}H_{13}NO_3$	Glyceryl-*o*-toluidide	MeOH	*2.44*	20	−32.55	(664)
		MeOH	*5.66*	20	−37.18	
	Glyceryl-*p*-toluidide	MeOH	*2.44*	20	−63.97	
			1.2121	98	−34.69	
			1.1376	179	−29.62	
$C_{10}H_{20}O_4$	Heptyl *d*-glycerate		1.0390	18	−11.30	(649); *cf.* (633, 655)
$C_{11}H_{22}O_4$	Octyl *d*-glycerate		1.0263	19	−10.22	
$C_{12}H_{24}O_4$	Heptyl α, β-dimethoxypropionate		0.9571	20	−54.84	(642)
$C_{13}H_{26}O_4$	Octyl α, β-dimethoxypropionate		0.9527	20	−50.46	(642)

SIMPLE DICARBOXYLIC ACIDS

Phenylsuccinic acid and derivatives (2217)

Formula	Name	Solvent	*C*	*t*, °C	$[\alpha]_D$	
$C_{10}H_{10}O_4$	α-Phenylsuccinic acid	Me_2CO	1.802	15.4	173.4	
		EtOH	1.534	16.5	148.3	
		AcOEt	1.550	15.5	174.2	
	l-Phenylsuccinic acid	Me_2CO	1.483	14.5	−173.3	
		MeOH	1.941	12.5	−147.1	
$C_{12}H_{14}O_4$	Dimethyl *d*-phenylsuccinate	Me_2CO	1.723	10	142.2	
		C_6H_6	1.443	15	159.0	
		CCl_4	1.272	15	169.8	
		EtOH	1.558	12	140.9	
		AcOEt	1.267	11.5	150.7	

COMMERCIAL EXPLOSIVES

WILLIAM RINTOUL AND GODFREY ROTTER

CONTENTS

ABBREVIATIONS

DNT	Dinitrotoluene.	N/G	Nitroglycerin.
MNN	Mononitronaphthalene.	TNN	Trinitronaphthalene.
N/B	Aromatic nitro body.	TNT	Trinitrotoluene.

INTRODUCTION

Pure compounds are not used to any great extent in civil applications of explosives. Ordinary commercial blasting and propulsive explosives have usually an empirical composition, with fairly wide tolerances for the proportions of the several ingredients, and very often one or more of these constituents is a substance of indefinite chemical composition. Furthermore the treatment during the process of manufacture, for example the fineness of the ingredients used, the time of mixing, and the physical condition of the product, have considerable influence on the properties of the finished explosive.

Data are tabulated relating to the principal explosive properties of the chief pure explosive substances, but for compounded explosives only typical or limiting compositions and properties are given.

TYPES OF TESTS

The principal tests used for explosives are described briefly below:

1. Calorimetric tests to determine the *heat of explosion* and the *volume and composition of the explosion gases*. For descriptions of the method of carrying out the experiments, *see* Vol. II, p. 440–444 of (25) and (39, 40).

The explosion temperature has not been determined directly, but can in principle be calculated from the pressure developed when the substance is exploded in a closed vessel. Various types of apparatus for determining the maximum pressures developed, or for recording variations in pressure, are described in (25). Explosion temperatures may also be calculated from the heat of explosion if the nature, amounts and specific heats of the explosion products are known.

2. *Trauzl Lead-block Test.*—This test is used for blasting explosives[1] as a ready means of estimating the relative powers of explosives of the same class fired under slight confinement. At the Berlin meeting (1903) of the International Congress of Applied Chemistry, standard conditions for carrying out this test were prescribed (2). Kast (19) gives a table of corrections for temperature.

3. The *fall-hammer test* is used to measure approximately the sensitiveness to shock of an explosive. The classification of explosives for transport on the German railways is based, in part, on the results of this test. The method of carrying it out is described in (14, 15), and by Marshall (25), Vol. II, p. 423.

4. The *deflagration test* for the determination of the explosion temperature serves to measure the sensitiveness of the explosive to active decomposition by the action of heat.

5. A large number of so-called "stability tests" have been developed in order to obtain some idea of the chemical stability of explosives during storage. Among these may be mentioned the *Abel*, *Bergmann-Junk*, *Will* and *Sy* tests.

6. The *bulk density* of an explosive is an important factor in its behavior and this property can be varied within fairly wide limits by modifications in the method of manufacture.

7. The *detonation velocity* of an explosive is one of the most important factors in its brisance, and, therefore, in its practical applications. The methods used for measuring it are described in the textbooks; *see*, for example (25) Vol. II, p. 476. A discussion by Kast of the sources of error when the Siemens spark chronograph is used is largely applicable to any chronographic method (17).

The value found depends on the diameter of the train of explosive used (up to a certain limiting value, varying with the nature of the explosive); on the degree of confinement to which it is subjected; and on the method of initiation.

The detonation velocity increases in general with the density. In the case of certain explosives this increase continues up to a certain critical density, after which it falls rapidly. In the case of some of the less porous nitro bodies it has not yet been proved that the detonation value does decrease in this way after a certain limit, although there are indications that this is probably so.

Nitroglycerin gelatinous explosives have two distinct detonation velocities. That which is attained depends on various factors, but especially on the nature of the initiation and on the degree of confinement.

The following tests are of special importance in connection with coal mine explosives:

8. *Tests in an experimental gallery* to determine the maximum charge which can be fired without igniting an air-gas mixture containing specified proportions of an inflammable gas or coal dust or both. Natural firedamp, artificially prepared methane and illuminating gas have been used as the inflammable gas. A brief historical sketch of the various gallery tests is given in (13). A table appended to that pamphlet gives data regarding the principal testing galleries. On the basis of these tests limiting charges of explosive are fixed for use in mines.

9. *Ballistic pendulum tests* are used in Great Britain and the United States to furnish a comparative estimate of the strength of the explosive, the results being published as a guide to the purchaser in the selection of an explosive suitable for his requirements.

In the United States the detonation velocity of permissible coal mine explosives is also published, but this is not done for the British "permitted" explosives.

10. For propulsive explosives, tests are carried out in appropriate weapons to measure the *pressure developed in the barrel of the gun*, usually by means of crusher gages, and to determine the *velocity of the projectile*, and, for shotgun cartridges, the *shot "pattern."*

Velocities are measured over a certain distance from the muzzle of the gun by the use of a suitable target in conjunction with a chronograph. The result may be given as the average velocity over this distance or as the "remaining velocity" at half the distance, or a calculated value of the "muzzle velocity" may be reported. V_x is used to denote the remaining velocity at x meters (or other unit) found by means of a target placed at $2x$ meters from the gun.

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[1] In the U. S. A. the ballistic mortar test described under 9, below, is largely used by manufacturers of explosives.

11. For initiating explosives, in addition to the heat of explosion, the explosion point and the result of the fall-hammer test, there may also be given the result of a test similar to the Trauzl lead-block test but using a smaller lead block; of the "*lead plate*" *test* (which, however, does not furnish definite numerical results); of tests on the *limiting charge* required to initiate the detonation of a definite quantity of some explosive (usually a nitro body); of the *Esop* and *Wöhler tests* in which an explosive is phlegmatized in some manner until it is just no longer "initiated" by the initiator under test; or of the "*sand*" *test* developed by the U. S. A. Bureau of Mines, in which a detonating charge is exploded in the center of graded sand, and the degree of pulverization of the sand produced by the explosion is measured.

SIMPLE EXPLOSIVES (PURE SUBSTANCES)

Heat of Explosion

Explosion in calorimetric bomb. The heat of explosion may also be calculated from thermochemical data (*q.v.*, Vol. V, p. 162, 169), the results agreeing well with the experimental. Alternative methods of decomposition may be possible and the heat of explosion may thus vary, for example, with the loading density or the nature of the initiation.

Abbreviations

(g), Gaseous; (l) liquid; d, density; L.d., loading density.

Conversion Factors

1 g-cal$_{15}$/g = 4.185 joule/g = 1.800 BTU$_{60}$/lb.

Substance	Heat of explosion, g-cal$_{15}$ per gram	Notes	Lit.
Ammonium nitrate	630	H_2O(l)	(32, 37)
$2NH_4NO_3 = 2N_2 + 4H_2O + O_2$ (requires strong detonator)	350	H_2O(g)	(1, 6)
$2NH_4NO_3 = N_2 + 4H_2O + 2NO$	115	H_2O(g)	(1, 6)
$NH_4NO_3 = N_2O + 2H_2O$	127.5	H_2O(g)	(1, 6)
Cyanuric triazide	1140		(21)
Guncotton, 13%N	982	H_2O(g); L.d., 1.3	(30)
	1100	H_2O(l)	(32, 37)
12%N	730	H_2O(l)	(32, 37)
Lead azide	364		(26)
	360		(6)
	260	Pb(g)	(21)
Lead trinitroresorcinate	205(?)	Pb(g)	(21)
Mannitol hexanitrate	1454, 1520		(20, 37)
Mercury azide	266		(26)
Mercury fulminate	410		(37, 38)
	431	Hg(l)	(21)
	368	Hg(g)	(21)
m-Dinitrobenzene	820	H_2O(g); L.d., 1.3	(30)
Nitroglycerin	1478	H_2O(g);	(30)
	1550 to 1590		(5, 29, 37)
Picric acid	717	H_2O(g)	(3)
	840	H_2O(l)	(32)
	914	H_2O(g); L.d., 1.3	(30)
	809	Mean for various L.ds.	(12)

Heat of Explosion.—(*Continued*)

Substance	Heat of explosion, g-cal$_{15}$ per gram	Notes	Lit.
Silver fulminate	470		(26)
Tetranitromethylaniline (tetryl)	1090	H_2O(g); L.d., 1.3	(30); *cf.* (10)
Trinitrobenzene	940	H_2O(g); L.d., 1.3	(30)
Trinitrotoluene	880	H_2O(l)	(32)
	924	H_2O(g); L.d., 1.3	(30)
	881 to 892	L.d., 0.2; d, 1.45	(12)

Trauzl Lead-Block Test

Explosive	Expansion, cm^3	Lit.
Ammonium nitrate	142*	(49)
	103†	(49)
	165 198	(19, 27)
Ammonium chlorate	240	(19, 28)
Ammonium perchlorate	140	(19)
	193	(27)
Dinitrobenzene	250	(19)
Dinitroglycerin (gelatinized)	330	(5)
Guncotton	360‡	(3)
	375	(19)
Dry, compressed, 12.77%N	317‡	(47)
Dry, compressed, 13.18%N	352‡	(47)
	290	(10)
With 13%N	420§	(6)
Wet	280	(19)
With 20% water	280	(32)
Hexanitrodiphenylamine	320	(19)
	352	(33)
Hexanitrophenyl sulfide	355	(33)
Hydrazine nitrate (basic)	362*	(50)
Nitroglycerin	515	(19)
	600	(32)
	600§	(6)
	550‖	(28)
	590‖	(28)
Nitromannite	650§	(6)
Nitropentaerythritol	460	(32)
Nitrostarch	305	(33)
Picric acid	302¶	(44)
	292*††	(47)
	330	(33)
	297	(10)
	287	(45)
Acid as powder	301*	(45)
Acid cast	264*	(45)
Acid compressed	292*	(45)
	305	(32)
Tetranitroaniline	400‡	(50)
	415	(33)
	430	(10)
Tetranitroanisole	390	(32)
Tetryl (Powder)	357**	(46)
(Cast)	322‡**	(46)

Trauzl Lead-Block Test.—(*Continued*)

Explosive	Expansion, cm³	Lit.
Tetryl.—(*Cont'd*)		
(Pressed)	322‡**††	(46)
	340	(19)
	375	(33)
	375	(10)
	369‡	(50)
	374‡	(49)
	348	(48)
Trinitroanisole	290	(19)
	322	(33)
Trinitrobenzene	330	(19)
	364	(33)
Trinitrochlorobenzene	295	(19)
	322	(33)
Trinitrocresol	275	(19)
	301	(33)
Trinitrotoluene	300‡	(3)
	285	(19)
	274	(33)
	254	(10)
	238	(48)
	260§	(6)
Mean of 25 results	249	(7.5)
Commercial (Powder)	289* **	(46)
(Cast)	102* **	(46)
(Pressed)	54**††	(46)
(Powder)	280‡‡	(46)
(Cast)	208‡‡	(46)
(Pressed)	255††‡‡	(46)

* Volume of borehole, 63 cm³, deducted.

† With picric acid as primer, 297 cm³ deducted for primer, 63 cm³ for original volume of borehole.

‡ Volume of borehole deducted.

§ After deducting 61 cm³ for borehole and 17 cm³ for No. 8 detonator.

‖ Liquid N/G with sand tamping.

¶ Acid finely crystalline.

** No. 8 detonator.

†† Pressed at 1246 kg per cm.²

‡‡ No. 8 tetryl detonator.

Lead-Block Test (Initiating Explosives) (21)

In testing initiating explosives a smaller lead block is used, 80 mm in diameter and 80 (or 100) mm high with a charge of 2 g of the substance

Explosive	Expansion, cm³	d*
Cyanuric triazide	131.3	1.2
Lead azide	26	2
Lead trinitroresorcinate	29	1.8
Mercury fulminate	33	1.7

* d = density of explosive, g/cm³.

Fall-Hammer Test

Results for 2 kg hammer

Explosive	Fall in cm	Lit.
Ammonium picrate	80	(36)
Copper picrate	7	(36)
Dinitrobenzene	>60	(16)
	150	(16)
Dinitroglycerin	7	(36)
Moist	30	(42)
Dinitrophenol	150	(36)
Guncotton compressed, 15% H_2O	85	(36)
20% H_2O	>180	(36)
Dry	17 to 18	(41)
+20% H_2O	>183*	(41)
+35% H_2O	>183	(41)
Hexanitrodiphenylamine	40	(36)
Iron picrate	7	(36)
Lead picrate	5	(36)
Nitrocotton (collodion cotton), compressed, 15% H_2O	100	(36)
20% H_2O	>180	(36)
Dry	36	(41)
+20% H_2O	>183*	(41)
+35% H_2O	>183	(41)
Nitroglycerin, dry	4	(36)
Moist	4	(42)
Liquid	10†	(43)
Frozen	38 to 40†	(43)
Picric acid (finely crystalline)	35 to 95	‡
Silver picrate	5	(36)
Sodium picrate	80	(36)
Tetryl	40 to 65	(36)
	30	(32)
Trinitroanisole	>60	(16)
Trinitrobenzene	40 to 50	(36)
Trinitrocresol	30	(36)
Trinitrodimethylaniline	95	(36)
Trinitronaphthalene	175	(36)
Trinitrotoluene	57–90 and up to 180	‡
Zinc picrate	60	(36)

* Partly caked residue.

† For 1 kg hammer.

‡ Various sources.

Explosive	Weight of explosive, g	Weight of hammer, g	Fall in cm	Lit.
Azides, Ba	0.02	599	14	(26)
Cd	0.02	964	27.5	(26)
Cu	0.01	599	9.5	(26)
	0.02	599	10.5	(26)
	0.03	599	13.0	(26)
	0.05	599	24.0	(26)
Pb	0.01	599	17	(26)
	0.02	599	17	(26)
	0.05	599	14.5	(26)
Hg	0.01	599	17	(26)
	0.02	599	16.5	(26)
	0.05	599	14	(26)
Ag	0.05	964	18	(26)
Na	0.05	820	>30	(22)
Fulminates, Hg	0.05	500	7.5	(22)
		2000	2	(9)
Na	0.05	620	30	(22)

Limiting Charges Necessary for Various Initiating Explosives

Initiating explosive A	Explosive B against which tested	Amount of explosive B, g	Limiting charge of explosive A required for detonation of B, g	Lit.
Lead azide*	Tetryl	0.5	0.025	(26)
	Picric acid	0.5	0.025	(26)
	TNT	0.5	0.09	(26)
	Trinitroanisole	0.5	0.28	(26)
Mercury fulminate†	Picric acid	1	0.25	(38)
	TNT	1	0.30	(38)
	TNT	0.5	0.25	(22)
	Tetryl	0.4	0.35‡	(34)
	Tetranitroaniline	0.4	0.45	(34)
	Picric acid	0.4	0.40§	(34)
	TNT	0.4	0.26‖	(34)
	Picric acid	0.5	0.30	(26)
	Tetryl	0.5	0.29	(26)
	TNT	0.5	0.36	(26)
	Trinitroanisole	0.5	0.37	(26)
	Trinitroxylene	0.5	0.43	(26)
	TNT		0.26¶	(35)
			0.30**	(35)
	Tetryl		0.24¶	(35)
			0.25**	(35)
	Guncotton	0.5	0.20††	(38)
	Picric acid	1.0	0.25 to 30††	(38)
	Trinitroresorcinol	1.0	0.20††	(38)
	Trinitrocresol	1.0	0.30††	(38)
	Trinitrobenzoic acid	1.0	0.25††	(38)
	Trinitrobenzene	1.0	0.25††	(38)
	TNT	1.0	0.30††	(38)
	Trinitroxylene	1.0	0.40††	(38)
Mercury fulminate +0.01g lead azide	TNT	0.5	0.02	(22)
Mercury fulminate +20% lead azide	TNT		0.18¶	(35)
			0.06¶	(35)
	Tetryl		0.06**	(35)
Mercury fulminate-potassium chlorate mixture, 90:10	Tetryl	0.4	0.3000	(34)
	Tetranitroaniline	0.4	0.3125	(34)
	Picric acid	0.4	0.3750‡‡	(34)
	TNT	0.4	0.2500‖	(34)
80:20	Tetryl	0.4	0.2750	(34)
	Tetranitroaniline	0.4	0.3125	(34)
	Picric acid	0.4	0.3750§§	(34)
	TNT	0.4	0.2400‖	(34)
Silver azide	Guncotton	0	0.05††	(38)
	Picric acid	1	0.025††	(38)
	Trinitroresorcinol	1	0.08††	(38)
	Trinitrocresol	1	0.05††	(38)
	Trinitrobenzoic acid	1	0.10 to 0.20††	(38)
	Trinitrobenzene	1	0.05††	(38)
Silver azide.—(*Cont'd*)	TNT	1	0.05††	(38)
Silver fulminate	Trinitroxylene	1	0.25††	(38)
	Tetryl	0.5	0.02	(26)
	Picric acid	0.5	0.05	(26)
	TNT	0.5	0.10	(26)
	Trinitroanisole	0.5	0.23	(26)
	Trinitroxylene	0.5	0.30	(26)

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* The Rheinische-Westfälische Sprengstoff A. G. say that lead azide detonates satisfactorily with as much as 5 % of water.

† The Rheinische-Westfälische Sprengstoff A. G. say that pure fulminate and its mixtures do not detonate satisfactorily when containing 1 % water.

‡ *0.24 in reinforced detonator.*

§ 0.25 in reinforced detonator.

‖ In reinforced detonator.

¶ At 200 atm.

** At 400 atm.

†† Pressure 2000 kg/cm².

‡‡ 0.2300 in reinforced detonator.

§§ 0.2200 in reinforced detonator.

Detonation Velocity

Name	Det. vel., km/sec, V	Δ,* g/cm³	D,† mm	Notes	Lit.
Ammonium nitrate	1.46	0.83	25	1, 2	(20)
	1.31	0.84	25	1, 2	(20)
	1.47	0.83	26	1, 3	(20)
	1.23	0.69	50	1, 4	(20)
	1.25	0.65	50	1, 4	(20)
	1.49	0.68	80	1, 4	(20)
	1.50	0.66	80	1, 5	(20)
	1.53	0.79	80	1, 4	(20)
	1.55	0.88	80	1, 4	(20)
	2.70	0.98	80	1, 6	(20)
	1.92	0.64	100	1, 4	(20)
	1.83	0.84	100	1, 15	(20)
Ammonium perchlorate	2.57	1.17	35	1, 7	(20)
	2.47	1.17	35	1, 7	(20)
	2.48	1.0	38	1, 8	(20)
Hexanitrodiphenylamine	7.10	1.58	21	9, 10	(17)
	7.15	1.67	21		
Mannitol hexanitrate	8.26	1.73	12.8	‡	(20)
Mercury fulminate	3.00			Loose	(30)
	3.92		6.45		(4)
	2.25	1.25		Ordinary temp.	(23)
	2.35	1.25		−190°C	(23)
Nitroglycerin (in Mannesmann tube)	8.00			liq.	(31)
	7.46	1.60	30		(19.5)
	1.53			liq.	(5)
	Det. not transmitted		6	11, 13 in 12	(7)
	0.65		9	13	(7)

Detonation Velocity.—(*Continued*)

Name	Det. vel., km/sec, V	Δ,* g/cm^3	D,† mm	Notes	Lit.
Nitroglycerin.—(*Cont'd*)	1.45 or 7.69		25	13	(7)
			25	14	(7)
	8.53		38	1, 13	(7)
(0.8 g detonator.)	2.02		38		(7); *cf.* (7.5)
(Det. fuse as primer)	7.23				
Picric acid	8.18	1.55	30		(3)
	7.25	1.63			(31)
	4.55	0.86			(14.5)
	6.16	1.34	21		(17)
	6.70	1.46	21		(17)
	7.00	1.53	21		(17)
	7.10	1.60	21		(17)
	7.26	1.69	21		(17)
	4.51	0.90	9.2		(8)
	5.10	0.94	20		(8)
	6.33	1.32	20		(8)
	6.94	1.46	20		(8)
	7.10	1.50	20		(8)
	7.37	1.62	20		(8)
	7.14	1.67	20		(8)
	7.49	1.72	20		(8)
In paper case	5.35	1.20	40		(11)
	5.71	1.40	40		(11)
	6.87	1.60	40		(11)
In Mannesmann tube	4.63	0.85	40		(11)
	5.21	1.20	40		(11)
Tetryl	7.15	1.53	21		(17, 18)
	7.16	1.59	21		(17, 18)
	7.20	1.63	21		(17, 18)
	7.25	1.63			(31)
Trinitrobenzene	6.27	1.33	21		(17, 18)
	6.30	1.35	21		(17, 18)
	6.94	1.56	21		(17, 18)
	7.00	1.60	21		(17, 18)
	7.00	1.64			(17, 18)
(Using various detonators and various amounts of dynamite as primer)	7.06	1.62			(8)
	7.35	1.64			(8)
	7.28	1.65			(8)
	7.35	1.66			(8)
	7.07	1.65			(8)
	7.00	1.53			(8)
	3.97	0.75	20		(8)
	3.81	0.62	20		(8)
	5.16	0.97	20		(8)
Trinitrochlorobenzene	6.80	1.66	21		(17)
(Pressed)	6.86	1.71	21		(17)
(Pressed)	7.13	1.75	21		(17)
(Cast)	7.15	1.76	29		(17)
Trinitrocresol	6.62	1.52	21		(17)
	6.85	1.62	21		(17)
Trinitrophenol	7.25	1.63·			(30)
Trinitrophenylmethylnitroamine	7.52	1.63			

Detonation Velocity.—(*Continued*)

Name	Det. vel., km/sec, V	Δ,* g/cm^3	D,† mm	Notes	Lit.
Trinitrotoluene, paper covers	4.05	0.79	40		(11)
	5.24	1.22	40		(11)
	6.38	1.45	40		(11)
	6.87	1.59	40		(11)
In Mannesmann tube	4.74	0.85	40		(11)
	5.40	1.22	40		(11)
	6.29	1.45	40		(11)
	6.77	1.59	40		(11)
Various conditions of confinement	6.46	1.47	21		(17)
	6.70	1.59	29		(17)
	6.69	1.59	160		(17)
	6.22	1.32	20		(8)
	6.68	1.46	20		(8)
	6.88	1.56	20		(8)
	7.06	1.59	20		(8)
	7.14	1.60	20		(8)
	6.94	1.61	20		(8)
Trinitroxylene	6.60	1.51			(30)

* Bulk density in cartridge form.
† Cartridge or tube diam., mm.
‡ Free lying cartridge.

NOTES

1. In wrought iron tube. 2. Primer 50 g pressed tetryl. 3. Primer 60 g pressed tetryl. 4. Primer 100 g pressed picric acid. 5. Primer 300 g pressed picric acid. 6. Primer 250 g pressed tetryl. 7. Primer 110 g pressed tetryl. 8. Primer 25 g pressed picric acid. 9. 10 g picric acid and 1 g detonator.
10. Tamped with sand. 11. Glass tube. 12. Larger tube attached. 13. 1.6 g detonator. 14. Sheet iron tube. 15. Primer 200 g pressed tetryl.

COMPOUNDED EXPLOSIVES

Blasting Explosives

The following classification of blasting explosives will be found useful, though the classes are by no means mutually exclusive. *A.* Non-detonating explosives. *B.* Detonating or high explosives.

A. Non-detonating explosives.

Black powder is the principal type of this class. The German "Sprengsalpeter" is similar to black powder, with sodium nitrate in place of potassium nitrate.

B. Detonating or high explosives.

I. Nitroglycerin explosives.
  (*a*) Gelatinous explosives.
  (*b*) Dynamites.
    (1) With inactive additions.
    (2) With active additions.
II. Ammonium nitrate explosives containing as sensitizer:
  (*a*) Nitroglycerin.
  (*b*) Aromatic nitro body.
  (*c*) Non-explosive substance.
III. Perchlorate explosives.
IV. Chlorate explosives.

Nitroglycerin explosives are liable to freeze and their use in the frozen condition gives rise to danger. This danger may be removed by partially or wholly replacing the nitroglycerin by nitrated chlorohydrin, ethyleneglycol dinitrate, dinitroglycerin, nitrated polyglycerin or aromatic nitro compounds such as nitrobenzene, thus forming low freezing (L. F.) explosives.

Some dynamites have a certain proportion of nitrocotton incorporated with the nitroglycerin to diminish the risk of exudation of the nitroglycerin during transport or storage. These may be called semi-gelatins. They resemble the dynamites rather than the gelatins in properties.

A special class of blasting explosives is constituted by those officially authorized for use in coal mines, which are often referred to as "safety explosives." They are known as "permitted explosives" in Great Britain, "permissible explosives" in the United States, "Wettersprengstoffe" in Germany, "Explosifs S. G. P., in Belgium, and "explosifs de sûreté" in France. They usually contain alkaline salts, or sometimes hydrated salts, to reduce the temperature of detonation, and the length and duration of flame.

COMPOSITIONS OF VARIOUS TYPICAL COMPOUNDED EXPLOSIVES
Blasting Explosives (*See* p. 495 for properties)

Key number	Explosive
1	**Black Powder:** KNO_3, 62–75.7%; S, 10–19.4%; charcoal, 12–5%. The properties can be modified to a considerable extent by varying the nature of the charcoal used, the time of mixing and the size of grain of the product.
2	**Bobbinite:** KNO_3, 65.31%; S, 2.63%; charcoal, 19.52%; paraffin, 3.35%; starch, 8.73%; H_2O, 0.46%.
3	**Blasting Gelatin:*** Nitroglycerin, 90–95%; nitrocotton, 5–10%.
4	**Nobel Gelatinous Explosives:*** Nitroglycerin, 25–85%; nitrocotton, 0.5–7%; liquid nitro body, 0.4–9%; woodmeal, 0.9–10%; K or Na nitrate, 6–45%; chalk, 0–0.3%.
5	**U. S. A. Gelatin Dynamites:*** L. F. Nitroglycerin, 20–80%; nitrocotton, 0.3–4.5%; combustible substances, 6–16%; $NaNO_3$, 1.5–6.2%; $CaCO_3$, 1%.
6	**French "Gommes":*** Nitroglycerin, 49–86%; nitrocotton, 2–6%; woodmeal, 0.25–10%; KNO_3, 4–36%.
7	**Kieselguhr Dynamite:†** Nitroglycerin, 72–75%; kieselguhr, 25–28%.
8	**Nobel Glasgow Dynamites (Semigelatinous):** Nitroglycerin, 24.4–57%; nitrocotton, 0.6–3.0%; $NaNO_3$, 21–55.75%; woodmeal, 16.5–19.25%.
9	**U. S. A. Straight Dynamites:** L. F. Nitroglycerin, 15–75%; $NaNO_3$, 5–66%; combustible substances, 5–20%; $CaCO_3$ or $MgCO_3$, 1%.
10	**Pittsburgh Standard 40% Straight Dynamite:** Nitroglycerin, 40%; $NaNO_3$, 44%; wood pulp, 15%; $CaCO_3$, 1%.
11	**Carbonites:** Nitroglycerin, 17–30%; $NaNO_3$, 24–30%; combustible (usually flour), 37–44%. Antacids are sometimes added, and the explosive may be made of the low freezing type by the use of tetranitrodiglycerin.
12	**Carbonite Type of Explosive Tested by U. S. A. Bureau of Mines (Explosive D):** Nitroglycerin, 24.92%; KNO_3, 25.37%; $Ba(NO_3)_2$, 4.42%; woodmeal, 34.60%; starch, 6.64%; H_2O, 4.05%.
13	**U. S. A. Ammonia Dynamites:** NH_4NO_3, 7–50%; $NaNO_3$, 14–60%; nitroglycerin, 12–25%; combustible substances, 8–20%; $CaCO_3$ or ZnO, 1%.
14A	**Grisoudynamite Couche:** NH_4NO_3, 87.5% (or 82.5% + KNO_3, 5%); nitroglycerin, 12%; nitrocotton, 0.5%.
14B	**Grisoudynamite Roche:** NH_4NO_3, 70% (or 65% + KNO_3, 5%); nitroglycerin, 29%; nitrocotton, 1%.
15	**Donarit:** NH_4NO_3, 80%; nitroglycerin (gelatinized or not), 4%; TNT, 12%; rye flour, 4%.
16A	**Grisounaphthalite Couche:** NH_4NO_3, 95% (or 90% + KNO_3, 5%); trinitronaphthalene, 5%.
16B	**Grisounaphthalite Roche:** NH_4NO_3, 91.5% (or 86.5% + KNO_3, 5%); dinitronaphthalene, 12%.
17	**Withnell Type of Explosive Tested by U. S. A. Bureau of Mines (Explosive J):** NH_4NO_3, 90.5%; TNT, 4.82%; flour, 4.23%; H_2O, 0.45%.
18	**Yonckites (Belgium):** NH_4ClO_4, 6–25%; NH_4NO_3, 17.5–65%; $NaNO_3$, 27–30%; $Ba(NO_3)_2$, 6–10%; TNT, 10–22.5% or TNN, 3.75%.
19	**Sabulex:** NH_4NO_3, 59–56%; $KClO_4$, 8–10%; TNT, 9–7%; NH_4Cl, 26–24%.
20	**Perchloratites (Germany):** The perchloratites authorized for use in Prussia include explosives with contents of $KClO_4$ ranging from 30–75%.
21	**Cheddites:** $KClO_3$, 70–90%; aromatic nitro compounds, 0–20%; paraffin, 0–14%.
22	**Cheddite Type Explosive Tested by U. S. A. Bureau of Mines (Explosive E)·** $KClO_3$, 75.36%; MNN, 1.3%; DNT, 17.85%; castor oil, 5.32%; H_2O, 0.17%.
23	**Silesia Type Explosive Tested by U. S. A. Bureau of Mines (Explosive F):** $KClO_3$, 75.27%; nitrated resin, 24.63%; H_2O, 0.10%.
24	**Chloratites (Germany):** The chloratites authorized for use in Prussia include explosives with contents of $KClO_3$ or $NaClO_3$ ranging from 70–91%, along with aromatic nitro derivatives and combustible substances.

* Camphor, soda or chalk have also been added in small proportions, and sometimes a little nitro body.

† Sometimes soda, talc or heavy spar is added in small proportions.

Explosives For Use in Fiery Coal Mines

POWER

The power of British "permitted explosives" is measured by means of a ballistic pendulum test. A stemmed charge is fired electrically from a gun into a ballistic pendulum and the deflection is compared with that given by 4 oz. of 60% gelignite under the same conditions. The standard charge gives a swing of 3.27 in., and the actual deflections are reduced to correspond to this value.

The values will be found in the "*Explosives in Coal Mines Orders.*"

The standard used in the United States is 40% straight dynamite. The unit deflective charge is that which gives the same deflection as 227 g (½ lb.) of the standard dynamite.

In Belgium a modified form of the Trauzl lead-block test is used for comparing the powers of S. G. P. explosives. The weight of explosive equivalent to 100 g of dynamite No. 1 is given. The values are published in the *Annales des Mines de Belgique.*

CHARGE LIMIT

For British "permitted" explosives the charge limits have in the past varied from 8 oz., to 40 oz., but are now fixed at the uniform figure of 28 oz. Results are published in the *Explosives in Coal Mines Orders.*

A general limit of 1½ lbs. is fixed for the maximum permissible charge of the U. S. A. "permissible explosives," and no explosive is placed on the list unless this maximum charge satisfies the gallery test.

Properties of Various Typical Compounded Explosives
Blasting explosives (*See* p. 494 for compositions)

Key number	Explosive	Heat of explosion, g-cal per g	Trauzl lead-block test, expansion in cm³	Fall-hammer test, weight of hammer 2 kg; fall, cm	Detonation velocity, meters per second	Loading density, g/cm³	Propagation of detonation by influence, cm	Diameter of cartridge, mm
1	Black powder	622–789 H_2O(l)	30	30–40	300–420 (rate of burning)	1.04–1.2		
2	Bobbinite*	623 H_2O(l)		>100	469	1.25		
3	Blasting gelatin	1530–1565 H_2O(g)	500–600	12–25	1500–2500 or 7200–8100	1.5–1.6		
4	Nobel gelatinous explosives		270–540		2300–5000 and up to 5000–9000	1.55–1.7		
5	U. S. A. gelatin dynamites				2100–2500 or 5000–7000			
7	Kieselguhr dynamite	1100–1300	300–370	7	1990–9700	Max., 1.67	30	32
9	U. S. A. straight dynamite	30%, 1025.8 60%, 1663.4	30% 190 60% 318		5%, 1294 60%, 5800–6000	20% 1.18		
10	Pittsburgh Standard 40% straight dynamite	1221.4	278	10	4688	1.22	43.2	32
11	Carbonites (U. S. A.)	573–770	120–185	6–13	2285–3470	0.98–1.33	7.5–2.3	32
12	Carbonite type (Explosive D)*	570.7	156	13	2589	0.68	10.2	32
13	U. S. A. ammonia dynamites	40%, 1122	40%, 202		3010–4380 40%, 3157	40%, 1.57		
14A	Grisoudynamite couche	783					3.7	30
14B	Roche	978					8.2	30
	Roche sâlpetrée	870						
15	Donarit	930–1220	375–400	30–160	3700–4150		2.7	30
16A	Grisounaphthalite couche				2460–3240 (according to diam. of cartridge)			
	Couche sâlpetrée	816						
16B	Roche						3.9	30
17	Withnell type (explosive J)*	1285.5	245	100	3971	0.94	7.6	32
21	Cheddites	1065–1185	210–280	14–36	2100–3100 (according to density)	13–1.6		
22	Cheddite type (explosive E)*	1065.1	212	23	2771	1.28	7.6	32
23	Silesia type (explosive F)*	865.5	201	3	2722	1.04		

* Tested by U. S. A. Bureau of Mines.

The charge limits for Belgian S. G. P. explosives vary from 400 g to 900 g. The values are published in the *Annales des Mines de Belgique*.

The charge limits fixed in the Prussian official regulations for the use of "Wettersprengstoffe" are 700 or 800 g, separate limits being fixed for fiery and non-fiery mines. In the great majority of cases the limit is 800 g in each case. *See* "Das Sprengstoffwesen im preussischen Bergbau."

DETONATION VELOCITY

The detonation velocities of U. S. A. permissible explosives vary from 1792 meters per second for Red H.C. L.F. to 4651 for Gelobel.

Values are not published by the authorities in Great Britain The detonation velocities of the permitted explosives made by Nobel Industries Limited range from 1900 to 5000 meters per second.

Propulsive Explosives

Propulsive explosives may be arranged under the following classes:

1. Black powder type.
2. Nitrocellulose powders.
   (*a*) Without additions.
   (*b*) With additions.

3. Nitroglycerin powders containing both nitrocellulose and nitroglycerin.

(*a*) Without other additions.

(*b*) With other additions.

Examples are given showing the composition and properties of various compounded explosives.

Black Powder, *see* Blasting Explosives.

Amide Powder (Chilworth Special Powder): NH_4NO_3, 35.38%; KNO_3, 40–46%; charcoal, 14–22%.

Ammonpulver: NH_4NO_3, 80–90%; charcoal, 10–20%.

Nitrocellulose Powders

American Pyrocollodion Powders: nitrocellulose 99.4% (mixture of di- and trinitrocellulose, average nitrogen content 12.60%), diphenylamine. Together with residual solvent and water 0.6%.

French B Powder: CP_2, 20–25% to 50–55% according to the liveliness of the powder, along with CP_1. The solvent used is ether-alcohol. Amyl alcohol or diphenylamine may be used as stabilizer. These are indicated by AM or D after the name. CP_1 is a nitrocotton with nitrogen content of about 13%. About 10% (<15%) is soluble in ether-alcohol. It gives off 205–214 cm^3 of N_2O_4/g in nitrometer test. CP_2 is a nitrocotton with nitrogen content of about 12%, almost completely soluble in ether-alcohol (>96%) and giving off 190–198 cm^3 of N_2O_4 per g in nitrometer.

Walsrode Shotgun Powder: Nitrocellulose, 97%; chalk, 2%; ether, 1%.

Nitrocellulose Powders with Additions

Amberite:* Nitrocellulose (insoluble, 18.6%, soluble, 46%); mineral nitrates, 2.8%; vaseline, 6%; H_2O, 1.4%.

Clermonite: Nitrocellulose with mineral nitrates.

E. C. Powder: Contains from 14% of mineral nitrates and vaseline, camphor, resin and woodmeal or some of them in addition to nitrocellulose.

Empire Powder: Contains mineral nitrates, 9%, and vaseline in addition to nitrocellulose.

Hasloch Jagdpulver: Contains $Ba(NO_3)_2$, 17%, and vaseline in addition to nitrocellulose.

J. Powder (French): Contains $(NH_4)_2Cr_2O_7$, 14%, and $K_2Cr_2O_7$, 3%, in addition to nitrocellulose.

T. Powder (French): Contains 2% KNO_3 in addition to nitrocellulose, CP_1 gelatinized with acetone.

S. Powder:† CP_1, 37%; CP_2, 28%; $Ba(NO_3)_2$, 29%; KNO_3, 6%.

Rottweil Smokeless Powder (Shotgun): Insoluble nitrocellulose, 72.3%; soluble nitrocellulose, 24.5%; camphor and diphenylamine, 1%; H_2O, 1.5%; metallic nitrates, 0.7%.

Rottweil Smokeless Powder (Rifle): Insoluble nitrocellulose, 72.8%; soluble nitrocellulose, 25.0%; camphor and diphenylamine, 1%; H_2O, 1.2%.

Nitroglycerin Powders

Ballistite:‡ Guncotton, 50%; nitroglycerin, 49%; diphenylamine, 1%.

Ballistite, Norwegian: Guncotton, 50%; nitroglycerin, 40%; nitronaphthalene, 5%; diamyl phthalate, 5%.

Sporting Ballistite: Nitrocellulose, 60.5%; nitroglycerin, 39.5%.

Cordite Mk. I: Guncotton, 37%; nitroglycerin, 58%; mineral jelly, 5%; H_2O, 0.5%.

Cordite M. D.: Guncotton, 65%; nitroglycerin, 30%; mineral jelly, 5%; H_2O, 0.5%.

Cordite R. D. B.: Nitrocotton (N = 12.2%), 52%; nitroglycerin, 42%; mineral jelly, 6%.

Nitroglycerine Powders with Additions

Köln-Rottweil TNT powder: Nitrocellulose, 61%; nitroglycerin, 20%; TNT, 15%; DNT, 3.5%; centralite, 0.5%.

Allestite: Nitrocellulose, 60%; nitroglycerin, 25%; DNT, 15%.

Austrian Flake Powder No. 1: Nitrocellulose, 36%; nitroglycerin, 36%; $Ba(NO_3)_2$, 18%; charcoal, 10%.

Austrian Flake Powder No. 2 (Graphited): Nitrocellulose, 40%; nitroglycerin, 40%; $Ba(NO_3)_2$, 20%.

Wetteren Smokeless Powder:* Nitrocellulose, insoluble, 16%, soluble, 46.2%; nitroglycerin, 27.3%; charcoal, 9%; H_2O, 1.5%.

In the application of propulsive explosives the nature of the weapon, the velocity of the projectile, and the maximum permissible pressure in the barrel are usually fixed, and the powder is modified in composition or physical properties to give the ballistics demanded.

The following table from an article by MacNab and Leighton ([24]) gives the heat of explosion and the volume and composition of the explosion gases for a number of sporting powders.

Properties of Some Sporting Powders ([24])

Powder	Heat of explosion, g-cal/g	Permanent gases per g, cm^3	Water vapor per g, cm^3	Total volume of gas at 0°C and 760 mm, cm^3 per g	Composition of permanent gases, %				
					CO_2	CO	CH_4	H	N
Imperial Schultze.	742	763	152	915	8.9	52.7	1.0	27.0	10.4
Amberite.........	745	635	156	791	12.0	50.0	0.4	25.5	12.1
S. S.............	755	695	131	816	11.8	51.3	0.8	23.7	12.4
E. C.............	762	718	158	876	11.9	52.1	0.5	23.9	11.6
Schultze..........	786	576	160	736	15.5	46.7	0.8	23.0	14.0
Kynoch's smokeless.......	807	600	126	726	14.8	49.5	0.7	18.8	16.2
Cannonite.........	845	725	146	871	14.6	49.9	0.6	22.2	12.7
Shotgun Rifleite..	896	705	169	874	19.0	45.3	0.8	21.5	13.4
Walsrode..........	1014	669	206	875	21.3	48.2	0.4	10.1	14.8
Cordite M. D.....	1031	726	215	941	16.3	50.4	0.0	19.7	13.6
Cordite...........	1253	647	235	882	24.9	40.3	0.7	14.8	19.3
Sporting Ballistite.	1286	591	234	825	32.2	37.1	0.4	10.1	20.2

Standard Ballistics for Shotgun Powders

A. TYPICAL AMERICAN STANDARD PROOF

Lead crushers are used, the Eley 1913 tables being employed to calculate the pressures from the remaining length.

The following are the average ballistics aimed at for various typical powders. They refer to matured powder containing $1\frac{1}{8}$% moisture.

Charges	Velocity over 40 yards = V_{20} yd. or $V_{18.3}$ M	Pressure at 1 in. (2.54 cm) from base
Smokeless Shotgun		
3 drams powder = about 5.30 g. $1\frac{1}{8}$ oz. = 31.89 g shot. $2\frac{5}{8}$ in. flat base case.	875 ft./sec = 307.38 m/sec	3.5 ton/in.^{2} = 551.2 kg/cm^2
$3\frac{1}{2}$ drams powder = about 6.20 g. $1\frac{1}{4}$ oz. = 35.44 g shot. $2\frac{3}{4}$ in. flat base case.	925 ft./sec = 282 m/sec	$4\frac{3}{4}$ ton/in.^{2} = 748 kg/cm^2
E. C. and Schultze Powders		
3 dram charge = 5.30 g. $1\frac{1}{8}$ oz. = 31.89 g shot. $2\frac{5}{8}$ in. flat base cases.	870 ft./sec = 265.2 m/sec	
$3\frac{1}{2}$ drams charge = 6.20 g. $1\frac{1}{4}$ oz. = 35.44 g shot. $2\frac{3}{4}$ in. flat base cases.	890 ft./sec = 271.3 m/sec	4.1–4.5 ton/in.^{2} = 645.7–718.7 kg/cm^2

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* Fibrous 42 % grain bulk.

† Partially gelatinized with ether-alcohol

‡ Gelatinized with acetone.

* Gelatinized with rifle powders.

TYPICAL BRITISH STANDARD PROOF

Lead crushers are used, the Eley 1918 Tables being employed to calculate the pressures from the remaining length. Pressure: 2½–3 ton/in.^{2} = 393.7 – 472.5 kg/cm.^{2} Velocity over 20 yards = V_{10} yd. or $V_{9.15}$ m = 320–335 m/sec.

Charges Which Give Standard Ballistics

Powder	Caliber	Length of cartridge case		Powder charge, wt.		Shot charge, wt.	
		in.	mm	grains	g	ounces	g
Smokeless Diamond E. C. Empire in flat base cases, 3 drams = 33 grains	12	$2\frac{3}{4}$	70	36	2.33	$1\frac{1}{4}$	35.44
	12	$2\frac{1}{2}$	65	33	2.14	$1\frac{1}{16}$	30.12
	16	$2\frac{3}{4}$	70	31	2.01	1	28.35
	16	$2\frac{1}{2}$	65	28	1.81	$\frac{7}{8}$	24.81
Schultze Amberite in flat base cases, 3 drams = 42 grains	12	$2\frac{3}{4}$	70	46	2.98	$1\frac{1}{4}$	35.44
	12	$2\frac{1}{2}$	65	42	2.72	$1\frac{1}{16}$	30.12
	16	$2\frac{3}{4}$	70	40	2.59	$1\frac{1}{16}$	30.12
	16	$2\frac{1}{2}$	65	36	2.53	$\frac{7}{8}$	24.81
Ballistite condensed powder in cone base cases	12	$2\frac{3}{4}$	70	28	1.81	$1\frac{1}{4}$	35.44
	12	$2\frac{1}{2}$	65	25	1.62	$1\frac{1}{16}$	30.12
	16	$2\frac{3}{4}$	70	23	1.49	1	28.35
	16	$2\frac{1}{2}$	65	21	1.36	$\frac{7}{8}$	24.81
				drams			
Black powder in flat base cases, 3 drams = 84 grains	12	$2\frac{3}{4}$	70	$3\frac{1}{4}$	5.75	$1\frac{1}{4}$	35.44
	12	$2\frac{1}{2}$	65	3	5.30	$1\frac{1}{8}$	31.89
	16	$2\frac{3}{4}$	70	3	5.30	1	28.35
	16	$2\frac{1}{2}$	65	$2\frac{3}{4}$	4.87	$\frac{7}{8}$	24.81

The bulk density of the 33 grain powders is 375–385 g per liter.
The bulk density of the 42 grain powders is 475–485 g per liter.
The bulk density of Sporting Ballistite is 700–710 g per liter.

RIFLE POWDERS

For rifle powders there are no fixed standard ballistics such as have been established for shotgun powders. As an example some data are given for the 7 mm Mauser rifle.

7 mm Mauser Rifle

Powder	Powder charge, grains	Weight of bullet, grains	Muzzle velocity, ft./sec	Pressure
American Military Rifle powder (*a*)...	48	139	2900	Best burning pressure, 3515–3967 kg/cm^2
(*b*)..........	42.5	139	2750	2109–3151 kg/cm^2
	44.0	139	2900	
(*c*)..........	36.9	175	2300	2320–2671 kg/cm^2
	40	175	2400	
	44	139	2786	
	45.5	139	2950	
(*d*)..........	5.0	84	950	703–1055 kg/cm^2
	8.0	120	1150	
British Rifle Neonite..........	38	173	2300	Pressure aimed at: 17.5 ton/in.^{2}
	43	140	2800	19.5 ton/in.^{2}

ORDNANCE POWDER

Here also, as in the case of rifle powders, the ballistic values required are fixed in advance, and the powder is modified in composition, in size and shape of grain, or by coating to modify its rate of burning. Examples are given of ballistics for the 7.5 cm field gun.

7.5 cm Field Gun

Gun	Powder charge, kg	Weight of projectile, kg	Muzzle velocity, m/sec	Range, km
U. S. A., 75 mm (Model 1923)....		6.8	665	13.5
Switzerland........		6.35	250–485	8.6
France............		7.25 (shrapnel)	550	11
		7.98 (H. E. shell)		
Japan (Model 05)..	0.631	6.8 (shrapnel)	510	5.8
	0.631	6.4 (H. E. shell)		8.35

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LITERATURE REFERENCES

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In all literature references cited in International Critical Tables the name of the journal or publication is indicated by means of a *Key number* corresponding to the list given below. The numbers which follow this key number in a literature citation are, in the order named: (1) the volume, (2) the page, and (3) the last two figures of the year. Thus 64*V*, **31**: 253; 22, indicates Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, page 253, 1922. Series numbers are not given. Key numbers referring to books and other non-serial publications are preceded by the letter *B*, and the volume number is given in roman numerals. Thus *B10*, **IV**: 191; 18, indicates Doelter, Handbuch der Mineralchemie, page 191 of Vol. 4 of the 1918 edition. The key number *O* is used to indicate "private communication from."

RÉFÉRENCES BIBLIOGRAPHIQUES

Le nom du journal ou de la publication de toutes les références bibliographiques citées dans les Tables Critiques Internationales est indiqué au moyen d'un *nombre-clé* correspondant à la liste donnée ci-dessous. Les nombres qui suivent ce nombre-clé dans un renvoi bibliographique indiquent dans l'ordre suivant: (1) le volume, (2) la page, et (3) les deux derniers chiffres de l'année. Ainsi *64V*, **31**: 253; 22, indique Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, page 253, 1922. Les numéros des séries ne sont pas donnés. Les nombres-clés se rapportant à des livres ou à des publications non périodiques sont précédés de la lettre *B* et le numéro du volume est donné en chiffres romains. Ainsi *B10*, **IV**: 191; 18, indique Doelter, Handbuch der Mineralchemie, page 191 du volume 4 de l'édition de 1918. Le nombre-clé *O* est employé pour indiquer "communication privée de."

DAS LITERATURVERZEICHNIS

In allen Literaturstellen, die in I. C. T. verzeichnet sind, ist der Name der Zeitschrift oder der Publikation mit Hilfe einer *Schlüsselnummer*, entsprechend der unten folgenden Liste, angegeben. Die Zahlen, welche diesen Schlüsselnummern bei einem Literaturzitat folgen, bedeuten der Reihe nach: (1) der Band, (2) die Seite, und (3) die letzten zwei Zahlen des Jahrganges. So bedeutet z. B. *64V*, **31**: 253; 22, Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Band 31, Seite 253, 1922. Serien-Nummern werden nicht angegeben. Der Schlüsselzahl wird ein *B* vorausgesetzt, wenn sie Bücher, oder eine andre nicht periodische Veröffentlichung bezeichnet. Die Bandnummer wird durch römische Ziffern angegeben. Es bedeutet z. B. also *B10*, **IV**: 191; 18, Doelter, Handbuch der Mineralchemie, Seite 191, des 4 Bandes, der Auflage des Jahres 1918. Die Schlüsselzahl *O* wird gebraucht, um anzuzeigen, dass es eine "private Mitteilung" ist.

INDICAZIONI BIBLIOGRAFICHE

In tutte le indicazioni bibliografiche che si incontrano nelle "Tabelle Critiche Internazionali" il nome del giornale o della pubblicazione è espresso con un *numero chiave* riportato nell'elenco dato più oltre. I numeri che, nella citazione, vengono dopo il numero chiave sono disposti con l'ordine seguente: (1) il volume, (2) la pagina, e (3) le ultime due cifre del millesimo. Così *64V*, **31**: 253; 22, indica la Verslag koninklijke Akademie van Wetenschappen te Amsterdam, Vol. 31, pagina 253, 1922. I numeri di serie non vengono dati. Quando un numero chiave è preceduto dalla lettera *B* si riferisce a libri o ad altre pubblicazioni non periodiche, e il numero del volume viene allora scritto in cifre romane. Così *B10*, **IV**: 191; 18, indica Doelter, Handbuch der Mineralchemie, pagina 191 del IV° volume dell'edizione 1918. Il numero chiave *O* indica "Comunicazione privata da . . ."

KEY TO THE PERIODICALS

Data regarding the libraries which receive many of these periodicals may be found through the following sources:

United States and Canada: "Periodicals Abstracted by Chemical Abstracts, 1926" (Chemical Abstracts, Ohio State Univ., Columbus, Ohio); "Union List of Serials in the Libraries of the United States and Canada, 1927" (H. W. Wilson & Co., New York City); "A Catalogue of Scientific Periodicals in Canadian Libraries, 1924" (McGill Univ., Montreal, Canada).

Great Britain: "A World List of Scientific Periodicals Published in the Years 1900–1921" (Oxford Univ. Press, London, 1925–1927).

Holland: "Chemisch Jaarboekje tevens Jaarboekje der Nederlandsche Chemische Vereeniging, Vol. 3." (Amsterdam, D. B. Centen, 1920).

1. Journal of the American Chemical Society.
2. Physical Review.
3. London, Edinburgh and Dublin Philosophical Magazine and Journal of Science.
4. Journal of the Chemical Society, London. (Memoirs of the Chemical Society; *continued as* Quarterly Journal; *later* Journal.)
5. Proceedings of the Royal Society (London). A. Mathematical and Physical Sciences.

5B. Proceedings of the Royal Society (London). B. Biological Sciences.

6. Annales de chimie et de physique. (*Divided into* Nos. 14 and 16 *in 1914*).
7. Zeitschrift für physikalische Chemie, Stöchiometrie und Verwandtschaftslehre.
8. Annalen der Physik. [Journal der Physik, 1790–1794. Neues Journal der Physik, 1795–1796. Annalen der Physik, 1799–1819; Annalen der Physik und der physikalischen Chemie, 1819–1824 (Gilbert). Annalen der Physik und Chemie, 1824–1899 (Poggendorff, Wiedemann). Annalen der Physik, 1900– (Drude, Wien and Planck).]
9. Zeitschrift für Elektrochemie und angewandte physikalische Chemie.
10. Tables annuelles internationales de constantes et données numériques.
11. American Chemical Journal. (*Combined with* No. 1 *in 1914.*)
12. American Journal of Science. (American Journal of Science and Arts, 1820–79; *known also as* Silliman's Journal of Science.)
13. Annalen der Chemie, Justus Liebig's.
14. Annales de chimie.
15. Annales des mines ou recueil de mémoires sur l'exploitation des mines et sur les sciences et les arts qui s'y rattachent.
16. Annales de physique.
17. Anzeiger der Akademie der Wissenschaften in Wien. Mathematisch-naturwissenschaftliche Klasse.
18. Archives néerlandaises des sciences exactes et naturelles. Séries IIIA (Sciences exactes).

18B. Archives néerlandaises de physiologie de l'homme et des animaux. (Séries IIIC of No. 18.)

19. Arkiv för Kemi, Mineralogi och Geologi.
20. Arkiv för Matematik, Astronomi och Fysik.
21. Astrophysical Journal.
22. Atti della reale accademia nazionale dei Lincei. (Rendiconti classe di scienze fisiche, matematiche e naturali.)
23. Atti della reale accademia delle scienze di Torino.
24. Atti del reale istituto Veneto di scienze, lettere ed arti.
25. Berichte der deutschen chemischen Gesellschaft.
26. Berichte der deutschen physikalischen Gesellschaft. *See also* No. 96.
27. Bulletin de la société chimique de France. (*Before 1908 was* Bulletin de la société chimique de Paris.)
28. Bulletin de la société chimique de Belgique. (*Before 1904 was* Bulletin de l'association belge des chimistes.)
29. Bureau of Mines, Bulletins.
30. Bureau of Mines, Technical Papers.
31. Bureau of Standards, Scientific Papers. (*Continued as* No. 546.)

31A. Bureau of Standards, Bulletin. (*Continued as* No. 546.)

32. Bureau of Standards, Technologic Papers. (*Continued as* No. 546.)
33. Chemical and Metallurgical Engineering. (*Name changed July, 1918, from* Metallurgical and Chemical Engineering.)
34. Comptes rendus hebdomadaires des séances de l'académie des sciences, de l'institut de France.
35. Elektrochemische Zeitschrift.
36. Gazzetta chimica italiana.
37. Helvetica Chimica Acta.
38. Journal of the American Ceramic Society.

38B. Bulletin of the American Ceramic Society.

39. Journal of the American Institute of Electrical Engineers.
40. Journal of the American Institute of Metals. (*See* No. 329.)
41. Journal of the Chemical Society of Japan (Nippon Kwagaku Kwai Shi). (*Name changed in Jan., 1921, from* Journal of the Tokyo Chemical Society.)

41B. Bulletin of the Chemical Society of Japan.

42. Journal de chimie physique.
43. Journal of the Faculty of Engineering, Tokyo Imperial University.
44. Journal of the Faculty of Science, Tokyo Imperial University.
45. Industrial and Engineering Chemistry. (*Name changed Jan., 1923, from* Journal of Industrial and Engineering Chemistry.)
46. Journal of the Institution of Electrical Engineers (London).
47. Journal of the Institute of Metals (London).
48. Journal of the Optical Society of America and Review of Scientific Instruments.
49. Journal de pharmacie et de chimie.
50. Journal of Physical Chemistry.
51. Journal de physique et le radium. (*Formed from* Le radium *and* Journal de physique, théorique et appliquée.)
52. Journal für praktische Chemie.
53. Journal of the Russian Physico-Chemical Society. (Chemical part.)
54. Journal of the Society of Chemical Industry.
55. Kolloid-Zeitschrift. (*Formerly* Zeitschrift für Chemie und Industrie der Kolloide.)
56. Mechanical Engineering. (*Formerly* Journal of the American Society of Mechanical Engineers.)

57. Monatshefte für Chemie und verwandte Teile anderer Wissenschaften.
58. Nature (London).
59. Nuovo Cimento.
60. Översigt af Finska Vetenskaps-Societetens, Förhandlingar. (*Discontinued with* Vol. 64, 1921–22.)
61. Oversigt over det Kongelige Danske Videnskabernes Selskabs, Forhandlinger.
62. Philosophical Transactions of the Royal Society of London. Series A, Physical and Mathematical.

62B. Philosophical Transactions of the Royal Society of London. Series B, Biological.

63. Physikalische Zeitschrift, vereinigt mit dem Jahrbuch der Radioaktivität und Elektronik.

64P. Proceedings of the Royal Academy of Sciences of Amsterdam.

64V. Verslag koninklijke Akademie van Wetenschappen te Amsterdam.

65. Proceedings of the American Academy of Arts and Sciences.
66. Proceedings of the American Society for Testing Materials.
67. Proceedings of the Physical Society of London.
68. Proceedings of the Royal Society of Edinburgh.
69. Proceedings and Transactions of the Royal Society of Canada.
70. Recueil des travaux chimiques des Pays-Bas.
71. Rendiconti dell'accademia delle scienze fisiche e matematiche. (Classe della società reale di Napoli.)
72. Rendiconti reale istituto Lombardo di scienze e lettere.
73. Rendiconti della società chimica italiana.
74. Revue de métallurgie.

74E. Revue de métallurgie, Extraits.

75. Sitzungsberichte Akademie der Wissenschaften in Wien, mathematisch-naturwissenschaftliche Klasse.
76. Sitzungsberichte der preussischen Akademie der Wissenschaften.
77. Stahl und Eisen.
78. Transactions of the American Electrochemical Society.
79. Transactions of the American Institute of Chemical Engineers.
80. Transactions of the American Institute of Mining and Metallurgical Engineers.
81. Transactions of the American Ceramic Society. (*Continued in 1917 by* No. 38.)
82. Transactions of the Ceramic Society (England).
83. Transactions of the Faraday Society.
84. Transactions of the Illuminating Engineering Society (New York).
85. Transactions of the Optical Society (London).
86. University of Illinois, Engineering Experiment Station, Bulletin.
87. Verhandelingen der koninklijke Akademie van Wetenschappen te Amsterdam.
88. Verhandlungen der physikalischen Gesellschaft zu Berlin. (*See also* No. 96.)
89. Wissenschaftliche Abhandlungen der physikalisch-technischen Reichsanstalt.
90. Wissenschaftliche Abhandlungen der Kaiserlichen Normal-Eichungs-Kommission. (*Now* Reichsanstalt für Mass und Gewicht.)
91. Zeitschrift für analytische Chemie.
92. Zeitschrift für angewandte Chemie.
93. Zeitschrift für anorganische und allgemeine Chemie. (*Name changed in 1915 from* Zeitschrift für anorganische Chemie.)
94. Zeitschrift für Krystallographie. (*Name changed in 1921 from* Zeitschrift für Krystallographie und Mineralogie.)
95. Zeitschrift für Metallkunde. (*Formerly* Internationale Zeitschrift für Metallographie.)
96. Zeitschrift für Physik. (Verhandlungen der physikalischen Gesellschaft zu Berlin, 1882–1898; Verhandlungen der deutschen physikalischen Gesellschaft, 1899–1902; Berichte der deutschen physikalischen Gesellschaft, 1903–1919; Zeitschrift für Physik, 1920– .)
97. Zeitschrift für technische Physik.
98. Zeitschrift des Vereines deutscher Ingenieure.
99. Zeitschrift für wissenschaftliche Photographie, Photophysik und Photochemie.
100. Sprechsaal, Zeitschrift für die keramischen, Glas- und verwandten Industrien.
101. Elektrotechnische Zeitschrift.
102. Céramique.
103. Keramische Rundschau.
104. Berichte der deutschen keramischen Gesellschaft.
105. Journal of the Society of Glass Technology.
106. Revue générale de l'électricité.
107. Electrical World.
108. Electrical Review (London).
109. National Advisory Committee for Aeronautics, Annual Reports.
110. New Jersey Ceramist.
111. New Zealand Journal of Science and Technology
112. Dinglers polytechnisches Journal.
113. Berichte der technisch-wissenschaftliche Abteilung deg Vereins keramische Gewerbe im Deutschland.
114. Electric Journal.
115. Engineering.
116. Sibley Journal of Engineering.
117. Scientific Proceedings of the Royal Dublin Society.
118. Annales de l'institut polytechnique du Don, Novocerkask.
119. Proceedings of the American Institution of Electrical Engineers. (*Discontinued in 1919.*)
120. General Electric Review.
121. Electrician.
122. Journal of the American Society of Mechanical Engineere. (*See* No. 56.)
123. British Clayworker.
124. Silikat-Zeitschrift.
125. Archiv für Elektrotechnik. (*Supplement to* No. 101.)
126. Bulletin de la société française des électriciens.
127. Elettrotecnica.
128. Journal of the Washington Academy of Sciences.
129. Transactions of the American Institute of Electrical Engineers.
130. Technische Studien.
131. American Journal of Physiology.
132. Anales de la sociedad española de física y química.
133. British Association for the Advancement of Science, Reports.
134. Bulletin de l'académie des sciences de l'union des républiques soviétiques socialistes. (*Formerly* Bulletin de l'académie impérial des sciences de St. Pétersbourg; *name changed in 1917 to* Bulletin de l'académie des sciences de Russie; *present name dates from 1925.*)
135. Chemical News and Journal of Industrial Science. (*Name changed in 1921 from* Chemical News and Journal of Physical Science.)
136. Chemiker-Zeitung.
137. Kongelige Danske Videnskabernes Selskab. Mathematisk-fysiske Meddelelser.
138. Societas scientiarum fennica. Commentationes physico-mathematicae.
139. Ferrum.
140. Journal of the Iron and Steel Institute, London.
141. Journal of Biological Chemistry.

142. Journal of the Society of Chemical Industry, Japan. (*Formerly* Journal of Chemical Industry, Japan.)
143. Journal of The Franklin Institute.
144. Mathematikai ès Természettudomânyi Ertesitö, Budapest.
145. Zeitschrift für Biologie.
146. Zement und Beton.
147. Meddelanden från K. Vetenskapsakademiens Nobelinstitut.
148. Zeitschrift für die gesamte Kälte-Industrie.
149. Archives des sciences physiques et naturelles. (Bibliothèque britannique, 1796–1815; Bibliothèque universelle des sciences, belles-lettres et arts, 1816–1835; Bibliothèque universelle de Genève 1836–1845; Supplément à la bibliothèque universelle de Genève. Archives des sciences physiques et naturelles, 1846–1847; Bibliothèque universelle de Genève. Archives des sciences physiques et naturelles, 1848–1857; Bibliothèque universelle, revue suisse et étrangère. Archives des sciences physiques et naturelles, 1858–1861; Bibliothèque universelle et revue suisse. Archives des sciences physiques et naturelles, 1862–1867; Bibliothèque universelle. Archives des sciences physiques et naturelles, 1878– .)
150. Mitteilungen über Forschungsarbeiten auf dem Gebiete des Ingenieurwesens insbesondere aus dem Laboratorium der technischer Hochschulen. Verein deutscher Ingenieure.
151. Mémoires de l'académie royale des sciences de l'institut de France.
152. Carnegie Institution of Washington, Publications.
153. Minutes of Proceedings of the Institution of Civil Engineers.
154. Iowa Geological Survey, Bulletin.
155. Missouri Bureau of Geology and Mines.
156. U. S. Geological Survey, Bulletin.
157. U. S. Department of Agriculture, Bulletin.
158. New York State Museum, Bulletin.
159. Science Reports of the Tôhoku Imperial University. Series I, Mathematics, Physics and Chemistry.
159B. Science Reports of the Tôhoku Imperial University. Series III, Petrology, Mineralogy and Mineral Deposits.
160. Arkansas Geological Survey, Annual Reports.
161. Mitteilungen aus dem königlichen technischen Versuchsanstalten zu Berlin. (*See also* No. 312.)
162. Mitteilungen aus dem Mechanisch-technischen Laboratorium der technischen Hochschule in München.
163. Minnesota Geological and Natural History Survey.
164. Colorado, Biennial Report Capitol Managers.
165. Bulletin internationale de l'académie des sciences de Cracovie. (*Name changed to* Bulletin internationale de l'académie Polonaise des sciences et des lettres.)
166. Science.
167. Jahresbericht über die Fortschritte der Chemie und verwandte Theile anderer Wissenschaften.
168. Communications from the Physical Laboratory at the University of Leiden.
169. Annales de l'Institut Polytechnique Pierre-le-Grand, Pétrograd.
170. Memorie della reale accademia nazionale dei Lincei, Roma.
171. Sitzungsberichte der Heidelberger Akademie der Wissenschaften. Mathematisch-naturwissenschaftliche Klasse. Abteilung A.
172. International Congress of Applied Chemistry.
173. Analyst, London.
174. Transactions of the Royal Society of Edinburgh.
175. Annales academiae scientiarum fennicae.
176. Chemisch Weekblad, Amsterdam.
177. Annales scientifiques de l'université de Jassy.
178. Archivio di fisiologia (Florence).
179. Nachrichten (Iswesti) des Polytechnikums, Petrograd.
180. Anzeiger der Akademie der Wissenschaften, Krakau.
181. Travaux de la société de physique et de chimie de Kharkoff.
182. Proceedings of the Chemical Society, London.
183. Annales de l'Institut électrotechnique Alexander III, Pétrograd.
184. American Journal of Pharmacy.
185. Chemisches Zentralblatt.
186. Bulletin de la classe des sciences, académie royale de Belgique.
187. Metall und Erz, Zeitschrift für Metallhüttenwesen und Erzbergbau, einschl. Aufbereitung.
188. Nachrichten von der königlichen Gesellschaft der Wissenschaften zu Göttingen. Geschaftliche Mitteilungen; mathematisch-physikalische Klasse.
189. Centralblatt für Mineralogie, Geologie und Paläontologie.
190. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie.
190B. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage Band.
191. Bulletin de la société française de minéralogie.
192. Metallurgie. (*Divided into* Nos. 139 and 187.)
193. Mitteilungen der Naturforschenden Gesellschaft zu Halle.
194. Journal of the Science Association, Maharajah's College.
195. Sitzungsberichte der Dorpater Naturforscher-Gesellschaft an der Universität.
196. Sammlung chemischer und chemisch-technischer Vorträge.
197. Proceedings of the National Academy of Sciences.
198. Revue générale des sciences pures et appliquées.
199. Le Radium. (*Merged into* No. 51 *in 1920.*)
200. Jahrbuch der Radioaktivität und Elektronik. (*Combined with* No. 63 *in 1924.*)
201. Proceedings of the Cambridge Philosophical Society.
202. Zeitschrift für physiologische Chemie.
203. Archiv für Anatomie und Physiologie. Physiologische Abteilung. (*Merged with* No. 278.)
204. Photographic Journal.
205. Biochemische Zeitschrift.
206. Comptes rendus des séances de la société de biologie.
207. Geologiska Föreningen i Stockholm, Förhandlingar.
208. Physica, Nederlandsch Tijdschrift voor Natuurkunde.
209. Japanese Journal of Chemistry.
210. Scientific Papers, Institute of Physical-Chemical Research. Tokyo.
211. Abhandlungen der sächsischen Akademie der Wissenschaften zu Leipzig. Mathematisch-physischen Klasse.
212. Transactions of the American Society for Steel Treating.
213. Sitzungsberichte der bayerischen Akademie der Wissenschaften zu München. Mathematisch-physikalischen Klasse.
214. Kongelige Danske Videnskabernes Selskab, Skriffer naturvidenskabelig og mathematisk Afdeling.
215. Lunds Universitets Årsskrift.
216. Giornale di chimica industriale ed applicata. (Annali di chimica applicata, *1914; continued as* Giornale di chimica applicata; *combined with* Giornale di chimica industriale, *March, 1920, to form* Giornale di chimica industriale ed applicata.)
217. U. S. Coast and Geodetic Survey, Special Publications.
218. Naturwissenschaften.
219. Proceedings of the Physico-Mathematical Society of Japan.
220. Jern-Kontorets Annaler, Stockholm.
221. Berichte der sächsischen Akademie der Wissenschaften zu Leipzig. Mathematisch-physische Klasse.
222. Giornale di mineralogia, cristallografia e petrografia.
223. Journal of General Physiology.
224. Kosmos, Stockholm.
225. Kosmos. (Polskie towarzystwo przyrodników imienia Kopernika.) Lemberg.
226. Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf.

227. Proceedings of the Society for Experimental Biology and Medicine.
228. Denkschriften der kaiserlichen Akademie der Wissenschaften zu Wien. Mathematisch-naturwissenschaftliche Klasse.
229. Journal of Bacteriology.
230. Biochemical Journal.
231. U. S. Public Health Service, Public Health Reports.
232. Soil Science.
233. Pharmaceutisch Weekblad.
234. Journal of the South African Chemical Institute. (*Name changed in 1922 from* Journal of the South African Association of Analytical Chemists.)
235. Comptes-rendus des travaux du laboratoire Carlsberg.
236. Ergebnisse der Physiologie.
237. Fortschritte der Chemie, Physik und physikalischen Chemie.
238. Travaux et mémoires du bureau international des poids et mesures.
239. Nouveaux mémoires de l'académie royale des sciences, des lettres et des beaux-arts de Belgique, Brussels.
240. Bibliothèque universelle des sciences, belles-lettres et arts. (*Continued as* No. 149.)
241. Proceedings of the American Philosophical Society.
242. Vierteljahrsschrift der naturforschenden Gesellschaft, Zürich.
243. Zeitschrift für Instrumentenkunde.
244. Journal of the Society of Automotive Engineers.
245. Zeitschrift für das gesamte Schiess- und Sprengstoffwesen.
246. Ice and Refrigeration.
247. Chemist-Analyst.
248. Proceedings of the University of Durham Philosophical Society.
249. Fortschritte auf dem Gebiete der Röntgenstrahlen.
250. Bulletin de séances de la société française de physique (1873–1910). (*From 1873–1901 as its* Séances; *continued as* No. 51.)
251. Proceedings of the Royal Society of Victoria, Melbourne.
252. Chemische Umschau auf dem Gebiete der Fette, Oele, Wachse und Harze. (*Before 1916* Chemische Revue über die Fett- und Harz-Industrie.)
253. Lubrication.
254. Zeitschrift für Beleuchtungswesen, Heizungs- und Lüftungstechnik.
255. Bulletin of the American Institute of Mining and Metallurgical Engineers. (*Continued as* No. 329.)
256. Comptes rendus de la société scientifique, Warsaw.
257. Bulletin of the Imperial Institute, London. (*Before 1903,* Imperial Institute Journal.)
258. Le cuir. Edition technique. (*Name changed Nov., 1923 to* Le cuir technique.)
259. Collegium.
260. Indian Forest Records.
261. Journal of the American Leather Chemists' Association.
262. Journal of the International Society of Leather Trades' Chemists. (*Before Oct., 1925,* Journal of the Society of Leather Trades' Chemists.)
263. Leather Trades' Review.
264. Ledertechnische Rundschau. (*Technical supplement of* Der Lederindustrie.)
265. Queensland Agricultural Journal.
266. Indianapolis Medical Journal.
267. Philippine Journal of Science.
268. Terrestrial Magnetism.
269. Mineralogical Magazine and Journal of the Mineralogical Society.
270. Berichte der naturforschenden Gesellschaft zu Freiburg, im Breisgau.
271. Revue scientifique.
272. Transactions of the Wisconsin Academy of Sciences, Arts and Letters.
273. Berichte der deutschen pharmazeutischen Gesellschaft. (*See also* No. 293.)
274. Pharmazeutische Zentralhalle für Deutschland.
275. International Sugar Journal.
276. Chemical Age, London.
277. Archiv für experimentelle Pathologie und Pharmakologie.
278. Archiv für die gesamte Physiologie des Menschen und der Tiere. (Pflüger.)
279. Zeitschrift für Untersuchung der Lebensmittel. (*Formerly* Zeitschrift für Untersuchung der Nahrungs- und Genussmittel sowie der Gebrauchsgegenstande.)
280. Umschau.
281. Zeitschrift für Psychologie und Physiologie der Sinnesorgane.
282. Wochenschrift für Brauerei.
283. Journal de psychologie normal et pathologique.
284. Journal of the American Pharmaceutical Association.
285. Journal of Mathematics and Physics (Massachusetts Institute of Technology).
286. Chemical Reviews.
287. Kolloidchemische Beihefte.
288. Revue générale des colloides et de leurs applications industrielles.
289. Journal of Physiology.
290. Journal of the Society of Dyers and Colourists.
291. Arbeiten aus dem Reichsgesundheitsamte.
292. Proceedings and Transactions of the Nova Scotian Institute of Science.
293. Archiv der Pharmazie. (*Combined with* No. 273 *in 1924 to form* Archiv der Pharmazie und Berichte der deutschen pharmazeutischen Gesellschaft.)
294. Mémoires de l'académie de Belgique.
295. Proceedings of the American Wood-Preservers' Association.
296. Kunststoffe, Zeitschrift für Erzeugung und Verwendung veredelter oder chemisch hergestellter Stoffe.
297. National Advisory Committee on Aeronautics. Technical Reports.
298. National Advisory Committee on Aeronautics. Technical Notes.
299. British Aeronautical Research Committee. Reports and Memoranda.
300. British Advisory Committee on Aeronautics. Reports and Memoirs.
301. Jahrbuch der Motorluftschiff-Studiengesellschaft.
302. Smithsonian Institution Publications. Miscellaneous Collection.
303. Bulletin de l'institut aérodynamique de Koutchino, Pétrograd.
304. Aerodynamische Versuchsanstalt zu Göttingen. Ergebnisse.
305. Transactions of the American Society of Civil Engineers.
306. Journal of the American Society of Naval Engineers.
307. Iron and Coal Trades Review.
308. Fortschritte der Mineralogie, Kristallographie und Petrographie.
309. Bulletin of the Lewis Institute, Structural Materials Research Laboratory, Chicago.
310. Transactions of the National Lime Manufacturers' Association.
311. France-Belgique. (Revue de l'ingénieur et index technique *merged with this in 1922.*)
312. Mitteilungen aus dem Materialprüfungsamt und dem Kaiser-Wilhelm-Institut für Metallforschung zu Berlin-Dahlem. (Mitteilungen aus dem königlichen technischen Versuchsanstalten zu Berlin, 1883–1903; *in 1904 became* Mitteilungen aus dem königlichen Materialprüfungsamt zu Gross-Lichter-

felde West; *later becoming* Mitteilungen aus dem königlichen Materialprüfungsamt zu Berlin-Lichterfelde West; *name changed in 1919 to* Mitteilungen aus dem Materialprüfungsamt zu Berlin-Lichterfelde West; *name changed in 1920 to* Mitteilungen aus dem Materialprüfungsamt zu Berlin-Dahlem; *present name dates from 1923.*)

313. U. S. Bureau of Mines, Reports of Investigations.
314. Tonindustrie-Zeitung.
315. Mémorial des poudres. (*Formerly* Mémorial des poudres et salpêtres.)
316. Journal and Proceedings of the Royal Society of New South Wales.
317. Chemische Industrie. (*Combined with* No. 92 *in 1921; separated again in 1923.*)
318. Journal of the Indian Institute of Science.
319. Die deutsche pharmazeutische Zeitung.
320. Journal of Analytical and Applied Chemistry. (*Merged into* No. 1 *in 1893.*)
321. Transactions of the Royal Dublin Society.
322. Schriften der Dorpater Naturforscher-Gesellschaft an der Universität.
323. Jahrbuch der königlichen kaiserlichen geologischen Reichsanstalt.
324. Canadian Chemistry and Metallurgy.
325. Proceedings of the Royal Institution of Great Britain.
326. Astronomical Journal.
327. Annales de la société scientifique de Bruxelles.
328. American Mineralogist.
329. Mining and Metallurgy. (Transactions of the American Brass Founders' Association, 1908–11; Transactions of the American Institute of Metals, 1912–16; Journal of the American Institute of Metals, 1917–18; *discontinued in 1918 and incorporated with* Bulletin of the American Institute of Mining Engineers; *with issue No. 148, 1919, this Bulletin became* Bulletin of the American Institute of Mining and Metallurgical Engineers; *with issue No. 154, 1919, name changed again to* Mining and Metallurgy.)
330. Psychological Monographs.
331. Archives of Psychology.
332. Philosophische Studien.
333. Psychological Review.
334. Journal of Experimental Psychology.
335. American Journal of Psychology.
336. Bulletin of the Geological Society of America.
337. Bulletin of the National Research Council.
338. Researches of the Electro-Technical Laboratory (Tokyo).
339. American Journal of Mathematics.
340. Philippine Agriculturist.
341. Journal of Agricultural Research.
342. Annales de chimie analytique et de chimie appliquée et revue de chimie analytique réunies.
343. Zeitschrift für öffentliche Chemie. (*Suspended at end of 1922.*)
344. Apotheker Zeitung.
345. Bulletin des sciences pharmacologiques.
346. Malayan Agricultural Journal. (*Formerly* Bulletin of the Department of Agriculture, Federated Malay States.)
347. Pharmaceutical Journal and Pharmacist.
348. Cotton Oil Press.
349. Seifensieder-Zeitung und Rundschau über die Harz-, Fett- und Ölindustrie mit dem Beiblatt: Der chemisch-technische Fabrikant.
350. Les matières grasses.
351. Journal of State Medicine, London.
352. Milchwirtschaftliche Zentralblatt. (*Name changed in 1912 from* Milch-Zeitung.)
353. Academia caesarea leopoldino carolina germanica naturae curiosorum.
354. National Physical Laboratory, Collected Researches and Reports, London.
355. The Engineer, London.
356. Journal of the Royal Society of Arts.
357. Anales de la asociación química Argentina. (*Name changed Jan., 1921, from* Anales de la sociedad química Argentina.)
358. Journal of the Institution of Petroleum Technologists and Record of Transactions.
359. Petroleum Age. (Petroleum; *name changed to* Petroleum Magazine, *and then back to* Petroleum; *in Sept., 1921, combined with* Petroleum Age *to form* Petroleum Age including Petroleum; *name changed back to* Petroleum Age, *Dec., 1925.*)
360. National Petroleum News.
361. Petroleum, Zeitschrift für die gesamten Interessen der Mineralöl-Industrie und des Mineralöl-Handels. (*Formerly* Petroleum, Zeitschrift für die gesamten Interessen der Petroleum-Industrie und des Petroleum-Handels.)
362. Chemické Listy pro vědu a Prumysl.
363. Petroleum Review. (*Replaced by* No. 364.)
364. Petroleum Times. (*See* No. 363.)
365. Bureau of Standards, Circulars.
366. Feuerungstechnik.
367. Oesterreichische Chemiker-Zeitung.
368. Proceedings of the Institution of Automobile Engineers, London.
369. Gornyĭ zhurnal.
370. Memoirs of the American Academy of Arts and Sciences, Boston.
371. University Geological Survey of Kansas, Reports.
372. Verein zur Beförderung des Gewerbefleisses, Verhandlungen.
373. Chemisch-technisches Repertorium. (*Supplement to* No. 136.)
374. Oil and Colourman's Journal.
375. Polytechnisches Centralblatt.
376. Automotive Industries.
377. Bulletin de la section scientifique de l'académie Roumaine.
378. Chimie et industrie.
379. Journal of the Japanese Ceramic Society.
380. Gesundheits-Ingenieur.
381. Automobile Engineer and Internal Combustion Engineering. (Automobile Engineer, London, *1910 to Oct., 1912;* Internal Combustion Engineering, *Oct., 1912, to Jan., 1914; present name since Jan., 1914.*)
382. Refrigerating Engineering. (Transactions of the American Society of Refrigerating Engineers, *1905–13;* American Society of Refrigerating Engineers Journal; *present name dates from July, 1922.*)
383. Revue générale du froid et des industries frigorifiques.
384. Le génie civil, Paris.
385. Journal of the American Society of Heating and Ventilating Engineers.
386. Canada Department of Mines.
387. Mineral Industry.
388. Öfversigt af kongl. Svenska Vetenskaps-Akademien, Förhandlingar.
389. South African Journal of Industries. (*United with the* Official Labour Gazette of the Union of South Africa *in 1925 to form the* South African Journal of Industries and Labour Gazette.)
390. Indian Forest Bulletin.
391. Indian Forester.
392. Indian Forest Pamphlet.
393. American Society for Testing Materials, Standards.

394. Fuel in Science and Practice.
395. Engineering and Mining Journal-Press. (*Formed in April, 1922 by the combining of* Engineering and Mining Journal *with* Mining and Scientific Press; *name changed July, 1926, to* Engineering and Mining Journal.)
396. Gas Journal. (*Formerly* Journal of Gas Lighting and Water Supply.)
397. Gas- und Wasserfach. (*Name changed Jan., 1922, from* Journal für Gasbeleuchtung und verwandte Beleuchtungsarten sowie für Wasserversorgung.)
398. Memoirs and Proceedings of the Manchester Literary and Philosophical Society.
399. Colliery Guardian and Journal of the Coal and Iron Trades.
400. Beama.
401. Revue de l'industrie minérale. (Bulletin de la société de l'industrie minérale; *name changed Jan., 1921, to* Revue de la société de l'industrie minérale; *name changed to* Revue de l'industrie minérale.)
402. Technique moderne.
403. Proceedings of the Institution of Mechanical Engineers.
404. Engineering News-Record. (*Formed by the combining of* Engineering News *with* Engineering Record.)
405. Glückauf, Berg- und Hüttenmännische Zeitschrift.
406. Monthly Weather Review.
407. Jornal de Sciencias Mathematicas, Physicas e Naturales, Lisbon.
408. Journal de mathématiques pures et appliquées (Paris). (*Continues* Annales de mathématiques pures et appliquées; *present name dates from 1836.*)
409. Bayerisches Industrie- und Gewerbe-Blatt. (Kunst- und Gewerbe-Blatt, *1815–68; present name dates from 1869.*)
410. Edinburgh Philosophical Journal, 1819–26; Edinburgh New Philosophical Journal, 1826–64; Quarterly Journal of Science, 1864–70; Quarterly Journal of Science and Annals of Mining, Metallurgy, Engineering, Industrial Arts, Manufactures and Technology, 1871–79; Monthly Journal of Science and Annals of Astronomy, Biology, Geology, Industrial Arts, Manufactures and Technology, 1879–85.
411. Proceedings of the North East Coast Institute of Engineers and Shipbuilders.
412. Horseless Age. (*Merged into* Motor Age *in 1918.*)
413. Journal of the Royal Aeronautical Society. (Annual Report of the Royal Aeronautical Society, *1866–96; superseded by* Aeronautical Journal; *later* Journal of the Royal Aeronautical Society.)
414. Mitteilungen über Forschungsarbeiten auf den Gebiete des Ingenieurwesens hrsg. vom Vereine deutscher Ingenieure.
415. Journal of the Textile Institute.
416. Brennstoff-Chemie.
417. Iron and Steel Institute, Carnegie Scholarship Memoirs.
418. Pottery Gazette and Glass Trade Review.
419. Ohio Journal of Science. (*Name changed Nov., 1915, from* Ohio Naturalist.)
420. Bulletin de la société d'encouragement pour l'industrie nationale.
421. Journal of West Scotland Iron and Steel Institute.
422. American Machinist.
423. Transactions of the American Foundrymen's Association. (Journal of the American Foundrymen's Association, 1896–1904.)
424. Oesterreichische Zeitschrift für Berg- und Hüttenwesen. (*Merged into* Montanistische Rundschau.)
425. Deutsche Mechaniker-Zeitung. (Beiblatt zur Zeitschrift für Instrumentenkunde.)
426. Acta societatis scientiarum fennicae. (1839–1842, Commentationes societatis fennicae.)
427. Physikalische Berichte. (Beiblätter zu den Annalen der Physik und Chemie; Beiblätter *united with* Fortschritte der Physik *and* Halbmonatliches Literaturverzeichnis *to form* Physikalische Berichte.)
428. Repertorium für Experimental-Physik für physikalische Technik für mathematische und astronomische Instrumentenkunde. (*Before 1867 was* Repertorium für physikalische Technik für mathematische und astronomische Instrumentenkunde; *also known as* Carl's Repertorium.)
429. Memoirs of the College of Science, Kyoto Imperial University. (*Before 1914 was part of* Memoirs of the College of Science and Engineering, Kyoto Imperial University.)
430. Iron Age.
431. Revue de la société russe de métallurgie.
432. Transactions of the Institution of Mining and Metallurgy (London).
433. Annual Report of the Royal Mint, London.
434. Scientific Transactions of the Royal Dublin Society.
435. Proceedings of the Institution of British Foundrymen.
436. Reports of the Research Department, Royal Arsenal, Woolwich.
437. Japanese Journal of Physics.
438. Transactions of the American Society of Mechanical Engineers.
439. Mémoires et compte rendu des travaux de la société ingénieurs civils de France.
440. Metal Industry and the Iron Foundry (London).
441. India Rubber Journal.
442. Annals of Botany.
443. Archief voor de Rubbercultuur in Nederlandsch-Indië.
444. Verhandlungen der preussischen Akademie der Wissenschaften.
445. Zeitschrift des Vereins der deutschen Zucker-Industrie. (*Before 1898 was* Zeitschrift des Vereins für die Rübenzuckerindustrie.)
446. Zeitschrift für die Zuckerindustrie der Cechoslovakischen Republik. (*Formerly* Zeitschrift für die Zuckerindustrie in Böhmen.)
447. India Rubber World.
448. Proceedings 4th International Congress of Refrigeration.
449. Caoutchouc et gutta percha.
450. Transactions of the Institution of the Rubber Industry.
451. Memoirs of the College of Engineering, Kyoto Imperial University. (*See* No. 429.)
452. Die oesterreichische pharmazeutische Post.
453. Proceedings of the Iowa Academy of Science.
454. Procès-verbaux et resumé des communications de la société française de physique.
455. Journal of the Chemical, Metallurgical and Mining Society of South Africa.
456. Gummi-Zeitung.
457. Chemist and Druggist.
458. Linnean Society of New South Wales, Proceedings.
459. Electrical Review and Industrial Engineer. (*Formerly* Electrical Review and Western Electrician.)
460. Deutsche Zuckerindustrie, Wochenblatt für Landwirtschaft, Fabrikation und Handel.
461. Proceedings of the Royal Society of New South Wales.
462. Bulletin institut international du froid.
463. Société de physique et d'histoire naturelle de Genève. Mémoires.
464. United States Public Health Service. Hygienic Laboratory Bulletins.
465. Zeitschrift der deutschen Öl- und Fett-Industrie.
466. Repertorium der analytischen Chemie (Organ des Vereins analytischer Chemiker). (*See also* No. 92.)

467. Zeitschrift für Chemie. Leipzig.
468. Kongliga Svenska Vetenskaps-Akademiens, Handlingar.
469. Bulletin of the Institute of Physical and Chemical Research (Tokyo).
470. Memoirs of the College of Engineering, Kyushu Imperial University.
471. Army Ordnance.
472. Papier-Fabrikant.
473. Cellulosechemie.
474. Zeitschrift für komprimierte und flüssige Gase sowie die Pressluft-Industrie.
475. Bulletin institut international du froid.
476. Giornale di farmacia, chimica e di scienze affini.
477. Journal of the American Medical Association.
478. Bulletin de l'association des chimistes de sucrerie et de distillerie de France et des colonies.
479. Memoirs of the College of Science and Engineering, Kyoto Imperial University. (*Divided in 1914 into* Nos. 429 *and* 451.)
480. Chemical Trade Journal and Chemical Engineer.
481. Tschermak's mineralogische und petrographische Mitteilungen.
482. Quarterly Journal of the Indian Chemical Society.
483. American Dyestuff Reporter (including the Proceedings of the American Association of Textile Chemists and Colorists).
484. Deutsches Archiv für klinische Medizin.
485. Teknisk Tidskrift. Upplaga C. Kemi och Bergsvetenskap.
486. Münchener medizinische Wochenschrift.
487. Die deutsche pharmazeutische Zeitung.
488. Archivio di farmacologia sperimentale e scienze affini.
489. Fermentforschung.
490. Atti e memorie della reale accademia di scienze, lettere ed arti in Padova.
491. Wochenblatt für Papierfabrikation.
492. Bulletin of the U. S. Dept. of Agriculture, Bureau of Soils.
493. Kali (Zeitschrift für Gewinnung, Verarbeitung und Verwertung der Kalisalze).
494. Beiträge zur chemischen Physiologie und Pathologie. Zeitschrift für die gesammte Biochemie. (*In 1908, merged with* No. 205.)
495. Vierteljahresschrift für präktische Pharmazie. (*Combined in 1923 with* No. 293.)
496. Mémoires de l'institut polytechnique, Pierre-le-Grand, Pétrograd.
497. Archiv for Pharmaci og Chemi.
498. Pharmazeutische Zeitschrift für Russland.
499. Archiv für Mineralogie, Geognosie, Bergbau und Hüttenkunde (Karstens).
500. Zeitschrift für das Berg-, Hütten- und Salinenwesen in dem preussischen Staate.
501. Mémoires couronnés et autres mémoires publiés par l'académie royale des sciences, des lettres et des beaux-arts de Belgique. Collection in 8vo.
502. Archives du Musée Teyler. (Harlem.)
503. Quarterly Journal of Science, Literature and the Arts.
504. Mémoires de l'académie des sciences de l'union des républiques soviétiques socialistes. (*Formerly* Mémoires de l'académie impérial des sciences de St. Pétersbourg; *name changed in 1917 to* Mémoires de l'académie des sciences de Russie; *present name dates from 1925.*)
505. Technology Reports of the Tôhoku Imperial University.
506. Monthly Weather Review.
507. Meteorologische Zeitschrift.
508. Rivista di mineralogia e cristallografia italiana.
509. Archiv für Chemie und Meteorologie. A section of Archiv für die gesammte Naturlehre (Kastners Archiv).
510. Zeitschrift für den physikalischen und chemischen Unterricht.
511. Zeitschrift für mathematischen und naturwissenschaftlichen Unterricht. (Verein zur Förderung des Unterrichts in der Mathematik und den Naturwissenschaften.) (Hoffmanns Zeitschrift.)
512. Proceedings of the Indian Association for the Cultivation of Science.
513. Zeitschrift für Mathematik und Mechanik.
514. Maandblad voor Natuurwetenschappen. (Genootschap ter Bevordering van Natuur-Genees- en Heelkunde te Amsterdam.)
515. Magyar Chemikai Folóirat (Budapest).
516. Zeitschrift für das gesamte Brauwesen. (*Now supplement to* Allegemeine Brauer- und Hopfenzeitung.)
517. Perfumery and Essential Oil Record.
518. Landwirtschaftlichen Versuchs-Stationen.
519. Svensk Kemish Tidskrift.
520. Monthly Notices of the Royal Astronomical Society. (London.)
521. Bulletins of the Lick Observatory. (Mt. Hamilton, Calif.)
522. Illuminating Engineer. (London.)
523. Gesammelte Abhandlungen zur Kenntnis der Kohle.
524. Abhandlungen der k. Akademie der Wissenschaften, Berlin. (K. preussische Akademie der Wissenschaften.)
525. Publications of the American Astronomical Society.
526. Bihang til Kongliga Svenska Vetenskaps-Akademiens Handlingar. (*In 1904, divided into* Nos. 19 *and* 20.)
527. Ertisitö az Erdélyi Muzeum Egylet Arvos-Természettudományi Szakosztályából. II. Természettudományi Szak.
528. Zeitschrift für wissenschaftliche Mikroskopie und für mikroskopische Technik.
529. Proceedings of the Institute of Radio Engineers (New York).
530. American Architect and the Architectural Review.
531. Internationale Zeitschrift für physikalisch-chemische Biologie.
532. Popular Astronomy.
533. Deutsche Bunsen-Gesellschaft für angewandte physikalische Chemie, Abhandlungen.
534. Proceedings of the National Electric Light Association.
535. Transactions of the International Electrical Congress.
536. Abhandlungen der k. Gesellschaft der Wissenschaften zu Göttingen. Mathematisch-physikalische Klasse.
537. Gesellschaft zur Beförderung der gesammten Naturwissenschaften (Marburg), Schriften.
538. Transactions of the International Astronomical Union.
539. Proceedings of the Royal Irish Academy. Section A, Mathematical, Astronomical and Physical Science. Section B, Biological, Geological and Chemical Science.
540. Radio Review. (*Now merged into* Wireless World.)
541. Transactions of the Society of Naval Architects and Marine Engineers.
542. Kongelige Danske Videnskabernes Selskab, Mathematisk-fysiske Meddelelser.
543. Proceedings of the Imperial Academy of Tokyo. (*Formerly* Tokyo Academy.)
544. Transactions of the Cambridge Philosophical Society.
545. Photographische Korrespondenz.
546. Bureau of Standards Journal of Research.
547. British Journal of Photography.
548. Sitzungsberichte der Gesellschaft zur Beförderung der gesammten Naturwissenschaften (Marburg).
549. Naturhistorisch-medizinischer Verein (Heidelberg). Verhandlungen.
550. Anales de la sociedad cientifica Argentina.
551. Monatsberichte der k. preussische Akademie der Wissenschaften (Berlin). (*Follows the* "Berichte" *and is followed by the* "Sitzungsberichte.")

552. Rensselaer Polytechnic Institute, Engineering and Science Series.
553. Cosmos. Revue encyclopédique hebdomadaire des progrès des sciences. *United with* Cosmos: Les mondes, revue hebdomadaire des sciences *to form* Cosmos: Revue des sciences et leurs applications.
554. Åbo Akademi. Acta academia aboensis, mathematica et physica.
555. Masarykova Universita (Brünn or Brno). Prirodovecka fakulta, Spisy = Publications de la Faculté de science de l'Université Masaryk.
556. Handelingen van Lettiende Vlaamsch Naturen Geneeskundig Congress.
557. Transactions Royal Society, South Africa.
558. Acta phytochimica.
559. Stain Technology.
560. Color Trade Journal.
561. Bulletin de la société de chimie biologique.
562. Archives of Internal Medicine.
563. Zeitschrift Farben Textile Chemie.
564. Annales des Mines de Belgique.
565. Explosives in Coal Mines Orders.
566. Jahresbericht der Centralstelle für wissenschaftlich-technische Untersuchungen, Neubabelsberg-Berlin.
567. Annual Reports of His Majesty's Inspectors of Explosives.
568. Die Sprengstoffe in preussischen Bergbau.

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B27. Hermann, Gesteine für Architektür und Sculptur. Berlin, Borntraeger, 1914.
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