SEMIMICRO
AND
MACRO
ORGANIC
CHEMISTRY

BY THE SAME AUTHOR

ORGANIC CHEMISTRY
SEMIMICRO AND MACRO ORGANIC CHEMISTRY

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A LABORATORY MANUAL BY

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PREFACE

The present laboratory manual was developed primarily to provide suitable experiments in elementary laboratory practice for all levels of students, both the average and the exceptional. Impressed by the possibilities of the semimicro technic in connection with this problem, the author began several years ago to experiment with it in his classes. After mature consideration and six years of trial and error with all types of students, he believes that it is possible to attain all the objectives of laboratory practice in elementary organic chemistry using the semimicro technic. In addition, this method offers the following advantages over the traditional method: (1) it permits better adaptation of the laboratory work to the varying needs of students; (2) it teaches students greater care, cleanliness, and manipulation; (3) it is more economical; and (4) it reduces substantially the seriousness of possible accidents since the quantities of reagents and size of equipment are only some 10 to 20 per cent as great as with macro methods.

It is realized, however, that a sudden and complete shift from traditional macro methods is usually not practical or desirable. For this reason, in practically all experiments, semimicro is paralleled with the macro method. In this manner teachers may experiment as widely with semimicro technic and with whatever students they wish.

The arrangement of the material in the manual is made according to the following plan: In the first part an attempt is made to introduce the students to the elementary technics, such as crystallization of solids, distillation of liquids, determination of boiling and melting points and of refractive indices, necessary for the study of organic chemistry. This is followed by a study of the preparation and properties of the simpler groups of organic compounds. The preparation of one or more compounds from each group serves to illustrate the general principles involved. This is followed by a systematic study designed to illustrate important group properties and variations of these among members of the same group. Beginning each experiment there is a brief introductory explanation relating the material of the experiment to the previous knowledge of the student and also orienting him to the work to be done. For each group of organic compounds there are usually listed several preparations. It should be emphasized that this practice does not place a premium on the amount of work done; it is rather the organization and understanding of the work done that are of primary importance. It is believed, however, that directions for several preparations will be an aid to the teacher in providing suitable work for students of different abilities and interests. A number of experiments are well adapted to discussion-demonstrations to be given by the instructor, and are so marked.

The latter part of the manual is devoted to compounds of greater complexity. Some of these require the preparation of several compounds which are used in the subsequent work in order to obtain the final product. Thus it is hoped that the manual achieves unity and organization for teaching rather than being a mere collection of unrelated preparations.

The author wishes to acknowledge his indebtedness to those who have aided him in this work: for suggestions, reading, and commenting on parts of the manuscript, to Louis Sattler of Brooklyn College, Joseph B. Niederl of New York University, Gordon Pritham of the University of Scranton, Ernest R. Kline of the University of Connecticut, Louise Wendt of Nebraska State Teachers College, John Entrikin of Centenary College, and to his colleagues, Sebastian Durban, James Parsons, and Conrad Ronneberg; to Joseph Drummond and Kurt Spitzmueller for many suggestions on apparatus and methods; to Milton Cooper and Michael Savoy for suggestions on the experiments for the determination of melting points; to his former students, Peter Arvan, Herman Teifeld, Alford Anderson, Richard Erhardt, and Carl Anderson for their patience and work in adapting the various preparations of organic compounds to the semimicro technic; to Walter Burfischer of Wilkens-Anderson Company for the many suggestions and help in the development of the semimicro apparatus; and, for assistance in the preparation of the manuscript, to Harold Woodson, Helen Karagianes, and Denver Cummings.

NICHOLAS D. CHERONIS

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PURPOSE OF LABORATORY WORK

Organic chemistry is an experimental science; it was developed by coordination of *reasoning* and *experiment*. The best way to obtain an introduction to this field of knowledge is a well-directed study involving a certain amount of laboratory practice. It is desirable to acquaint the student at the very beginning with the purpose of laboratory work. From the instructor's point of view the chief aims of laboratory practice in the study of elementary organic chemistry are:

(1) To acquaint the student with the methods used for the *preparation* of representative members of the most important groups of organic compounds. The carbon compounds are arranged into groups which show related properties. The preparation of one or two members in each group serves to illustrate the principles of the method which is applicable to an entire group of compounds.

(2) To provide a *systematic study* of the general properties and reactions of the simpler groups of organic compounds. By means of simple experiments it is possible to study some of the physical and chemical properties of several compounds which belong in the same group. In this manner the student obtains firsthand information as to general group properties and reactions, and also as to differences in reactivity among members of the same group.

(3) To develop the *simpler skills* and *technics* necessary in the study of this particular field of experimental science. In order to prepare and study organic compounds it is often necessary to perform distillations, crystallizations, extractions, determinations of melting points, and other operations. Therefore, a number of these operations are introduced at the beginning.

The aims listed above are not given in order of importance for they are all equally important for the beginner. A number of other aims can be listed. It is hoped, for example, that laboratory practice in any science will: (1) contribute to the teaching of the scientific method; (2) aid in the development of critical thinking; (3) enhance the student's enjoyment by enabling him to find out "how things happen" and "how things behave." These are regarded as by-products of any well-organized laboratory course in science.

Laboratory work exemplifies the general principle of *learning by doing*. The attention of the student should be called to the fact that one can be kept busy doing things for many years without learning much. Acquisition of skills, technics and other mechanical operations, although necessary for some scientific investigations and very important to the beginner in the present study, are tools in the study of science. The student may keep himself busy for two or three hours in laboratory "goose-stepping" and following directions without learning much except a few isolated facts which, before the year is over, are forgotten. In order that the student may obtain as much benefit as possible from the laboratory work, a method of procedure is outlined. It should be noted that this is *only one method*, and for the same purpose the student may develop his own. Any method is satisfactory provided the student knows, while he is working, *what he is doing and observing, and the explanation for his observations.*

GENERAL DIRECTIONS FOR LABORATORY WORK

Home preparation. It is advisable to study the assigned experiment thoroughly before going to class. The student must not expect to look at the directions one minute and work the next. It is therefore necessary to *have a definite plan* before going to the laboratory. This is best accomplished by preparing an outline of what to do and how to do it.

It is advisable to obtain specific directions from the instructor as to the type (and method of recording) of the outline. The important point is to have a definite plan. If the student can convince the instructor that he knows how to work efficiently without an outline, then the ritual of recording the outline can be omitted.

General precautions. Once in the laboratory, there are some general rules to which every student *must conform* in order to avoid accidents and insure the safety of his fellow students as well as his own. Laboratory work in organic chemistry is connected with some *special hazards*. Most organic compounds are highly inflammable; in addition, some of the reagents, such as sodium metal, bromine, concentrated acids and alkalies, and other reagents, are a source of danger. Therefore a few general "Do's" and "Don'ts" are given at this point:

(1) Read carefully the rules posted in the laboratory.
(2) Follow the directions which appear in each experiment.

Use the amounts of reagents specified. Be accurate, both in following directions and in making observations.

(3) Follow the *special directions* and *warnings* given by the instructor. If in doubt, ask the instructor or assistant.

(4) *Do not point* the open end of a test tube toward yourself or another student. Tests which may give rise to violent reactions should be performed in the hood with the mouth of the tube directed toward the wall of the hood.

(5) Always *wear goggles* when performing distillations or mixing reagents which may give rise to spattering.

(6) *Work slowly* and *carefully.* It is better to do a small amount of work *neatly* and to understand it, than to do a large amount hastily, carelessly, and to be vague about what you have done.

(7) *Cleanliness* is extremely important in all laboratory work. Begin your work with clean apparatus and a clean bench, and end your work in the same manner; the desk top and reagent bottles should be cleaned and arranged before leaving the laboratory.

(8) *Do not talk* while you are working, but center all your attention on what you are doing.

(9) The *hands should be washed* immediately after using poisonous substances such as potassium cyanide or sodium cyanide, arsenious oxide, phosphorus, etc. This precaution should be extended to the majority of organic compounds.

(10) *Never heat inflammable solvents* in open vessels.

(11) Do not heat closed systems. Inspect all vessels (flasks, distilling flasks, etc.) before starting to apply heat.

(12) Do not throw sodium residues into sinks or waste jars.

(13) Do not pour large volumes of inflammable or volatile solvents down the sinks.

(14) *Read the first-aid instructions* which appear in the appendix; refer to them in case of accidents.

(15) Record your observations *promptly,* in the manner described in the following section.

THE NOTEBOOK

The recording of the observations is an important step in all scientific work. The following method of recording experiments is used in the author's laboratory; other instructors have methods which better fit the particular conditions in their laboratories. The important point, however, is that all methods are directed toward training the student in the proper procedure of recording observations and conclusions as they are made, so that the notebook becomes the mirror of the work which was done. For this course, it is reasonable to expect that a person informed in organic chemistry, in examining a student's notebook, will obtain a clear picture of what the student did, the observations he made, and the conclusions which were drawn from these observations. The general directions given below are to be modified in accordance with the directions of the instructor in charge.

(1) The records of the student's work are made in a bound notebook approximately 8 x 10 inches in size. This should always be brought to the laboratory by the student, and must be ready for inspection without notice. Loose-leaf books, individual sheets of paper on which notes are kept and later copied, are not acceptable to those working in the field of science.

(2) The first entries for an experiment represent the student's preparation and are made *before* coming to the laboratory. The descriptive paragraphs and directions of the manual should be studied, with particular attention to the **cautions** for handling dangerous materials. The lecture notes and textbook should be consulted about the topic covered by the experiment. The following information is then entered in the notebook:

(*a*) Date, title, and object of the experiment;

(*b*) Equation(s) involved in the preparation, or in the reactions to be studied;

(*c*) If the experiment involves a preparation, other reactions for making the same compound;

(*d*) The amounts (in grams and moles) of the reagents used, and the theoretical yield;

(*e*) A table of the physical properties, such as melting or boiling point, density, solubility, of each organic substance used or formed in the reaction;

(*f*) A qualitative test to confirm nature of the compound;

(*g*) A diagram or flow sheet of the procedures and manipulations;

(*h*) A list of the chemicals and apparatus needed, listing separately those which must be obtained from the stock room;

(*i*) The answers to the questions in the manual which are marked with an asterisk. Those without an asterisk are to be answered after the experiment has been performed.

(3) On arriving at the laboratory the student should obtain his *instructor's approval* of the outline which he has entered in his notebook, and should then proceed with the work. During or immediately after the experiment, entries are to be made in the notebook giving a brief and concise account of the following:

(*a*) The operations performed and procedures followed;

(*b*) The observations made by the student, expressed in the passive voice;

(*c*) The conclusions reached based upon the observations made, and the explanation of the results obtained. If the equations included in the homework preparation could not be completed, they should be completed as soon as the experiment is performed. A write-up of a typical experiment is given in the Appendix.

It is important for the student to learn a correct method of expressing his observations, conclusions, and ideas about his work. Many students have a good understanding of a reaction but have difficulty in expressing their ideas in an orderly and concise manner. Therefore, the statements given by the student should be grammatically as well as technically correct.

(4) Often in the laboratory a reaction is started but is not finished immediately, and another reaction is undertaken. In such cases, space should be left for the results to be inserted later. Some instructors prefer, however, that students leave no empty spaces, but record their observations as they are made; a line, and a small caption, "Continued from page —," serve to provide continuity. In this manner the laboratory notebook is a diary of the student's experiences in the laboratory recorded as they occur. The instructor will indicate which method he prefers.

(5) Mistakes are made by all workers, including instructors. In such cases they should be so marked in the notebook. Mark all unsatisfactory data across with the word "canceled," or in any other manner directed by the instructor. Figures should never be erased nor pages torn out. All data, including those which are unsatisfactory, are of importance. The errors represent *definite experiences* with one or more factors being responsible; the *understanding* of these is of great importance to the student in his effort toward self-improvement.

(6) Demonstration experiments should be written in the same manner as those experiments performed by the student himself, with the notation that they are demonstrations.

(7) In many experiments it is possible to summarize a large number of observations and other data by means of tables. In such cases the tables appear in the questions and exercises at the end of this manual. The pages of the manual on which the tables appear (as questions with space for one- or two-word answers) may be detached after the material is filled in and pasted in the notebook. If the student does not wish to detach these sheets, the tables can be ruled in the notebook before coming to the labora-

tory. In either case the assigned brief essay-type questions should be answered at the end of the write-up of the experiment.

(8) When the experiment is completed, the notebook should be submitted to the instructor for approval before the next assignment is begun. If the experiment is a preparation, the compound obtained should be placed in a clean bottle or vial, labeled with the name of the student, the name and physical constants of the compound, the weight in grams, and the percentage of theoretical yield. The preparation, together with a report made according to directions given below, should be handed to the instructor at the same time that the notebook is submitted for his approval. The instructor probably will at this time discuss the student's work to determine whether he has a clear understanding of his observations and conclusions. After this, the student may proceed with the next experiment.

Reports and chemical accounting. A part of the student's training is to obtain experience in summarizing and reporting his experimental work. Therefore, for all experiments which involve preparation of an organic compound, there is a standard form[1] which the student should fill in with all questions and problems properly answered. There are four parts to each report. In the first part the student reports the reaction used to prepare the compound, the yield obtained, and the constants of the substance. In the second part the equations of other reactions by which the same compound could be prepared are given. In the third part the student outlines a method by which the nature of the compound prepared may be confirmed. In the last part of the report there is a question on *chemical accounting* to be answered. It is common, in organic preparations, for the yield to be very far from the amount calculated on the basis of the chemical equation representing the reaction. Yields of only 40 to 50 per cent of the theory are common in organic syntheses. It is reasonable to expect an accounting in the products for every reagent that is put into a flask or beaker. Although this is expecting a good deal from the beginner, an attempt is made in the report sheets to encourage the student to think about the other 50 or 60 per cent which was lost mysteriously on the way. In some reactions it is possible to predict most of the side reactions and to outline methods for the isolation of the products formed. In others, one of the products may be a tar of unknown composition, and the problem of accounting is more difficult. Nevertheless, the student should attempt to find

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[1] Standard *report sheets* will be found at the end of the book.

some explanation as to the parts of the reactants that are not accounted for in the yield. It is believed that the question of chemical accounting, aside from the practical consideration, is important because it reminds the student that the law of conservation of mass applies as well when the yield is 20 per cent as when it is 90 per cent of the theory; further, it emphasizes the fact that most organic reactions are multidirectional.

APPARATUS AND ITS CARE

APPARATUS FOR MACRO METHODS

Condenser. The condenser is one of the more common pieces of glass apparatus used in the organic laboratory. It is employed to cool the vapors from evaporating liquids and condense them into the liquid state. In Figure 1 are shown two condensers of Liebig type. They consist of an inner glass tube which fits inside the outer jacket within which tap water is circulated. If the liquid boils above 150° the water-cooled condenser is replaced by a long inner tube called an air condenser. An ordinary condenser can be used as air condenser, providing no water is passed through the jacket. The condenser with the constricted-bulb inner tube is used at times over a flask in which a liquid is being heated, in such a way that the evaporated liquid continuously flows back again; this is called *heating under reflux*. The length of the condenser jacket varies from 300 to 700 mm, and of the inner tube from 500 to 950 mm. The type most commonly used for students has a jacket length of 400 mm.

Distilling flasks. The common distilling flask has the side arm placed usually 77 mm below the top of the neck so that the thermometer can be immersed about 75 mm in the vapors of the boiling liquids. The sizes vary from 25 ml to 3000 ml.[2] For beginners the sizes of 50 ml, 125 ml, and 250 ml capacity are sufficient for most purposes. The Claisen type, shown in Figure 1 has two necks, one for filling or stirring, and the other as a vapor tube to which the side arm is sealed. This flask is particularly useful in distillations in which considerable "bumping" and foaming occurs.

Flasks. Various types of flasks find use in the organic laboratory. The student is already familiar with the boiling or Florence flask and the Erlenmeyer flask. The sizes of the former most useful for beginners are the 250 ml, 500 ml, and 1000 ml capacity; of the Erlenmeyer flasks the 125 ml, 250 ml and 500 ml are the sizes most

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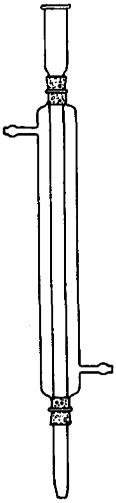
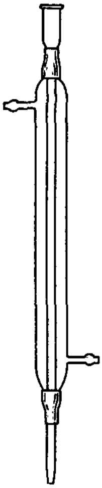
[2] The term "milliliter" (ml) is used throughout in the place of cubic centimeter.

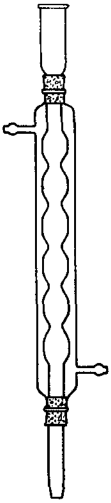


Condenser, Liebig type (modern style)

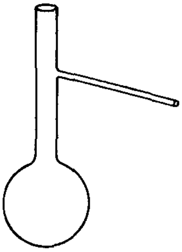


Condenser, Liebig type (old style)

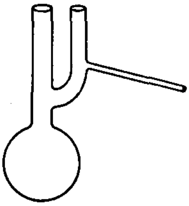
Inner condenser tube



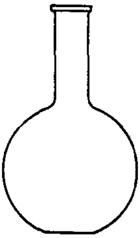
Condenser with constricted-bulb inner tube



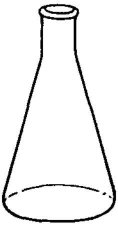
Distilling flask



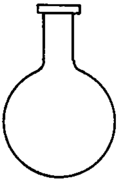
Claisen-type distilling flask



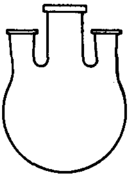
Boiling (Florence) flask



Erlenmeyer flask

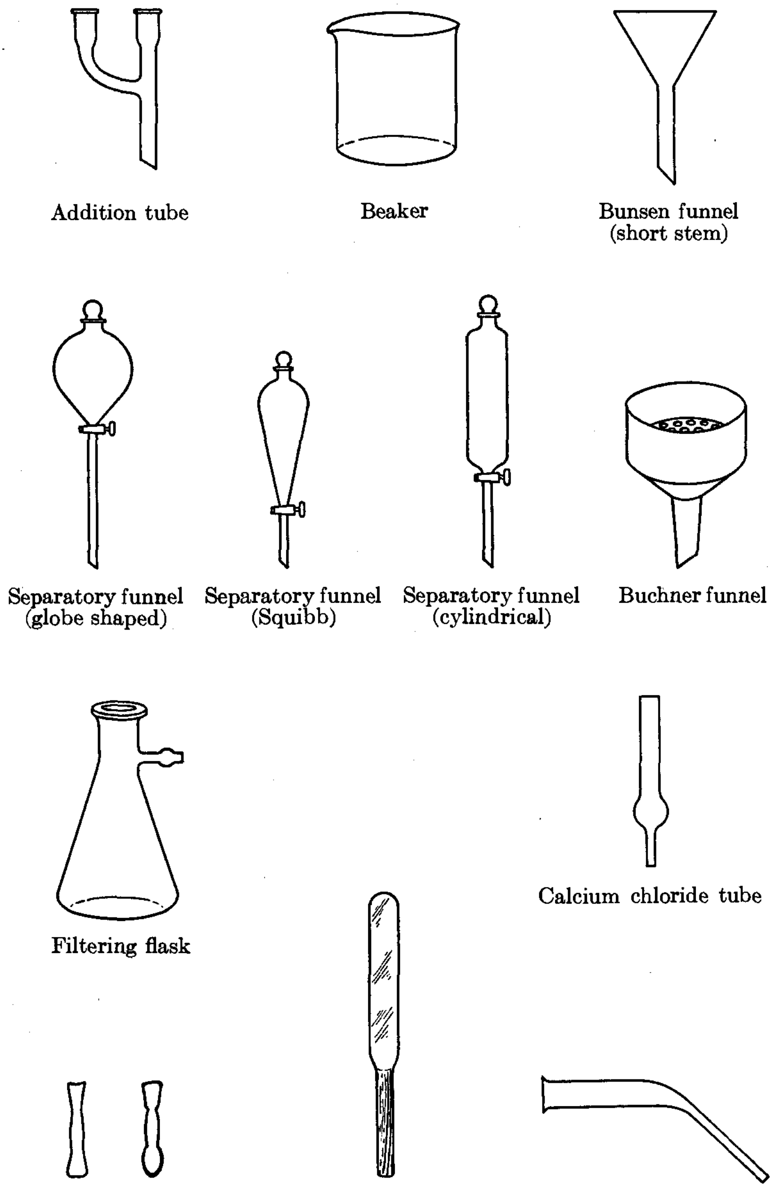


Round-bottom short-neck flask



Three-neck round-bottom flask

Fig. 1(*a*)



Addition tube

Beaker

Bunsen funnel (short stem)

Separatory funnel (globe shaped)

Separatory funnel (Squibb)

Separatory funnel (cylindrical)

Buchner funnel

Filtering flask

Calcium chloride tube

Porcelain spatulas

Steel spatula

Adapter

Fig. 1(b)

commonly used. The round bottom flask with short ring neck, is extensively used in advanced work, particularly in the preparation of organic chemicals on a laboratory scale. The most useful sizes are those of one and five liters capacity. The three-neck flask is useful where a stirring device, reflux condenser, and addition of reagents during the reaction are desired. An ordinary round bottom flask can be used for the same purpose by placing on top an addition tube.

Beakers. The beakers most useful for beginners are the 150 ml, 250 ml, 600 ml, and 800 ml or 1000 ml. Sizes of 2, 3, and 4 liters are available for work involving the preparation of larger quantities of organic compounds than usually are prepared by beginners. Even for macro work it is desirable to have one or two 25 ml and 50 ml beakers for handling small quantities of materials.

Funnels. The student is familiar with the common (Bunsen) funnel. The size most useful for the beginner has a diameter of 65 mm and a stem with a length of 65 mm. There are three general shapes of separatory funnels as shown in Figure 1. For beginners the globe-shaped type (125 or 250 ml) is most commonly used. A long stem is desirable since it can be used both for the separation of two immiscible layers and for the addition of reagents (dropping funnel).

The Buchner[3] funnel has a perforated porcelain plate on which to support the filter paper. It is used extensively in the organic laboratory for the separation of crystals from a liquid. The sizes available vary from 50–200 mm. The sizes most commonly used are 90–100 mm. These funnels are used in conjunction with the filtering flask. The funnel is fitted into the neck of the flask by means of a rubber stopper, and suction is applied through the side arm of the filtering flask.

Other macro apparatus. Either a porcelain or a stainless steel spatula is very useful in the organic laboratory. A glass spatula may also be made by heating a piece of glass rod and pressing it to the desired shape.

The calcium chloride tube is filled with granular calcium chloride and is attached through a stopper on a flask or bottle containing liquids from which moisture is to be excluded.

The adapter tube is used to facilitate the delivery of the distillate from the condenser to the receiver. It can be obtained either straight, or bent at a 45° angle as shown in the diagram.

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[3] Also spelled Büchner and Buechner.

APPARATUS FOR SEMIMICRO METHODS

Simple apparatus can be constructed for work with small amounts of materials in elementary organic experimentation. The apparatus shown in Figures 2(*a*) and 2(*b*) is commercially available.[4]

Test tubes. For most reactions tubes of 25 mm x 200 mm (eight-inch tubes) are used. Three to four tubes of this size are ample for a beginner. Standard Pyrex tubes of 20 x 150 mm (six-inch tubes) are used in many of the semimicro technics; the number required by a beginner is about ten to twelve tubes. A tube with a side arm, 25 x 200 mm, is useful as a filtering tube. The test-tube rack shown in Figure 2 has places for four large tubes and six small tubes.

Semimicro distillation apparatus. The Pyrex micro distilling flasks which are commercially available have a capacity of 10 ml and 25 ml. It is advisable to modify the side arm of these flasks as shown in Figure 2. The distilling tubes have been more successfully used in semimicro work than the ordinary distilling flask with the straight arm because they are easier to clean, and because they permit boiling with less danger of contaminating the distillate by a spray from the bumping liquid. The distilling tubes are made from ordinary six- and eight-inch Pyrex test tubes. A Claisen type of distilling tube, useful in distillations under reduced pressure, is made from an eight-inch Pyrex test tube.

Condenser. The semimicro condenser shown in Figure 2(*b*) is of the so-called "cold finger" type. It consists of a glass tube about 150 mm long and 8–10 mm wide sealed at one end. Through the opening is inserted an inner tube 160 mm in length and 4 mm wide. The inner tube is held in position by means of a small piece of rubber tubing. Two to three micro condensers are necessary for a beginner. The rubber tubing for the circulation of water has about a 5 mm inside diameter.

Heating baths. Beakers, of 125 ml and 250 ml capacity, may serve as water-heating baths in semimicro work. Small tin cans of two to three inches in diameter serve the same purpose without any danger of breakage.

A three-purpose heating bath, specially developed for semimicro work in organic chemistry, is shown in Figure 2(*b*). The bath is made of metal and is 70 mm in depth and 90 mm in diameter. The top is detachable but fits snugly so that no vapors can leak through it. The top has four holes provided with short rings to support the

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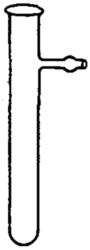
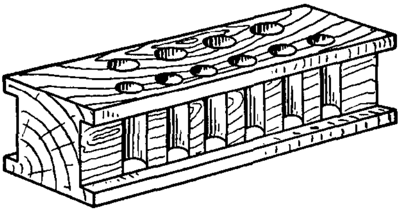
[4] Semimicro Apparatus for Organic Chemistry (Chicago: Wilkens-Anderson Co.).

Eight-inch test tube

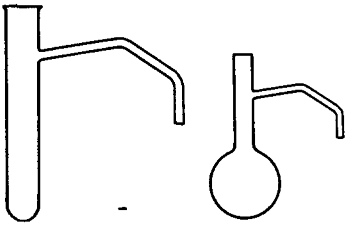
Six-inch test tube



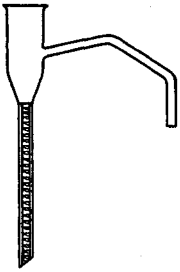
Six-inch test tube with side arm



Semimicro test-tube rack for eight- and six-inch test tubes

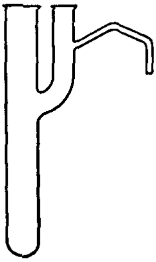


Semimicro distilling tube and flask with modified side arm (25 ml and 10 ml)



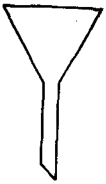
Semimicro fractionating column

Fig. 2(*a*)

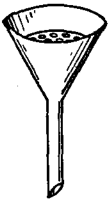


Semimicro Claisen distilling tube

Semimicro condenser



Semimicro Bunsen funnel



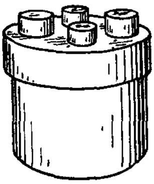
Semimicro Buchner funnel

Porcelain disc used with Bunsen funnel to serve as semimicro suction funnel

Semimicro Monel-blade spatula

Semimicro calcium chloride tube

Separatory tube used in semimicro work in place of separatory or dropping funnel



Heating bath used in semimicro work, adaptable as water bath, steam-distillation bath, or constant-temperature bath

Fig. 2(b)

distilling tubes. There are two openings of 20 mm in diameter for six-inch tubes, one opening 26 mm in diameter, and one 35 mm in diameter. The two large openings are suitable to hold eight-inch tubes. The openings are stoppered by corks (nos. 8, 14, and 20) to convert this type of water bath to a steam distillation apparatus as directed on page 165, and to a constant temperature bath as directed on page 329.

Funnels. The glass Bunsen funnel which is used with the semimicro technic is 50 mm in diameter with a stem 60 mm long. The Bunsen funnel is easily and economically converted to a Buchner funnel by using a 20 mm porcelain disc as shown in Figure 2(*b*). The micro Buchner funnel has a diameter of 42 mm at the top, 8.5 mm diameter of perforated area, and stem of about 50 mm in length. The porcelain perforated disc is 20 mm in diameter, has beveled edges, and fits inside the funnel at a depth of 30 mm from the rim.

Beakers. The beakers most useful in semimicro work are those with a capacity of 25 ml, 50 ml, 100 ml, 150 ml, and 250 ml. Stirring rods for these beakers should be constructed of 4 mm tubing since with the solid stirring rods commonly used for macro work there is danger of tipping over the small beaker.

Spatulas, pipettes and droppers. Glass spatulas of various sizes are made by heating a piece of glass rod and pressing it to the desired shape. For general use, the end of a glass rod, 5 mm in diameter and 150 mm or 250 mm in length, is heated until the glass softens and then flattened by pressing with a metal spatula or knife against a piece of hard asbestos (transite). The process is repeated until the edge of the flat part is 1 mm or less. The semimicro spatula, shown in Figure 2, has a hard rubber handle, a blade of Monel metal and a total length of 180 mm. The blade is 4 mm wide and 20 mm in length.

For measuring and adding liquids in semimicro work *pipette droppers* are used. So-called medicine droppers are commercially available and each student should have at least two or three droppers. The student can make several pipette droppers of his own by heating pieces of glass tubing 6–8 mm in diameter and then drawing them out to a capillary. Directions are given in the Appendix. Several pipette droppers should be made and kept in a small box. One side of the pipette droppers is made approximately uniform so that the rubber bulbs are interchangeable. Two pipette droppers should be graduated for 0.5 ml and 1 ml. Such pipette droppers are commercially available. One or two pipettes with a long capillary should be made for drawing small amounts of liquids or separating two immiscible liquids when the amount is less than 0.5 ml.

Gas burners. Several semimicro gas burners are commercially available. The ones which are most useful are those which can give a luminous flame of 10–15 mm in height when the air inlet is wide open. The top of the burners consists of two tubes, the outer 8–10 mm and the inner 4–5 mm in diameter.

Semimicro separatory apparatus. The separatory tube (described on page 113) has been found more suitable and economical for students than micro separatory funnels. The separatory stopper, shown in Figure 2, can be constructed to fit any size test tube. Thus it is possible to separate two immiscible liquids having a total volume of 1–2 milliliters by using a three-inch tube, or 60 milliliters by using an eight-inch tube.

Weighing and measuring for semimicro work. In place of the horn-pan hand balance which heretofore was imported, an American-made "Sanolite" plastic-pan hand balance is recommended. Solids are weighed on pieces of glazed paper. An ordinary 8½ x 11 sheet of paper is folded and cut in four equal pieces which are suitable for weighing 2–5 g of solids. For quantities of 1 g or less each of these squares is folded and cut into two equal parts. A piece of paper is placed on each pan, and counterbalanced if necessary by adding small bits of paper before the weights are placed. The solid is placed on the paper with a spatula, care being taken not to spill any solid on the pan of the balance. After weighing, the paper on which the solid was placed is washed with water and thrown in the waste jar.

Weighing of solids or liquids directly in the six-inch or eight-inch tubes is easily accomplished by means of the *weighing rings*. To make a weighing ring, take a piece of number 20 or 22 gauge iron wire 200 mm in length and wrap two loops around the test tube under the lip. Twist the two ends of the wire together twice and cut one end near the loop. Bend the other end at right angles to the loop so that it projects upwards about 30 mm; bend the end of the single wire into the form of a hook. The ring thus obtained has a loop of 20 mm in diameter if a six-inch tube was used for making the ring and 25 mm in diameter if an eight-inch tube was used. A tube allowed to drop through the loop of the ring becomes suspended at the lip.

The hook of the ring is then inserted at the support from which the pan of the balance is suspended from the beam. The tube and ring are counterbalanced by means of weights and then the proper quantity of solid or liquid is added to the tube. Small quantities of liquids (0.5 ml or less) are more easily weighed than measured. The density of the liquid is ascertained and the milliliters are converted to grams. A small amount of liquid is poured into a 25 ml beaker and by means of a pipette dropper the liquid is weighed, adding a drop at a time. It is advisable to have two rings each for six-inch and eight-inch tubes. The iron rings, if lacquered, remain free from rust for some time.

CARE OF APPARATUS

Glass apparatus should be handled with care. When heating, the flame should be applied gradually, as a sudden heating will produce strains which may result in cracks or breakage. When a flask or tube has been heated, it should not be placed upon a cold surface immediately. Distilling flasks should be examined for cracks on the bottom before using. A sharp-pointed intense flame should be avoided. Constant use and heating in one spot tends to produce strains in the glass which eventually lead to breakage.

Ground glass joints, as in the stopper and stopcock of the separatory funnel, are a source of trouble unless certain precautions are taken. It is advisable to place a fine film of vaseline or stopcock grease on the ground glass surface when not in use; another suggestion is to insert a small piece of paper between the ground surfaces. There is always a tendency for ground joints to stick, particularly when the surfaces are not clean. In the case of separatory funnels, it is always advisable to fasten the stopper and stopcock with string, fine copper wire, or special rubber, to the funnel. It is also advisable for the student to have two or more cardboard or wooden boxes in his desk, one to be used for corks and stoppers, another for small pieces of glass tubing, files, etc., and still another for soap, knife, scissors, or old safety razor blades.

Cleaning of glass apparatus. Glass apparatus is best cleaned immediately after use. Aside from the unpleasant sight of a desk filled with accumulated dirty apparatus, organic residues left standing adhere tightly and are more difficult to remove.

In the case of beakers, the cleaning is simple; abrasive powders, soap and water, and a brush or metal spatula carefully handled can remove most residues. In flasks, particularly distilling flasks, the cleaning often presents a difficult problem. If the residue is not tightly-adhering tarry carbon, it can often be removed by washing with denatured alcohol, acetone, kerosene, or other cheap solvent. If the residue is not easily removed, warming with dilute hydrochloric acid or 10 per cent sodium hydroxide may be of aid. Finally, if the above methods have little effect on the residue, "cleaning solution" is used. As the student already knows, this is a mixture of chromic acid and concentrated sulfuric acid; its preparation is described in the Appendix.

The vessel to be cleaned with the chromic acid mixture is first rinsed well with water, then 50 ml or more of the cleaning mixture is added. The vessel is rotated carefully so as to bring as much of its surface as possible in contact with the acid mixture; most of the cleaning solution is then poured back into the stock bottle, and the adhering acid mixture is allowed to remain in contact with the vessel for a few minutes. A small amount of water (5–10 ml) is added slowly and the vessel rotated as before. This procedure is repeated until the surface is entirely clean.

When the residue is carbonized and is not greatly affected by the treatment described above, then proceed thus: Place 1–2 g of solid sodium dichromate in the flask; add 1–2 ml of water; place in the hood with the mouth of the vessel away from you and towards the wall of the hood. Add 5–10 ml of concentrated sulfuric acid (technical grade). Clamp the vessel on a stand and heat with a free flame. If a reaction starts, remove the flame until it subsides, then heat until most of the tarry carbon has disintegrated. Allow it to cool. Pour acid mixture into a beaker and then rinse with water. The acid-mixture residue is carefully poured into the sink, unless it contains tarry matter which may cause clogging. The student is reminded that potassium permanganate *is never* used in place of potassium dichromate for cleaning solution.

In cleaning glassware, avoid scratches, particularly on the inner surfaces. Just as glass tubing scratched with a file breaks easily, in the same manner a scratch on the inner surface of the flask or beaker may lead to breakage. The scratches are points of weakness and during heating develop stresses of varying intensity which may lead to fractures.

PART I

INTRODUCTION TO LABORATORY METHODS

Experiment 1

THE SOURCES OF ORGANIC COMPOUNDS

Introduction. A large number of organic compounds are obtained from plant and animal tissues. Sugars, starches, oils, and proteins are examples. Coal, petroleum, and natural gas are mixtures of carbon compounds and their origin is associated with plants and animals which lived in past ages of the earth. From these mixtures a large number of organic compounds are obtained by distillation. The greater number of organic compounds are derived from reactions which are initiated and controlled by the chemist. These reactions in general involve: (1) the formation of a new molecule by the union of two or more molecules; (2) the disruption of a large molecule to form smaller ones; (3) the replacement within a molecule of one group by another; (4) the rearrangement of atoms within a molecule. The present experiment is designed to show: (1) the isolation of organic compounds from milk, which is a mixture secreted by animal tissues; (2) the carbonization of bituminous coal and formation of coal gas and coal tar, from which compounds containing mostly carbon and hydrogen can be isolated.

The analysis of cow's milk shows it to be a mixture consisting of 78 per cent water and 12 per cent solid substances in solution or colloidal dispersion. Of this 12 per cent *casein*, the most important, belongs to a complex group of organic compounds called proteins; a sugar (lactose), butter-fat, and small amounts of inorganic salts comprise the remainder. By addition of a small amount of acetic acid the dispersed protein is precipitated. By evaporation of the filtrate the crude sugar is obtained.

The carbonization of coal illustrates the formation of organic compounds by the disruption of large molecules to form smaller ones. Coal is a mixture of complex organic compounds whose nature is mostly unknown. Heating causes disruption of the molecules. Some of the fragments, such as methane, CH_4, carbon dioxide, CO_2, appear in the products; others combine to form such compounds as benzene, C_6H_6, toluene, C_7H_8, naphthalene, $C_{10}H_8$, which are isolated from the viscous tar. The coke which remains in the retort consists of carbon produced during the decomposition, together with inorganic compounds (ash) which are derived mostly from the muds in which the plant remains changed into coal. The small amount of ammonia which appears in the gaseous decomposition products is traced to the proteins that once existed in the plant tissues.

(A) **Preparation of Casein from Milk.** To 40 ml of milk in a 250 ml beaker, add 40 ml of water and five drops of 6 *N* acetic acid. The coagulated protein to which the fat adheres settles out. Filter the precipitate and wash it with water twice, so that it collects at the lower point of the folded filter paper. When most of the water has drained, remove the filtrates if it is desired to isolate the lactose. Wash twice with a 5 ml portion of alcohol and then twice with a 5 ml portion of ether. Collect the alcohol and ether washings separately and place them in a bottle provided for this purpose. Save the aqueous filtrate if the preparation of lactose is desired. Remove the solid product with a spatula to a watch glass and dry at room temperature. Place the casein in a test tube and properly label it, noting the yield, which is about 0.5 g.

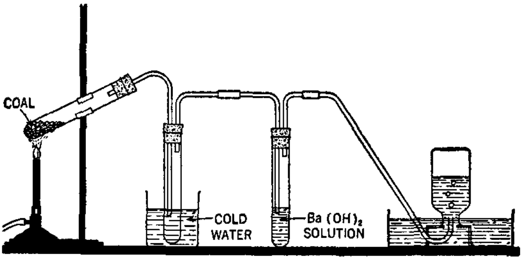


Fig. 3. Apparatus for experiment on the products obtained by the carbonization of coal

(B) **Preparation of Lactose.** Boil the filtrate from casein for a few minutes, cool, and filter again. Add small amounts of magnesium carbonate until the reaction of the solution is neutral to litmus paper. Pour mixture into an evaporating dish and evaporate on the water bath to dryness. Pour 5 ml of alcohol on the residue and stir. Pour the alcohol out and dissolve the residue in 10 ml of water. Filter and evaporate the clear liquid to a volume of 3 ml. Add 4 ml of alcohol and allow to stand. Filter the crystals through a small filter paper, and save for further tests.

(C) **Products from Carbonization of Coal.** Arrange apparatus as shown in Figure 3. Place 10 g of bituminous coal in the ignition tube, then heat it with a Bunsen flame. Note the changes in the first and second receiver. The gas collected over water is a mixture of compounds of carbon and hydrogen with some carbon monoxide. This is commonly known as *coal gas,* and results from the decomposition due to the heating of the mixture of carbon compounds in coal. Similarly, the viscous tar which collects in the first receiver results from decomposition of the compounds in coal to smaller molecular fragments, followed by recombination to give a complex mixture of compounds. By distillation and further purification of coal tar, a number of pure substances are obtained, such as *benzene, toluene, naphthalene,* and other compounds.

Note the change in color of the barium hydroxide solution of the second receiver and explain. Towards the end, disconnect the delivery tube and pass the gas for a minute into a test tube which contains a few cubic centimeters of distilled water. Determine the *p*H of the solution by the addition of a few drops of universal indicator.[1] Confirm the presence of ammonia with *Nessler's* solution. The Nessler test is also applied to a solution known to contain ammonia, and to a sample of distilled water.

[1] See Appendix.

Experiment 2

THE PURIFICATION OF SOLID ORGANIC COMPOUNDS BY CRYSTALLIZATION

GENERAL CONSIDERATIONS

Introduction. Compounds of carbon, whether obtained from natural sources or by means of a reaction, are seldom pure. Organic compounds from plants or animals usually occur in mixtures with related compounds; those obtained through a chemical reaction are contaminated with small amounts of other compounds which are produced along with the desired product. It is necessary, therefore, to consider in detail the methods used for the purification of both *solid* and *liquid* compounds of carbon. In the present experiment the purification of solids will be considered.

Generally solids are divided into two classes, *crystalline* and *amorphous*. The former are characterized by arrangement of particles according to a definite pattern, while the latter, as, for example, glass, do not have a crystalline structure. Most organic solid compounds are crystalline. The purification of impure crystalline compounds is usually accomplished by crystallization from an appropriate solvent. The property which is most frequently observed in order to determine the purity of a crystalline compound is the *melting point*, as discussed in the next experiment on page 41.

Crystallization. In the purification of organic solids by crystallization, the first step is to select a solvent which will dissolve the crude solid readily when hot, but only sparingly when cold. The crystalline substance is then dissolved in the hot solvent so as to form a nearly saturated solution. If the solution is colored, a small amount of powdered charcoal is added to adsorb and remove the traces of coloring matter; the solution is then filtered to remove the charcoal and insoluble impurities. On cooling, a certain amount of the dissolved substance separates out as crystals, leaving the greater part of the impurities in solution. The crystals are removed from the solution (often called "mother liquor"), by filtration. The resulting crystalline solid is tested for purity, and if found impure it is again crystallized, using fresh solvent. In this manner it is possible, by repeated crystallization, to purify crystalline substances.

The removal of impurities by crystallization is based upon the following considerations. Assume that in a reaction a crude compound *A* is obtained which contains 5 per cent of another substance *B* produced in the same reaction. In most cases the solubilities of *A* and *B* are different for any particular solvent. Let us assume for the first case that in a solvent S_1, at 20° *B* dissolves to the extent of 2 g per 100 ml of solvent and *A* to the extent of 1 g per 100 ml of solvent. If 50 g of the crude (which is composed of 47.5 g of *A* and 2.5 g of *B*) is dissolved in 100 ml of solvent S_1 while hot, and the solution is allowed to cool, the mother liquor at 20° will contain 1 g of *A* and 2 g of *B*. Therefore, the crystals (47 g) which separated on cooling contain 0.5 g of *B*. If the crystallization is repeated using 100 ml of fresh solvent S_1, the second mother liquor will contain 1 g of *A* and 0.5 g of *B*. In this manner 45.5 g of *A* can be obtained in the pure state.

In the above case it was assumed that the impurity is more soluble in a given solvent than the compound which is being purified. For the second case assume that the impurity is less soluble in a given solvent than the compound which is being purified. For example, 100 ml of solvent S_2 dissolves at 20° 10 g of *A* and 3 g of *B*. If 50 g of the impure compound is dissolved in 100 ml of solvent S_2 while hot and the solution is allowed to cool, the mother liquor at 20° will contain 2.5 g of *B* (that is, all of *B*), and 10 g of *A*. In this manner 37.5 g of *A* will be obtained in the pure state. This discussion illustrates the general principle used in the purification of solids. The effect of each of the compounds on the solubility of the other, however, was not taken into consideration. In dealing with very small quantities this effect must be taken into account. For example, the solubility of a compound in alcohol may be 0.5 g per 100 ml but in the presence of another compound it may rise to 1.5 g per 100 ml.

Choice of solvent. The solvent cannot be selected on the basis of rules or theoretical considerations but must be experimentally determined. There are certain theoretical considerations which serve as a general guide; for example, it is known that naphthalene, $C_{10}H_8$, is insoluble in water, H_2O, but soluble in benzene, C_6H_6. From similar studies the general rule is drawn that a solid is best dissolved in a liquid which it resembles in chemical composition and structure. An organic carboxylic acid RCOOH is expected to dissolve in water since it contains the hydroxyl group, OH; but if the organic radical R is quite complex, the solubility is diminished, and in such a case a base like sodium hydroxide may be used to advantage as a solvent. For example, the acid may be dissolved in dilute sodium hydroxide and then precipitated by the addition of hydrochloric or sulfuric acid.

The choice of the solvent for a particular crystallization depends on several factors. The first, of course, is that it should dissolve, when hot, an appreciable amount of the substance to be purified without reacting chemically with it. In addition, the solvent should be relatively safe to handle (not poisonous or inflammable) and easy to remove from the filtered crystals. Some of the solvents most commonly used for crystallization are given in Table 1. The solvent is selected on the basis of solubility tests. One method of performing these tests is to place 0.1 g of the substance in a small test tube and then to add 1 ml of the warm solvent. If all the solid does not dissolve even on heating, then another ml of the solvent is added, and heat again applied. If a total of 3 ml is added and the substance does not dissolve when heated, then the substance is regarded as difficultly soluble in that solvent. Such a solvent is not suitable for crystallization, for it would require more than 100 ml of hot solvent to dissolve 2–3 g of the substance. Care should be exercised to distinguish small solubility from the presence of insoluble impurities.

Table 1

COMMON SOLVENTS FOR ORGANIC COMPOUNDS

SOLVENT	BOILING POINT (° C)	USE
Water	100	Use wherever possible
Methyl alcohol	64.7	Poisonous and inflammable
Ethyl alcohol	78	Inflammable
Benzene	80	Very inflammable and difficult to extinguish its fire
Ethyl ether	34.6	Inflammable; avoid wherever possible
Ethyl acetate	77	Inflammable
Acetic acid	118	Vapors inflammable and irritating
Acetone	56.5	Inflammable
Petroleum ether[a]	40-60	Inflammable
Chloroform	61	Not inflammable; vapors toxic
Carbon tetrachloride	76.8	Not inflammable; vapors toxic

[a] A mixture of hydrocarbons obtained from petroleum; also called "ligroin." Higher boiling fractions are also commercially available; such as b.p. 60–80°, and other fractions.

If the solid dissolves in the hot solvent, the tube is cooled to determine whether crystallization occurs. If crystallization does not take place this may be due to the absence of "nuclei" on which crystal growth begins. To produce crystallization the tube is scratched with a glass rod below the surface of the solution, since the points of the scratches may serve as nuclei for crystal growth. If crystals do not separate, or if the sample dissolves immediately upon the addition of 1 ml of solvent or upon slight warming, such solvent is unsuitable. In such cases the use of a mixture of two solvents may be employed. For instance, many substances are too easily soluble in alcohol and the crystals do not separate out on cooling. However, if the compound is sparingly soluble in water, addition of a small amount of the latter will cause crystallization. The use of "solvent pairs" is advisable whenever the compound to be purified is very soluble in one solvent and difficultly soluble in another, provided the two solvents are miscible. For example, benzoic acid, C_6H_5COOH, may be recrystallized by first dissolving in a small amount of hot alcohol and then adding water until a cloudiness just appears. The addition of the solvent in which the solute is sparingly soluble should be dropwise, to avoid the formation of oils and syrups which solidify slowly on standing.

Reference to Table 1 shows that a number of organic solvents are inflammable. Both methyl and ethyl alcohols are inflammable; in addition methyl alcohol is poisonous when absorbed in sufficient quantities in the body. The terms "inflammable" and "poisonous" need some explanation. The inflammability of a substance depends to some extent on its vapor pressure at ordinary temperatures. For example, ether and benzene are more inflammable than ethyl alcohol. Another factor to be considered with reference to the inflammability of solvents is the relative ease with which the fire of the burning solvent can be extinguished. Addition of water in sufficient amounts will extinguish the fire in a vessel which contains alcohol, but will only help to spread the fire if the burning substance is benzene. The latter is immiscible with water and floats on top of water. Therefore, addition of water to benzene "on fire" may spread the water along with a layer of burning liquid.

The designation of methyl alcohol as "poisonous" in contrast to ethyl alcohol is made in order to acquaint the student with the fact that though the two alcohols are closely related one must be handled with some caution; in other words, methyl alcohol vapors should not be inhaled for any length of time, and the liquid should not be brought in contact with the hands. This does not mean, however, that one drop of methyl alcohol coming in contact with the skin will cause poisoning. Though the drop should be washed off with running water, it should be remembered that the amount necessary to cause toxic effects varies with different poisons. In general, it is a good practice for the beginner to regard all organic compounds as toxic and as substances whose vapors are very likely to be inflammable.

GENERAL DIRECTIONS FOR CRYSTALLIZATION

Solution. The solvent and the ratio of solute to solvent may be determined by preliminary tests as outlined above. More often, however, this information can be obtained by consulting the solubility data in handbooks on chemistry. For example, assume that the compound to be purified is acetanilide, $C_6H_5NHCOCH_3$. By referring to the tables on physical constants of organic compounds which appear in such handbooks[1] the student will find under Acetanilide the data on solubility listed in abbreviated form as follows:

$$\text{Soly. } 0.56^{25},\ 3.5^{80}\ \text{w.};\ 21^{20},\ 46^{60},\ \text{al.}$$

At the beginning of the tables a list of abbreviations is given by which the solubility data are translated thus: *Solubility* (expressed in grams of substance dissolving in 100 ml of the solvent): water as solvent, 0.56 g at 25° and 3.5 g at 80°; ethyl alcohol, 21 g at 20° and 46 g at 60°. If it is desired to obtain additional information on the solubility of acetanilide in alcohol at higher temperatures, a more complete reference book on solubility should be consulted. Seidell's book[2] on solubilities gives the solubility of acetanilide in ethyl and methyl alcohols at 60° as 46.4 g and 59.2 g respectively per 100 g of saturated solution.

It should be noted that the units used in the two references are not uniform. One author expresses solubility in grams of solute per 100 g of solvent and the other in grams of solute per 100 g of saturated solution. It is not difficult, however, to estimate the approximate amount of acetanilide which dissolves at 60° per 100 g of methyl alcohol. Since 100 g of saturated solution in methyl alcohol at 60° contains 59.2 g of the solute, it is obvious that the bal-

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[1] N. A. Lange, *Handbook of Chemistry* (4th ed.; Sandusky, Ohio: Handbook Publishers, Inc., 1941). C. D. Hodgman, *Handbook of Chemistry and Physics* (25th ed.; Cleveland, Ohio: Chemical Rubber Co., 1941).

[2] A. Seidell, *Solubilities of Inorganic and Organic Substances* (3rd ed.; New York: D. Van Nostrand Co. 1940).

ance, about 40 g, is solvent. Therefore 100 g of the alcohol will dissolve about 150 g of acetanilide at 60°.

The collected data on solubilities in various solvents are now used to determine the appropriate solvent and the ratio of solvent to solute. Assume, for example, that the amount of crude acetanilide to be purified is 10 g. If water is used as a solvent the amount necessary to effect solution at or above 80° is 300 ml. The amount which will remain in the mother liquor will be about 1.5 g. If methyl alcohol is used as a solvent it will require 6.6 g or 8.4 ml of the solvent (6.6 g divided by 0.8 specific gravity of methyl alcohol) to dissolve 10 g of the crude acetanilide. Such a solution will be difficult to handle because crystallization will occur during filtration. If 20 ml of the solvent are used, all the solute will remain in solution at 20°. Therefore water can be added after filtration until cloudiness just appears, and the solution is then allowed to cool. Addition of 80–85 ml of water will cause the crystallization of about 8 g of acetanilide. If the amount of solid is 5 g or over and the solvent is *water*, solution is effected in a beaker or Erlenmeyer flask. The water is heated to nearly boiling and then the solid is added and stirred with a rod to break the lumps; the heating is resumed until solution is complete. If the solvent is inflammable, toxic, or volatile, solution is effected in a flask provided with a reflux condenser as shown in Figure 4. The flask is heated by means of a water bath or steam bath. If a water bath is used, care should be taken to have a small flame and to make sure that the cork by which the condenser is attached to the flask does not leak and that the cold water circulates through the condenser.

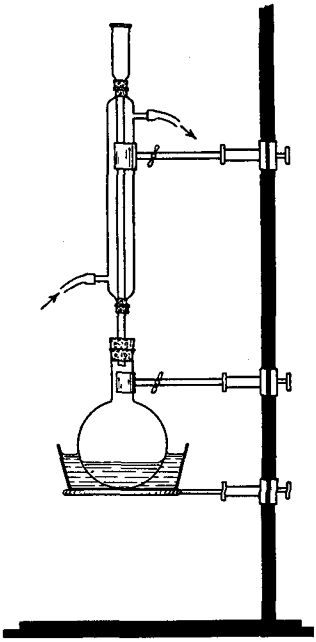

Fig. 4. Flask with reflux condenser for heating liquids (by means of a water bath)

For smaller amounts, for example, 0.5–1 g as used in semimicro procedures, the amount of solvent has to be more closely calculated and the method slightly modified. Assume, for example, that it is desired to purify 0.5 g of acetanilide. If water is used as a solvent, about 15 ml should be taken. The amount remaining dissolved in the mother liquor will be about 0.1 g, or 20 per cent of the total, hence greater care should be exercised to minimize other losses. Alcohol cannot be used as a solvent, for it would require only 1 ml, an amount too small to handle. The procedure may be modified by

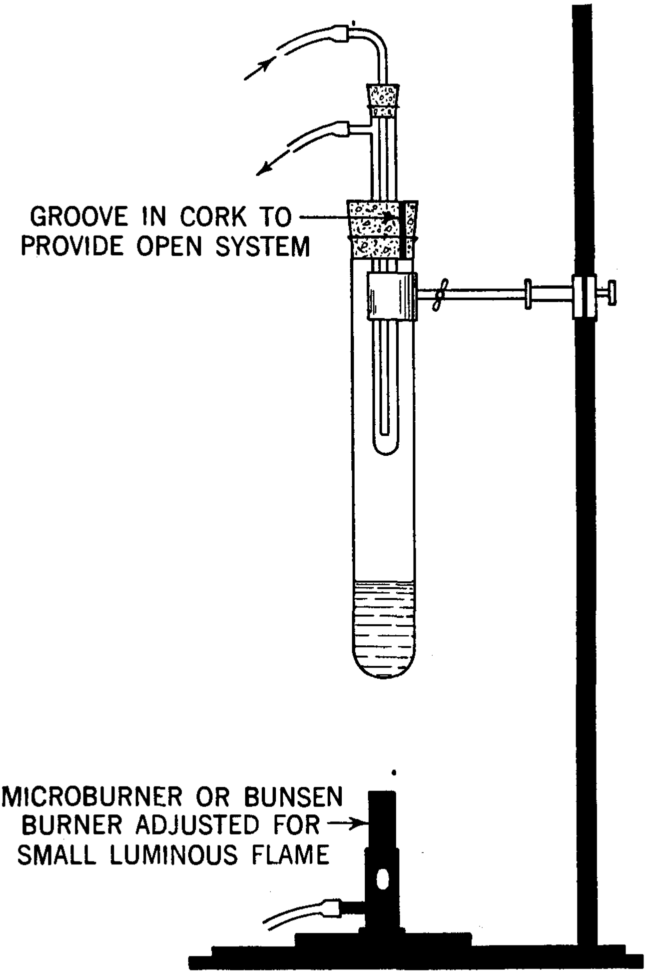

Fig. 5. Semimicro apparatus for heating under reflux (for inflammable liquids, *provide water bath*)

using a mixture of 1.5 ml of methyl alcohol to 7.5 ml of water to dissolve the crude acetanilide. The mixture is heated in a test tube provided with a micro condenser as shown in Figure 5. After filtration the funnel and paper are washed with 0.5 ml of alcohol (thus dissolving what adheres to the paper) and then 4–5 ml of water is added to the filtrate.

Filtration of the hot solution. The solution is boiled for a few minutes and observation is made whether the solid has dissolved completely and whether any colored impurities are present. To remove these a very small amount of activated carbon (special kind of decolorizing carbon) is added at this point. The amount of carbon to be added depends on the amount of colored impurities present; about 1 to 3 per cent of the amount of the crude solid may be taken as an average. Thus, for 10 g of solid the amount of carbon to be added is 0.1–0.3 g. The use of most activated carbons has the disadvantage of carbon passing through the common filter paper. If filter paper with very small openings is used, the filtration will be too slow and crystallization will start while the solution is being filtered. The use of a small amount of *Super-cel*[3] or asbestos fiber, if added before filtration, gives clear filtrates.

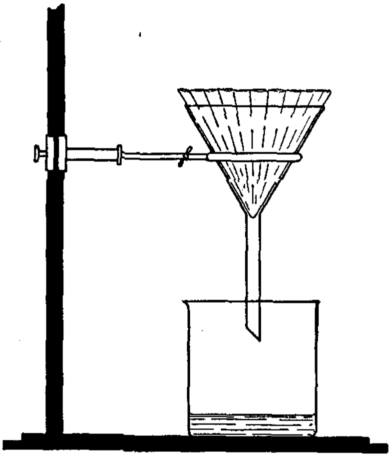

Fig. 6. Macro apparatus for ordinary filtration

If the solvent is inflammable, care must be taken to see that no flames are in the vicinity. The hot solution must be filtered through a piece of fluted paper immediately, to prevent deposition of crystals in the solution during filtration. If, after filtration has started, crystals begin to separate in the unfiltered solution, the latter is transferred back into the flask, more solvent is added so that the solution is not saturated, and it is then heated again to boiling. Apparatus for filtration is shown in Figure 6.

For the filtration of small amounts of solution a funnel with a very short stem is selected and is warmed gently over a free flame. A piece of fluted paper (made according to directions given below)

[3] Also called *Filter-cel*, a high grade infusorial earth.

is fitted into the funnel and moistened with some warm solvent. The funnel is then fitted over a small beaker or filter flask. The hot solution is added in small portions. When all has been added, a small amount of fresh solvent is added to the flask, heated, and used for washing the filter. Apparatus used for ordinary semimicro filtration is shown in Figure 7.

Preparation of fluted filter paper. Fold the filter paper into halves and again into quarters. Open the half sheet as shown in Figure 8(*a*), and fold edges 1, 2 and 2, 3 on to 2, 4, thus producing the new folds 2, 5 and 2, 6 as shown in Figure 8(*b*). Do not crease the folds too tightly at the center. This causes weakening of the central section, which might break during filtration. Continue the inward folding, bringing 2, 3 to 2, 6, 1, 2 to 2, 5, 1, 2 to 2, 6, and 2, 3 to 2, 5 (as shown in Figures 8[*c*] and 8[*d*]).

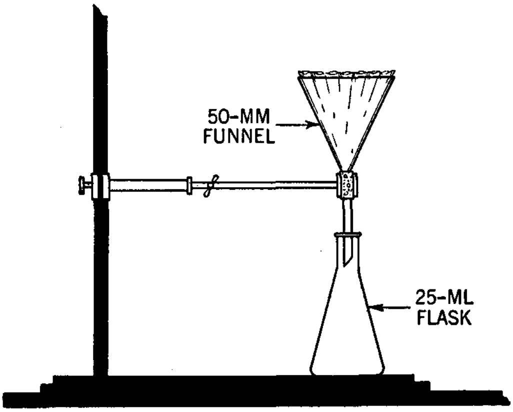

Fig. 7. Semimicro apparatus for filtration

Now make a new fold in each segment between 2, 3 and 2, 9, 2, 9 and 2, 5, etc., in the direction opposite to the first series of folds, that is, make outward folds instead of inward folds as at first. The final folded paper is shown in Figure 8(*e*).

Filtration of large quantities of solution. For the filtration of larger quantities of hot solutions it is advisable to use a funnel heated by a hot water jacket, shown diagrammatically in Figure 9. If the solvent is inflammable, the side arm is heated with a free flame until the water boils, and the flame is shut off before the filtration is started. Where steam is available it may be used to advantage as the source of heat. If the amount of solution to be filtered is fairly large, a Buchner funnel and suction flask, shown in Figure 10, may be used. A filter paper is selected of a size to fit the flat perforated plate. If the paper is too large and extends beyond the edges, it is trimmed so as to project just beyond the outside row of perforations. If the solvent is non-aqueous, the filter paper is first moistened with water, and then carefully fitted upon the perforated plate so that it lies flat and without wrinkles. A small amount of alcohol is poured over the paper, and suction is applied; finally, it is washed with some of the cold solvent, which is sucked out and added to the discarded filtrate. The Buchner funnel is warmed by filling it with some hot solvent. When the funnel is ready, a small amount of the hot solution is poured into the funnel, allowed to pass through completely, and then returned to the original hot solution. This insures the formation of a mat which will give a clear solution.

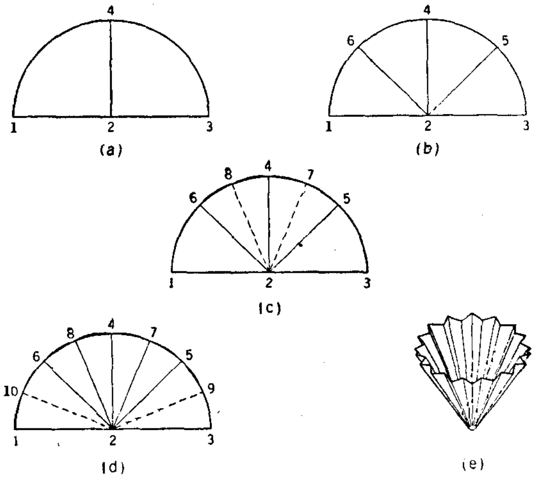

Fig. 8. Method for preparation of fluted filter paper

The filtered hot solution is placed either in a beaker and covered with a watch glass or in a wide mouth Erlenmeyer flask and stoppered with a cork. The solution is allowed to cool slowly if large crystals are desired. Small crystals, however, are often preferable, as they are less likely to be contaminated by adhering and occluded mother liquor. The vessel containing the solution is placed in cold water or a freezing mixture and stirred from time to time. If crystals do not separate immediately, crystallization may be induced by scratching the sides of the vessel with a glass rod. If the substance separates as an oil, it can often be made crystalline by recrystallizing from more dilute solutions.

Filtration and drying of crystals. The crystals are usually separated from the mother liquor by filtration with suction in a Buchner funnel. A filter paper is fitted into the flat part of the funnel and moistened with some of the solvent, and suction is applied before the mixture of crystals and solution is added. When most of the liquid has drained from the funnel, the suction is discontinued and a little of the filtrate is used to rinse the adhering crystals from the beaker in which crystallization takes place. Suction is again applied, and the crystals are pressed down with a spatula, in order to remove as effectively as possible the adhering mother liquor. When the draining has almost ceased, the suction is discontinued and the cake of crystals is loosened with a spatula. A small amount of cold pure solvent is added and carefully distributed in the funnel so as to moisten all the crystals. Suction is once more applied and the crystals are pressed as before. The washing is repeated after the suction is first discontinued. When more effective washing is desirable, the cake of crystals is removed from the funnel into the beaker, the pure solvent is added, and the crystals are stirred so as to bring them in contact with the solvent. The crystals are then filtered and resuspended. If the crystals are

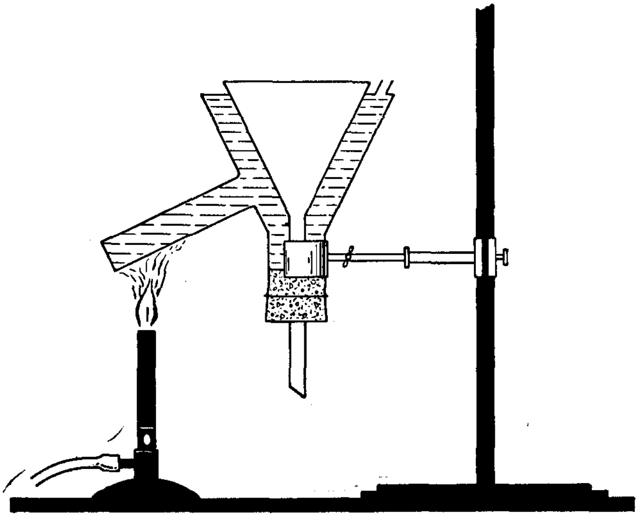

Fig. 9. Funnel for hot filtration

very large, grinding in a mortar before resuspending is of aid in effectively removing the adhering and occluded mother liquor.

In order to dry the crystals, the funnel is removed from the filter flask and inverted over a large watch glass, and the cake is removed with the aid of a spatula and spread to dry. If the substance melts above 100° and is stable, it can be dried by heating over a water bath. If the substance decomposes on heating or has a low melting point, it can be air-dried by placing it on a porous plate or on a pad made of newspaper with two pieces of filter paper on top. In air-drying it is advisable to cover the crystals with a piece of paper perforated with a number of holes to allow evaporating of the solvent. If a melting-point determination is required immediately, it is possible to dry a small amount of material rapidly by pressing it several times with a pad of five thicknesses of filter paper and placing it on a watch glass in a warm place. For careful drying the crystals are placed in a dessicator containing an appropriate substance for absorbing the solvent. The drying is hastened by using a vacuum dessicator. Small traces of solvent may lower the melting point considerably and therefore care must be taken to insure a dry sample of the substance before attempting a melting point determination.

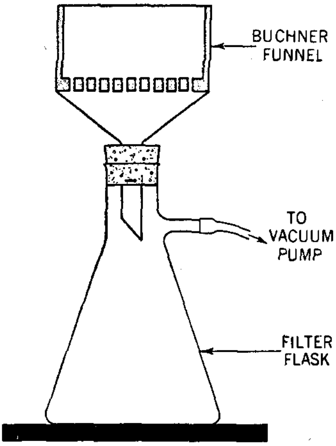

Fig. 10. Macro apparatus for filtration, using suction

Semimicro procedure for crystallization. By exercising sufficient care a beginner can acquire the technic of crystallizing and filtering quantities of 200–500 mg or less. The procedure is the same, with a few variations in the apparatus used. Solution of the impure substance is effected in a test tube (4 inch or 6 inch). The amount of solvent is seldom much over 5–10 ml; the upper part of the tube can be used as a condenser if the heating is not prolonged. If an inflammable solvent is used, it is advisable to use the arrangement shown in Figure 5. The test tube is placed in a small water bath (or beaker with water) and a micro condenser inserted at the top. The filtration of the hot solution is made through either a semimicro Buchner funnel or through the filter such as shown in Figure 11. The filter tube is made of 16–25 mm glass tubing. Obtain an eight or six inch test tube, heat it in the flame until it is soft, and then draw it out slowly for about 100 mm. After the tube has cooled, the drawn-out part is cut so as to provide a stem of 70 mm. The stem is then fire-polished. The upper part of the tube is flared open by heating and then smoothing it out with the round handle of a file. Put two or three small pieces of glass in the neck of the filter, and then add small glass beads to make a layer of about 4–5 mm. The glass beads are made by heating a 6 mm glass rod and then immersing it in a small beaker containing cold water. The filter is now inserted through one opening of a two-hole No. 4 rubber stopper; a short L tube serves as a side arm for attachment to a suction pump. The filter is fitted to a six- or eight-inch test tube and the latter is clamped to a stand. A small amount of asbestos fiber pulp or filter paper pulp is added and sucked dry. The thickness of the filter mat should be about 4–5 mm.

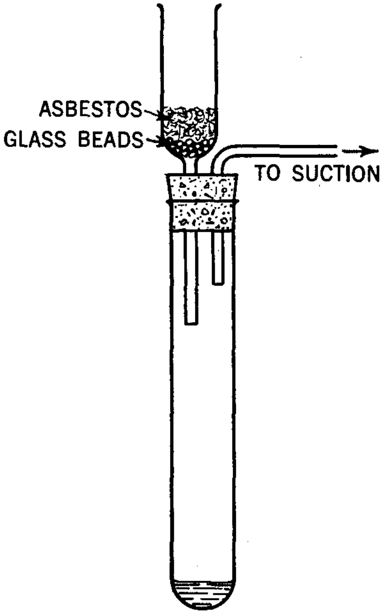

Fig. 11. Semimicro apparatus for suction filtration, using funnel made by student

A convenient micro Buchner funnel can be made by the insertion of a porcelain perforated disc with beveled edges into a Bunsen funnel, as described on page 14. The porcelain disc (20 mm) is fitted inside a Bunsen funnel of 50 mm diameter at the top, and pressed down slightly. A filter paper slightly larger (21 mm) is placed over the disc and moistened with a few drops of the solvent. The tube is fitted through a rubber stopper over the top of an eight-inch tube with a side arm, and filtration is carried out as usual. This arrangement, shown in Figure 12, is more economical than a Semimicro Buchner funnel, and less troublesome than the filter tube shown in Figure 11.

The selection of a semimicro funnel for filtration with suction is a matter of cost. The Buchner funnel shown in Figure 2 costs about 75 cents. The perforated disc which when fitted into an ordinary funnel gives an efficient suction filter costs about 20 cents. The filter tube, which is made in the laboratory by the student, costs the same as the test tube. The funnel with the removable perforated disc is preferred; it has been found as useful

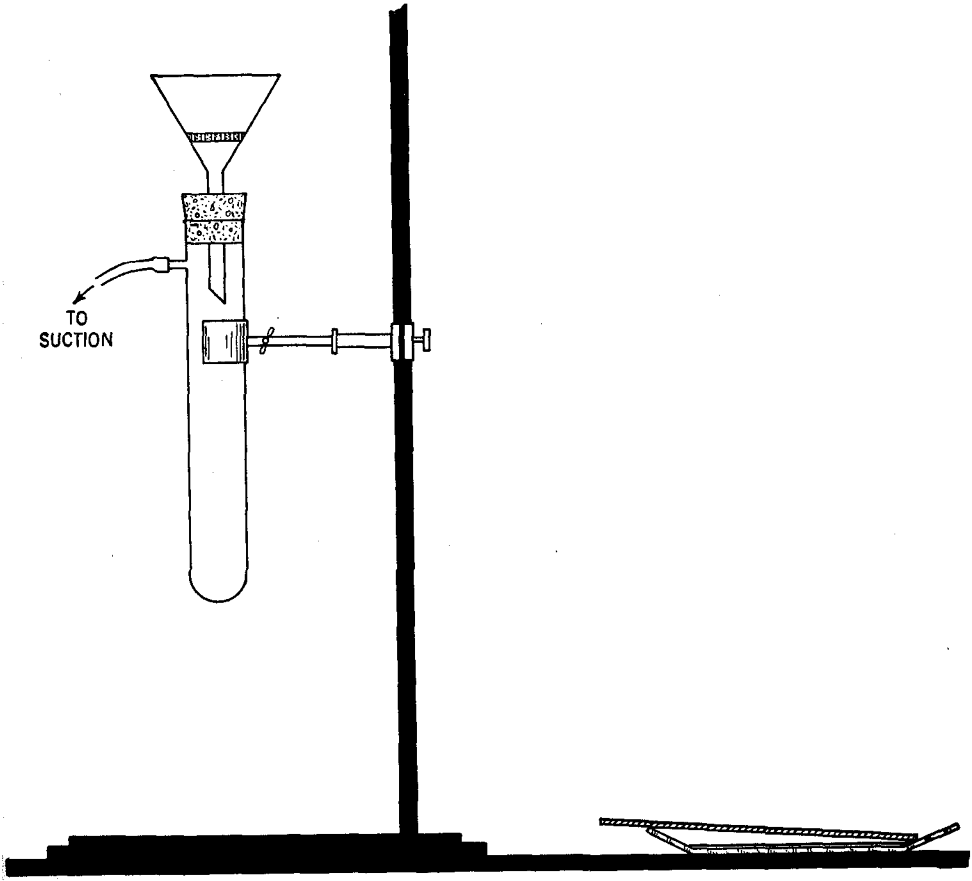

Fig. 12. Semimicro apparatus for filtration, using ordinary funnel and perforated porcelain disc

as the complete semimicro Buchner funnel and has the additional advantage that it can be cleaned more efficiently.

After the semimicro Buchner funnel has been fitted over the receiving tube which is clamped to a stand, 2 ml of the hot solution are added, with the use of only small suction. Toward the end of the process the filtrate should be very clear. The filtrate is returned to the unfiltered part of the solution, heated again, and filtered through the prepared mat. When the filtration is finished, the receiving tube is corked and cooled in running water, with shaking from time to time. The filter is cleaned immediately. The filter mat is removed with a spatula. If a filter with glass beads has been used, it is cleaned by washing first with 5 ml of the solvent, then with water, and finally by running a little cleaning solution through it. It is then washed with water again and a new filter mat inserted before putting it away. It is advisable to prepare several of these filter tubes. In case the porcelain disc is used, it is removed, cleaned, and placed in a small box.

Filtration of small amounts of crystals. A number of methods can be used for the filtration of small quantities of crystals. Any of the semimicro Buchner funnels described above may be used with advantage. The tube containing the crystals is shaken so as to distribute the liquid throughout, and the contents are then added in a slow steady stream to the micro Buchner funnel. The filtrate is used to wash the adhering crystals in the crystallizing tube. When all the crystals have been transferred to the funnel, suction is resumed until all the mother liquor has been drained. The suction is discontinued, ten to twenty drops of the solvent are added to the crystals with a medicine dropper, and the suction is resumed; the washing is repeated, and the crystals are now pressed gently down with a glass spatula. If the amount of crystals exceeds one gram and a more thorough washing is desired, the crystals are removed into a small beaker and a few milliliters of solvent added. The crystals are thoroughly stirred and then filtered. After washing the suction is continued for some minutes, and then, by using a long narrow spatula, the crystals are removed and placed on a watch glass or on a filter paper disc to dry. The discs are about 70 mm in diameter and 2 mm in thickness.

SPECIFIC DIRECTIONS FOR CRYSTALLIZATION

(A) Test for Solubility. Obtain 1 g each of acetanilide, benzoic acid, and naphthalene, and test their solubility with each of the following solvents: water, ethyl alcohol or methyl alcohol, and benzene. For each test use 0.1 g as described in the directions on page 26. On the basis of these tests and the solubility data obtained from the handbook, determine the best solvent for the crystallization of each substance tested.

(B) **Crystallization from Water** (M.).[4] Write a brief outline for the purification of impure acetanilide or benzoic acid. If the macro method is employed, use 5 g; in the semimicro method use 0.5–1 g. The outline should include (1) the amount of substance to be recrystallized; (2) the amount of water; (3) the procedure for filtering the hot solution and crystals, and also for drying the latter. The outline is presented to the instructor for approval, and the sample is obtained. For the macro method, place the 5 g of impure solid in a 250 ml beaker, add 100 ml of water, and heat nearly to boiling. Add the required amount of hot water until all the solid has dissolved. Add about 0.5 g of decolorizing carbon and a very small amount (0.1 g) of Super-cel and boil gently for a few minutes. Prepare the funnel and fluted filter paper according to the directions given on page 32. Use a 250 ml beaker or a 250 ml Erlenmeyer flask to collect the filtrate. Pour the hot solution into the filter until the funnel is two-thirds full, then replace the beaker on the wire gauze and continue to heat with a very small flame to prevent cooling. When all the solution has been filtered, cover the receiver with a watch glass and cool rapidly with stirring. Allow to stand for about thirty minutes and then filter the crystals with suction through a Buchner funnel. The crystals are washed twice with 10 ml of cold water in accordance with previous directions. Press them compactly with a spatula, and when completely drained transfer to a watch glass or large clean paper. Remove a small sample of the crystals, dry it on a small watch glass or filter disc, and determine the melting point according to the directions given in the next experiment. If the product melts within 1 or 2 degrees of the melting point recorded in the literature, it is sufficiently pure for the purpose of this experiment; otherwise, the crystals which are still wet are again dissolved and the process of crystallization is repeated. When the melting point indicates satisfactory purity, the crystals are dried, and then placed in a tared bottle or tube, after which the weight is ascertained. The bottle or tube is properly labeled and handed to the instructor together with the report of the experiment.

(C) **Crystallization from Water** (Sm.). Place 0.5 g of impure acetanilide or benzoic acid in a six-inch test tube, and add a mix-

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[4] The initials "M." and "Sm." indicate the use of macro and semimicro methods, respectively.

ture of 2 ml of methyl alcohol and 3 ml of water. Arrange the tube with a micro condenser as shown in Figure 5, and heat in a water bath until the solvent begins to boil. If the solid has not dissolved completely, add alcohol through a medicine dropper until solution is complete, then a few drops more. Add as much charcoal as can be held on the tip of a micro spatula (about 50 mg) and a minute amount of Super-cel, and heat for a few minutes in the water bath. Prepare a micro filter (Figure 7 or 12); pass through it 5 ml of hot water and then 5 ml of 50 per cent methyl alcohol which has been heated nearly to boiling. Drain the receiving tube and then pour the hot solution through it. The first part of the filtrate is returned to the tube containing the hot solution if it is not clear. The suction is discontinued and water is added (dropwise) to the filtrate until cloudiness just appears. A drop of alcohol is added to clear the solution and then the tube is cooled rapidly with stirring by immersing it in cold running water. After 15–20 minutes the crystals are filtered and washed as described on page 38. The melting point is determined according to the directions given in the next experiment. The product should melt within 1 or 2 degrees of the melting point recorded in the literature.

(D) **Crystallization from Alcohol** (M.). Review general directions on page 28. Weigh 5 g of benzoic acid or naphthalene in an Erlenmeyer flask and arrange as shown in Figure 4. Add 30 ml of methyl alcohol if benzoic acid is used, or 60 ml if naphthalene is used. Warm the mixture until the alcohol boils, and add 0.5 g of decolorizing carbon and 0.1 g of Super-cel if solution is complete. The water bath is lowered or the flask is removed before the addition of charcoal, since gases adsorbed by the charcoal are given off and frothing may occur. Prepare funnel and filter paper as directed on page 31; use a 250 ml Erlenmeyer flask for receiver. Filter the hot solution and then add water dropwise until cloudiness just appears. Cool the flask in cold water and allow to stand for 15–20 minutes. Filter the crystals with suction in a Buchner funnel; wash twice (see page 34), using 5–10 ml of 50 per cent methyl alcohol. Remove a small sample, and dry it for melting point determination. If the crystals are sufficiently pure, they are dried on clean paper and then are placed in a tared bottle and weighed.

Experiment 3

DETERMINATION OF MELTING POINTS

GENERAL CONSIDERATIONS

Introduction. It was stated in the preceding experiment that solids are divided into *crystalline* and *amorphous*. The latter are non-crystalline and are often called *glasses*, since glass is a common example of this type of solids. Glasses when heated soften gradually, while crystalline solids, if pure, melt sharply at a definite temperature.

The melting point of a pure and stable carbon compound is used as a criterion of its purity. The greater part of crystalline organic compounds are assumed to be molecular, that is, the individual crystal is a geometrical arrangement of molecules. When such a solid is heated, the vibrational energy of the molecules is increased. When this energy becomes sufficiently great, the individual molecules leave the fixed arrangement of the crystal and assume the random motion characteristic of liquids and gases. When a pure crystalline substance is heated slowly, the temperature remains constant until all the solid has melted; if the substance is not heated or cooled but kept at this point, the solid phase exists *in equilibrium* with the liquid phase. The temperature at which both solid and liquid can exist in contact with each other (at a pressure of one atmosphere), is defined as the *melting point.*

Effect of impurities on the melting point. The student will recall that a substance in either the solid or liquid form exerts a definite vapor pressure and that this pressure increases with the temperature. It will also be recalled from the vapor-pressure diagram of water that at 0° C. the vapor pressure of ice (solid) and of water (liquid) are the same (4.5 mm of mercury). Figure 13 represents the vapor pressure of naphthalene. At 80° the vapor pressures of both liquid and solid are the same. The rate of transformation of solid naphthalene to liquid at 80° equals the rate of transformation of liquid naphthalene to solid. Below 80° the transformation of liquid naphthalene to solid proceeds faster than that from the solid to liquid, and the substance solidifies. Above 80° the vapor pressure of the solid is higher than that of the liquid; hence the rate of transformation of solid to liquid naphthalene is greater than from the liquid to the solid, and consequently the substance liquefies. Only at the intersection of the two vapor-pressure curves can the two phases (solid and liquid) exist together.

Assume that an impurity is added to the equilibrium mixture of pure solid and liquid naphthalene. Assume further that this impurity is biphenyl, which is soluble in liquid but not solid naphthalene. The vapor pressure of the liquid is lowered. Consequently the liquid will pass to the solid state at a lower rate than solid to liquid; in other words, the solid will melt faster, and this process requires heat, so that, since no heat energy is added, the temperature will fall. The vapor pressures of the solid and of the impure liquid meet at point M_1, Figure 14. This point corresponds to the temperature of 75°, which is below the melting point of pure naphthalene.

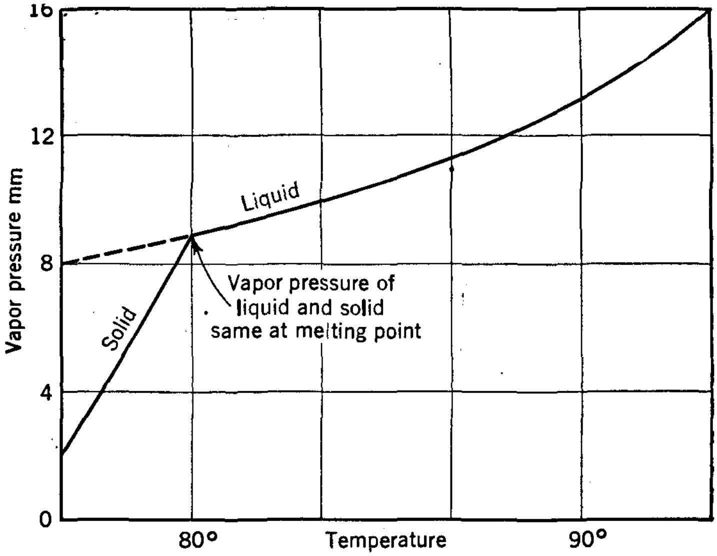

Fig. 13. Vapor pressure of naphthalene

According to Raoult's law, the lowering of the vapor pressure of the pure liquid naphthalene is proportional to the mole fraction of the dissolved biphenyl. *The mole fraction is the number of moles of one component divided by the total number of moles of all the components present;* therefore the mole fraction of biphenyl is the number of moles of biphenyl divided by the sum of the moles of naphthalene and biphenyl. In the above example there are 0.9 moles naphthalene and 0.1 moles of biphenyl; the mole fraction of biphenyl is 0.1 and the mole per cent is 10. Increase of the mole fraction of biphenyl to 20 mole per cent reduces the vapor pressure so that the two meet at point M_2, corresponding to a temperature of 70°. Further addition of biphenyl produces a proportionate depression, until the fraction of biphenyl is 56 per cent, represented by point M_3 and corresponding to a temperature of 39.4°, called the *eutectic point*. Below this temperature the impure liquid naphthalene solidifies. The solid consists of separate crystals of naphthalene and biphenyl. At this temperature both solid naphthalene and biphenyl exist in equilibrium with a liquid having a composition of 44 mole per cent of naphthalene and 56 mole per cent of biphenyl. This corresponds to 40 per cent naphthalene and 60 per cent biphenyl by weight. Such a mixture, if melted and allowed to solidify, will melt at 39.4°, which is lower than the melting point of either naphthalene (80°) or biphenyl (69°); hence it is called a *eutectic* (i.e., easily melting). The effect of the addition of biphenyl to naphthalene is represented in the melting point–composition diagram shown in Figure 15.

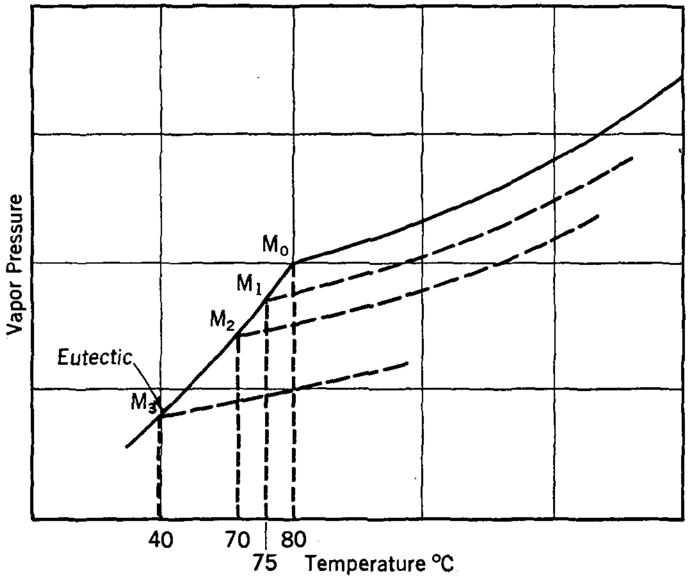

Fig. 14. Effect of addition of biphenyl on the melting point of naphthalene

In the above discussion it was assumed that biphenyl is soluble in liquid naphthalene but not in solid, and also that no molecular compound is formed between the two substances. Although this is true of naphthalene, it is not true of other substances. It is possible for two substances to combine and form a chemical compound or to mix in the liquid state and solidify as homogeneous crystals called *solid solutions.* The diagram in Figure 16 shows the two components *A* and *B* combining to form a compound *AB*. The melting point of the compound is indicated as the maximum point *C* while E_1 and E_2 are the two eutectic points. E_1 is the eutectic point at which a certain mixture of substance *A* and compound *AB* melts; E_2 is that at which a certain mixture of substance *B* and compound *AB* melts. Therefore, addition of small amounts of *B* to *A* will lower the melting point until E_1 is reached; further addition will cause a rise until *C* is reached, which represents the melting point of the compound. In many cases two components are able to form a whole series of different compounds.

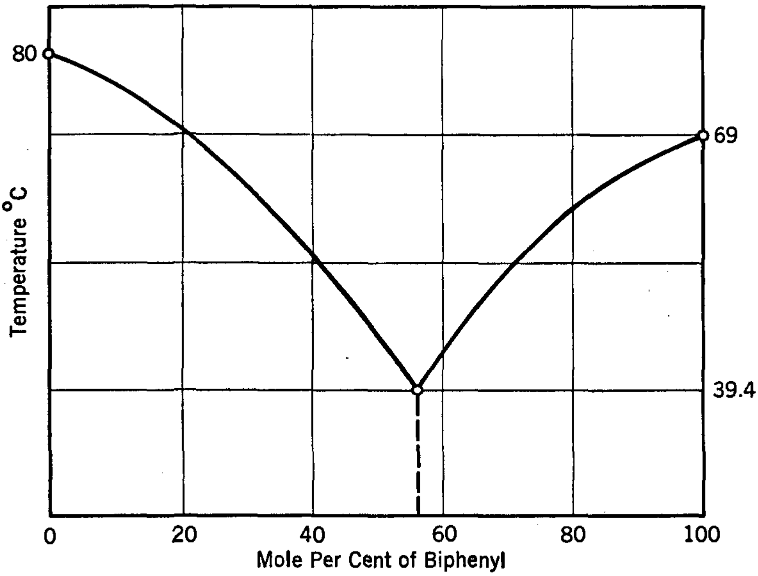

Fig. 15. Melting-point–composition diagram of naphthalene and biphenyl, involving formation of eutectic

In Figure 17 the two components *A* and *B* are completely homogeneous in the solid as well as in the liquid state without being combined chemically. The solid solution phase does not have the same composition as the liquid from which it separates but is somewhat richer in the higher melting component *B*. In this case the melting point of each component is lowered, but all mixtures of *A* and *B* melt at temperatures intermediate between the melting points of the two components. There are cases, however, in which mixtures of the two components melt at lower or higher temperatures than the melting points of pure *A* and pure *B*.

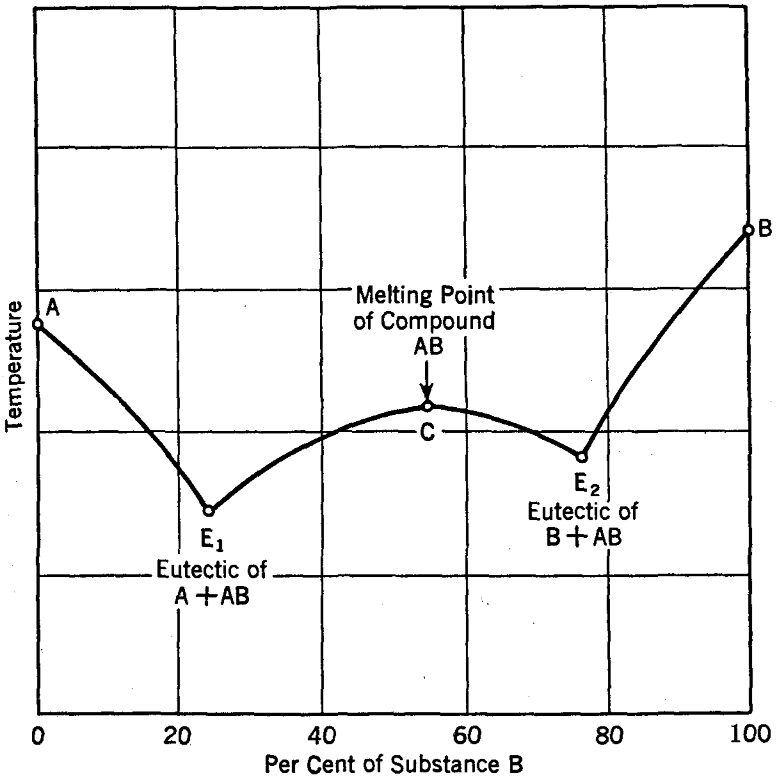

Fig. 16. Melting-point–composition diagram involving compound formation

The beginner will usually encounter compounds with impurities which lower the melting point of the pure substance. If the solid melts at a constant temperature, it is said to have a *sharp* melting point; that is, when heated slowly, it will melt at or within 0.5° of a certain temperature called its melting point. If the substance is impure, then no sharp melting point is obtained. In the latter case, upon heating, the substance softens and melts gradually, usually *below* the melting point of the pure compound. For instance, benzoic acid, pure, melts at 121°. In the impure state it may begin to melt at 105° to 110°, then melt completely at 115°. There are some pure compounds which may decompose slightly before melting, and the products so formed will cause a lowering of the melting point.

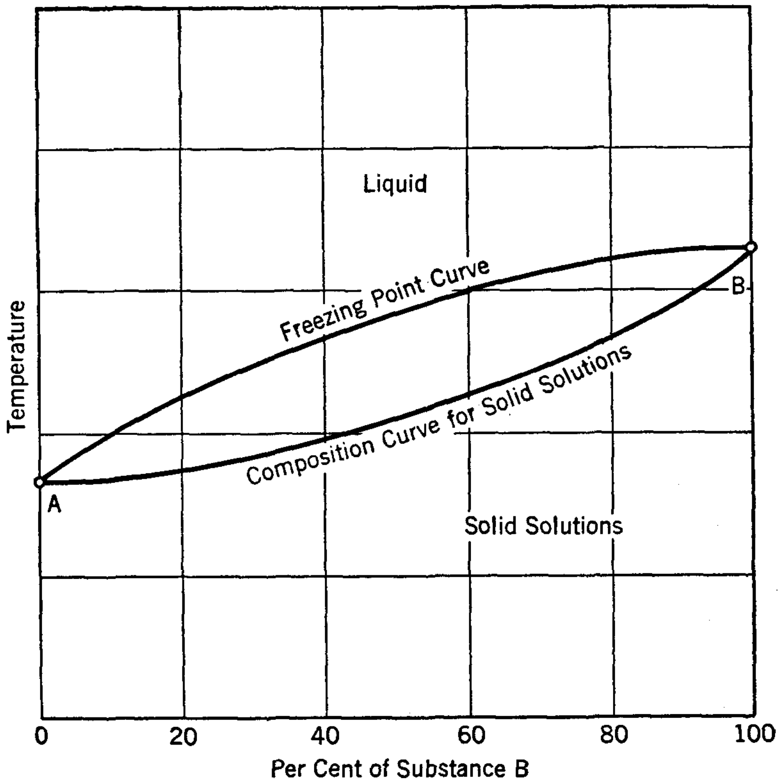

Fig. 17. Melting-point–composition diagram involving solid solutions

Besides their use as criteria of purity, melting-point data are extensively used in the identification of carbon compounds. The melting point usually restricts the identification to a few compounds which have approximately the same melting point. For this purpose, melting-point curves of mixtures are used; for example, if three given substances have approximately the same melting point as the unknown, mixtures are made of each of the three substances with the unknown. If the mixtures of the first two with the unknown are found to melt below the melting point of the unknown alone, then these two substances are eliminated. If the third substance does not depress the melting point of the unknown, the two are identified as the same compound. This topic will be discussed further in the next experiment.

GENERAL DIRECTIONS

For the determination of melting points the *capillary-tube* method (micro) is commonly used. About a milligram (or less) of the solid is placed in a glass capillary tube having a diameter close to 1 mm. The capillary tube is attached to a thermometer, then placed in a liquid bath, and heated slowly. The interval of temperature at which the solid within the capillary tube begins to liquefy and the temperature at which the liquid is clear is recorded as the *observed melting point.* It should be noted that melting points determined by this method are slightly higher than those determined by the macro method (described below), which are the true melting points. For all ordinary purposes the capillary-tube method is used.

The macro method requires a quantity of 20–30 grams. The solid is placed in an appropriate test tube (8 inch) with a thermometer inside, and heated rapidly until an appreciable amount has melted. The temperature is noted, and the tube is then cooled and placed in a beaker containing water if the observed temperature was below 100°, or in oil if the observed temperature was above 100°. The bath is heated to about two degrees above the observed temperature. The material within the tube is stirred with the thermometer, and its reading taken from time to time. The temperature becomes constant at the melting point.

Several micro methods have been developed for the determination of the melting point, using one or two crystals of the substance. In most of these methods the crystals are placed on a slide and covered with a cover glass. The slide is then placed on a metal plate which is heated electrically by resistance wires. The temperature is measured by a thermometer or thermocouple placed close to the sample. The change in the crystals is observed through a magnifying lense or a microscope.

Melting-point tubes. Several capillary tubes are made by heating and drawing out glass tubing that has been thoroughly *cleaned.* A soft glass tube of 12–16 mm in diameter, or any thin-wall glass tube

6–8 mm in diameter and 16–20 mm in length, is rotated in the hottest part of the Bunsen flame. When soft, it is removed from the flame and drawn out slowly in such a manner as to insure a uniform capillary bore; this should be about 1 mm in diameter. The capillary is cut into lengths of 10–12 cm and one end is sealed by heating for a few seconds in the outside tip of the flame. Care should be taken not to make the sealed end thick. The capillaries are placed in a dry test tube which is tightly corked to keep out moisture. To load the capillary tube, a few milligrams of the crystalline material are placed on a watch glass and crushed to fine powder by drawing the spatula over them. The open end of the capillary tube is pressed into the fine powder, followed by tapping the closed end, or by lightly scratching the tube with the flat part of a file, in order to force the sample to the bottom. The tube is filled to a height of about 1 or 2 mm, and is then attached to the thermometer so that the end of the capillary tube reaches the middle of the mercury bulb. The fastening of the capillary tube to the thermometer is accomplished by a small rubber band cut from ordinary $\frac{3}{16}$ inch tubing. The rubber band is so adjusted that it is near the top of the capillary tube.

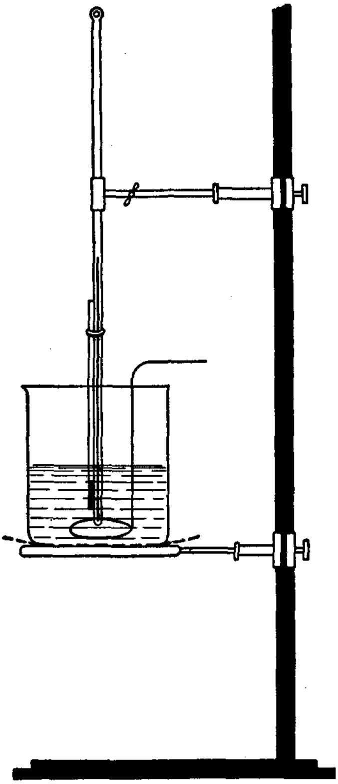

Fig. 18. Heating bath (beaker) for determination of melting points

Heating bath. A number of different types of apparatus and liquids are used as heating baths. Three types of melting-point apparatus are shown in Figures 18, 19 and 20. Either the beaker or the flask method is convenient. In the beaker method (Figure 18) a glass rod is bent in the form of a loop at one end and a handle at the other. This rod is used as a stirrer by slowly raising it and lowering it to insure uniform temperature. In the flask method a Pyrex 200–250 ml round-bottom flask with a long neck is used.

The thermometer, which is provided with a cork, is so adjusted that the mercury bulb reaches the middle of the liquid in the flask. A section of the cork is cut out to allow vapors of the liquid to escape, and also to make the thermometer scale visible at that point.

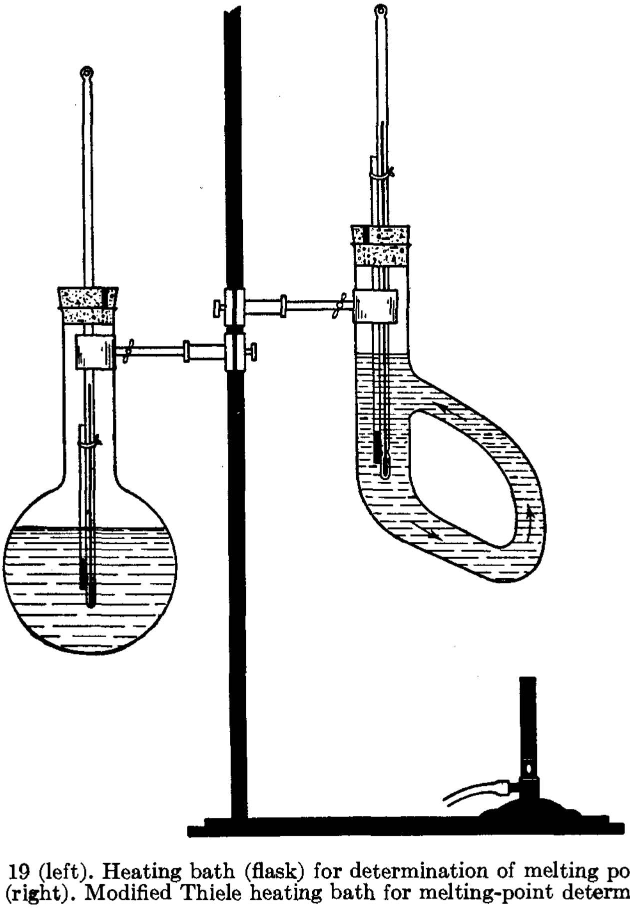

Fig. 19 (left). Heating bath (flask) for determination of melting points
Fig. 20 (right). Modified Thiele heating bath for melting-point determination

The beaker or flask is filled three-fourths full with high-boiling white paraffin oil or with hydrogenated vegetable oil. The thermometer is so adjusted that the rubber band holding the capillary tube is out of the bath, and the mercury bulb is near the middle of the oil bath. The beaker or flask is heated over an asbestos wire gauze or a free flame; the apparatus shown in Figure 20 (modified Thiele apparatus) is heated by a free flame. It has an advantage over the flask method in that it permits better circulation. The circulation is increased by stirring with a current of air or a very small mechanical stirrer.

When the thermometer bearing the capillary tube has been adjusted, the beaker or flask is heated rapidly to about 10–15° below the known melting point of the substance. If the substance is an unknown the approximate melting point is first determined by heating fairly rapidly until the substance has melted. The bath is then allowed to cool to about 20° below the observed melting point, the thermometer is carefully removed and held until it has acquired the temperature of the room and then a new loaded capillary tube inserted. The thermometer is replaced and the bath heated until the temperature rises to within 10–15° of the melting point. The flame is removed until the temperature begins to drop. The heating is then resumed at such a rate that the temperature rises 2–3° per minute, until the temperature comes to within 2–4° of the melting point, when a rise of 1° per minute is desirable. The temperature at which the substance begins to liquefy and the temperature at which the liquid is clear are noted. This interval of temperature is recorded as the melting point of the substance. For a pure substance this interval should not exceed 0.5°.

Thermometer correction. The temperature which is read on the thermometric scale must be corrected because there are several errors in such determinations. One source of error arises from the construction and calibration of the thermometer. The bore of the capillary may not have the same diameter throughout; further, the scale graduation and the calibration of low-priced thermometers are not very accurate. A second source of error is the method used in the common melting point apparatus. The common thermometer has been calibrated while totally immersed in a bath. In the melting-point apparatus described, only a part of the stem is immersed. The column of mercury above the oil bath has a lower temperature than that at which the thermometer was calibrated. Therefore either a thermometer calibrated by partial immersion should be used or a correction must be made for the unequal heating of the mercury in the stem of the thermometer. Although thermometers calibrated by partial immersion are available, the latter practice is the more common.

The correction for unequal heating of the thermometer is given by the formula:

$$\textit{Stem Correction (degrees)} = 0.000154\ (t_o - t_s) N,$$

where the fraction 0.000154 represents the difference in the coefficients of expansion of glass and mercury, t_o is the temperature read, and t_s is the average temperature of the column of mercury not immersed in the substance; t_s is determined (approximately) by reading a second thermometer whose bulb is held at the midpoint of that part of the column of mercury not immersed in the substance. N is the length in degrees of the part of the column which is not immersed. The error due to this variable is small at temperatures below 100°, but may amount to 3–6° at temperatures of 200° and above.

In order to make corrections for errors due to construction, it is necessary to calibrate the thermometer. This is best accomplished by the placing of the thermometer side by side with another thermometer already calibrated by the Bureau of Standards and then taking three to four readings over the entire scale. Another method of calibration is to compare the readings of the thermometer with the freezing or boiling points of reference compounds. Several compounds which are used for the calibration of thermometers are listed in the Appendix.

SPECIFIC DIRECTIONS

(A) Melting Point of a "Known" Substance. In the preceding experiment one or two substances were purified by crystallization. The determination of the melting point of each batch of crystals is required as a criterion of its purity. In this way the student obtains practice in melting-point determination. It is advisable to repeat the determination of the melting point of benzoic acid, or acetanilide, or naphthalene until the student is sure of the reproductibility of his results.

Place 100 mg of the substance on a small watch glass, microscope slide, or a piece of clean, dry, glazed paper. Crush the crystals to fine powder with a spatula. Collect the powder with a spatula in the form of a mound and press the open end of the capillary tube into it. Scratch lightly the capillary tube by means of the flat end of a file and tap it on the table in order to force the sample to the bottom. Repeat until the capillary tube has been filled to a height of about 2 mm; then proceed to determine the melting point in accordance with directions given on pages 47–48.

(B) Melting Point of an "Unknown" Substance. Obtain from the instructor a sample of an unknown substance for determination of its melting point. First make a rough determination of the melting point by heating the bath somewhat rapidly (avoid a strong flame). Allow the bath to cool to about 20° below the approximate melting point, and in the meantime prepare a new tube. Repeat the determination, heating slowly as previously directed. Enter all observations in your note book.

(C) **Lowering of Melting Point.** Weigh out separately 0.5 g of benzoic acid and 0.1 g of cinnamic acid, or naphthalene. Place them together in a small watch glass and mix thoroughly, pulverizing the mixture at the same time by means of a spatula. Determine the melting point of the mixture.

Experiment 4

DETERMINATION OF MELTING POINTS OF MIXTURES

Introduction. Melting points are very often used in the identification of organic compounds. If an unknown substance on repeated crystallization gives a constant melting point, reference to tables of melting points considerably reduces the possibilities as to the nature of the substance. For example, assume that an unknown compound on repeated crystallization melts at 122°. Reference to page 1093 in the *Handbook of Chemistry and Physics* (25th edition), or to page 265 in Lange's *Handbook of Chemistry* (4th edition), shows that there are three compounds which melt in the region of 122°: benzoic acid, C_6H_5COOH, *o*-fluorobenzoic acid, FC_6H_4COOH, and β-naphthol (2-hydroxynaphthalene), $C_{10}H_7OH$. A few crystals of the unknown substance dissolved in water fail to show acid reaction with indicators, therefore the tentative assumption is made that the substance may be β-naphthol. If this assumption is correct then a mixture of the unknown and pure β-naphthol will melt at 122°. If, however, the unknown is not β-naphthol then the mixture of the unknown and pure β-naphthol will melt at a different temperature than 122°; usually the melting point of such a mixture will be observed to be markedly lower than 122°. In practice it would be advisable to make several mixtures of varying composition of the unknown and β-naphthol. The melting point of each mixture is determined and then plotted against the per cent of either component as shown in Figure 21, which represents the case where the unknown is the same substance as β-naphthol; the melting points of the mixtures give a straight line. Figure 22 represents the case where the unknown and β-naphthol are different; the melting points of the mixtures, in such case, give a curve usually with a minimum at some intermediate composition.

The melting points of mixtures may be used to determine the percentage composition of mixtures whose components are known. For example, in Figure 22, assume that a mixture of *A* and *X* melts at 75°. The composition of this mixture will be either 80 per cent of *A* and 20 per cent of *X*, or 78 per cent *X* and 22 per cent *A*. To a sample of this mixture is added a small amount of compound *A* and the melting point of this new mixture is determined. If the original mixture contained 80 per cent *A* the new mixture will melt above 75° and if it contained 22 per cent *A* it will melt below 75°.

Specific Directions. (A) Weigh out 1.0 g of benzoic acid on a triple-beam balance or on a Sanolite hand balance, and dissolve in 100 ml of alcohol.[1] Make a similar solution of naphthalene. Place the solutions in small flasks or bottles and cork them to prevent evaporation of the solvent. Prepare three dry test tubes and mark them 1, 2, 3. In tube 1 prepare a mixture of 75 per cent benzoic acid and 25 per cent naphthalene by adding with a pipette 3 ml of benzoic acid solution and 1 ml of naphthalene solution. In tube 2 prepare a mixture of 50 per cent naphthalene and 50 per cent benzoic acid by adding 2 ml of each solution. In tube 3 prepare a solution of 25 per cent benzoic acid solution and 75 per cent naphthalene by adding 3 ml naphthalene solution and 1 ml benzoic acid

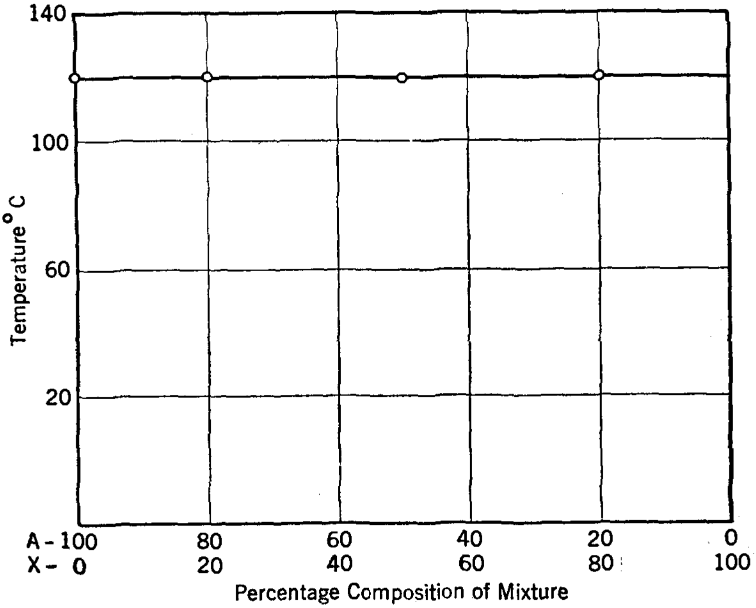

Fig. 21. Melting points of three mixtures of β-naphthol and an unknown (β-naphthol and unknown being the same)

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[1] This amount is sufficient for fifteen students.

solution. Place the three tubes in a hot water bath and evaporate to dryness. Remove some of the crystals from each tube separately on a piece of filter paper, press with spatula so as to remove any adhering solvent and allow to dry in air for 10 minutes; then determine the melting point of each mixture. Make a melting point curve diagram by plotting the melting point against the composition as shown in Figure 22. The melting points of pure naphthalene and benzoic acids are obtained from the tables of a handbook.

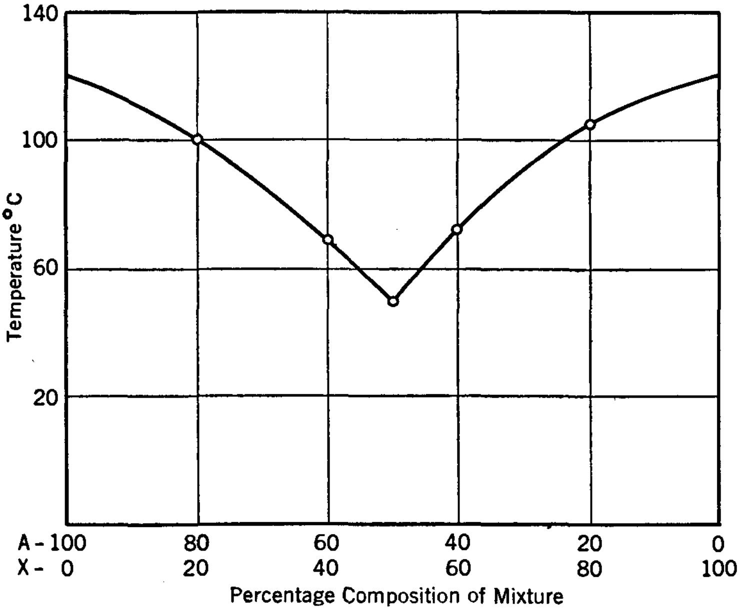

Fig. 22. Melting points of five mixtures of variable amounts of β-naphthol and an unknown (β-naphthol and unknown not being the same)

(B) If pipettes are not available the experiment may be performed as follows: The solutions of benzoic acid and naphthalene are prepared by dissolving 0.1 g of the solid in 10 ml of alcohol which is measured as accurately as possible through a small graduate. A clean dropper is placed in each flask. Place a small watch glass over a 250 ml beaker which contains water and is arranged for heating. By means of the droppers add to the watch glass 7 drops of benzoic acid solution and 3 drops of naphthalene solution, and evaporate rapidly over the water bath. When dry, remove the crystals on a piece of paper properly marked, and set aside in a dry place. Clean the watch glass and repeat the procedure, using first 5 drops of each solution, and for the final mixture 3 drops of benzoic acid solution and 7 drops of naphthalene solution. Determine the melting point of each mixture and make a melting-point curve diagram by plotting the melting point against the composition as shown in Figure 22.

Experiment 5

THE PURIFICATION OF ORGANIC COMPOUNDS BY DISTILLATION

GENERAL CONSIDERATIONS

Introduction. In the previous experiments we considered the purification of organic compounds that are solids by the process of crystallization from an appropriate solvent. In the present experiment we will consider the purification of organic compounds by distillation. Generally the process of distillation involves the change of the organic compound to the vapor state by heat, then passing the vapor into another vessel and condensing it back into the liquid state. This procedure is usually employed for the purification of organic compounds which are liquid at room temperature and which do not decompose when boiled. If the impurities are not volatile and the compound does not decompose when boiled at normal atmospheric pressure, *simple distillation* is used. If the compound undergoes some decomposition when boiled, the pressure within the distilling flask is lowered by means of a suction pump, thus reducing the temperature necessary to produce boiling. This method is known as *distillation under reduced pressure*, or *vacuum distillation.* If the liquid to be distilled contains two or more components which are miscible in each other, the method employed is known as *fractional distillation.* If an organic liquid is insoluble in water and has an appreciable vapor pressure, it may be distilled with steam at a temperature which is far below its boiling point. This method is known as *steam distillation.*

Boiling. Consider a liquid in the flask shown in Figure 24. The molecules at the surface of the liquid phase pass into the vapor state while other molecules return from the vapor and pass into the liquid. If the surrounding temperature remains constant for some time, ultimately the number of molecules passing into the vapor phase equals the number returning to the liquid. Since the molecules in the vapor state exert a definite pressure, therefore at a given temperature a liquid has a definite *vapor pressure.* For example at 20° the vapor pressure of water is 17 mm of mercury; of ethanol, 44 mm, and of ether, 442 mm. Therefore if the liquid in the flask (Figure 24) is water, the temperature 20°, atmospheric pressure 750 mm, then the pressure of the water vapor is 17 mm and the pressure of the air is 733 mm. If the flask is heated, the vapor pressure of the liquid increases as the temperature rises. The vapor-pressure curves of water, ethyl alcohol, and ether are plotted in Figure 23, and all show the same general characteristics. As the heating is continued the liquid in the lower part of the flask acquires a vapor pressure equal to that of the atmosphere. Further heating would increase the vapor pressure above that of the atmosphere; this is prevented by the passage of some liquid to vapor, which in the form of a bubble rises to the surface and pushes out of the flask into the condenser. The liquid is said to *boil.* Therefore the *boiling point of a liquid is defined as the temperature at which the vapor pressure of the liquid is equal to the pressure of the atmosphere.*

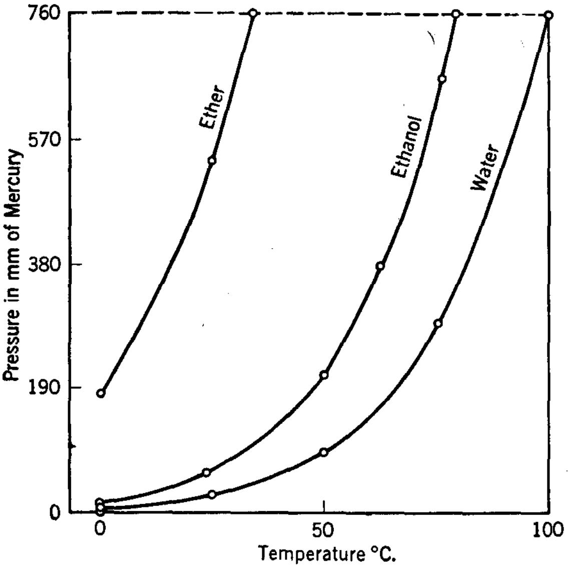

Fig. 23. Vapor-pressure curves of water, ethyl alcohol, and ether

As the liquid boils in the flask it displaces the air and finally the vapor passes through the side tube into the inner tube of the condenser, which is kept cold by circulation of tap water through the outer jacket. The gaseous molecules of the vapor, on cooling, coalesce to form drops of liquid which run down the condenser tube into the receiving flask. This process is called *distillation.* If the impurities are not volatile and the organic liquid does not decompose on boiling, it can be purified by *simple distillation.*

Bumping. In practice, uniform formation of bubbles in the lower part of the distilling flask (which permits boiling to proceed smoothly) is not common. The boiling is intermittent; the liquid lies quiescent for a few moments, then suddenly throws off a large amount of vapor, ejecting a spray of liquid at the same time. This is known as *bumping.* To avoid this trouble, it is common practice to introduce into the liquid to be distilled a few small pieces of unglazed clay (called *boiling stones*) or fine capillary tubes. Unglazed clay occludes a considerable amount of gases in its cavities and also adsorbs gases on its surface. As the air is expelled from the boiling stones it assists in the formation of vapor bubbles, and the boiling takes place smoothly. It is *very important* that the boiling stones be added before heating is commenced, and not after the heating is well under way. If the temperature is near or at the boiling point, a sudden evolution of vapor and spray will take place. In case the boiling stones have been omitted, the liquid in the flask is first cooled well below the boiling point and then the boiling stones are added. If the distillation is interrupted, fresh stones must be added. Two stones about 2–3 mm square are sufficient for distillation in a 500 ml flask.

Distillation under reduced pressure. A large number of carbon compounds distill with decomposition. In such cases, as well as in the distillation of high-boiling liquids, the pressure within the distilling flask is reduced by means of a vacuum pump and the liquid is made to distill at lower temperatures. The following table gives the variation of the boiling point of water and also the variation for a compound *A* with a boiling point of about 350°:

Table 2

CHANGE OF BOILING POINT WITH PRESSURE

WATER		COMPOUND *A*	
Pressure (mm)	Boiling Point (° C)	Pressure (mm)	Boiling Point (° C)
760	100.0	760	350 (Approx.)
750	99.6	1.0 –0.1	160–210
526	90.0	0.05 –0.01	100–130
4.6	0.0	0.005–0.001	40–60

The apparatus commonly used in distillations under reduced pressure is discussed in detail in Experiment 45 (page 232), in which the method is employed. For the present discussion it will be sufficient to note that a suction pump is used to reduce the pressure within the distilling flask.

Fractional distillation. Mixtures of liquids which are miscible in each other, such as water and alcohol, or water and acetone, may be regarded as solutions. Since each compound exerts its own vapor pressure and lowers the vapor pressure of the other, the mixture will boil when the combined vapor pressure equals the atmospheric pressure, and the boiling point of the solutions will change during the distillation. The distillate will contain a mixture of the two compounds. It is possible by collecting the distillate in separate portions and repeating the distillation to separate part of each component in the pure state. This process is called *fractional distillation* and is discussed in detail in the next experiment.

Steam distillation. If two liquids are nearly insoluble in each other, neither one lowers the vapor pressure of the other; therefore the total vapor pressure of a mixture of these two liquids will be the sum of their vapor pressures. If the mixture is heated, boiling begins when the combined vapor pressure of the two immiscible components equals the pressure of the atmosphere. The vapor and hence the distillate contain both components in the ratio of their vapor pressures. If, for example, at the temperature of the distillation 95 per cent of the vapor pressure is due to component *A* (of a mixture *A* and *B*), then the composition of the distillate will be 95 mole per cent *A* and 5 mole per cent *B*. This principle is applied in the separation of organic compounds from a mixture, at temperatures which are far below their boiling point, by distillation with steam. Consider, for example, a mixture of aniline, which boils at 184°, and water. At 100° the vapor pressure of aniline is 45 mm and that of water 760 mm; at 98° the vapor pressure of water is 727 mm and that of aniline 40 mm. Therefore the combined vapor pressure of a mixture of water and aniline at 100° is 805 mm, and at 98°, 767 mm. It is evident that near 98° the total vapor pressure will be one atmosphere and the mixture will boil. The distillate will contain water and aniline in the mole ratio of their partial pressure. The process is called *steam distillation* and is further discussed in Experiment 27 (page 163).

SPECIFIC DIRECTIONS

(A) Macro Simple Distillation. Arrange a 125 ml distilling flask for distillation as shown in Figure 24. Select a cork to fit the neck of the flask, another to connect the side arm of the distilling flask with the condenser, and one for the adapter. The corks should go into the openings about a third of their lengths. The first cork is bored to fit the thermometer, the second the side arm of the distilling flask, and the third the lower end of the condenser.

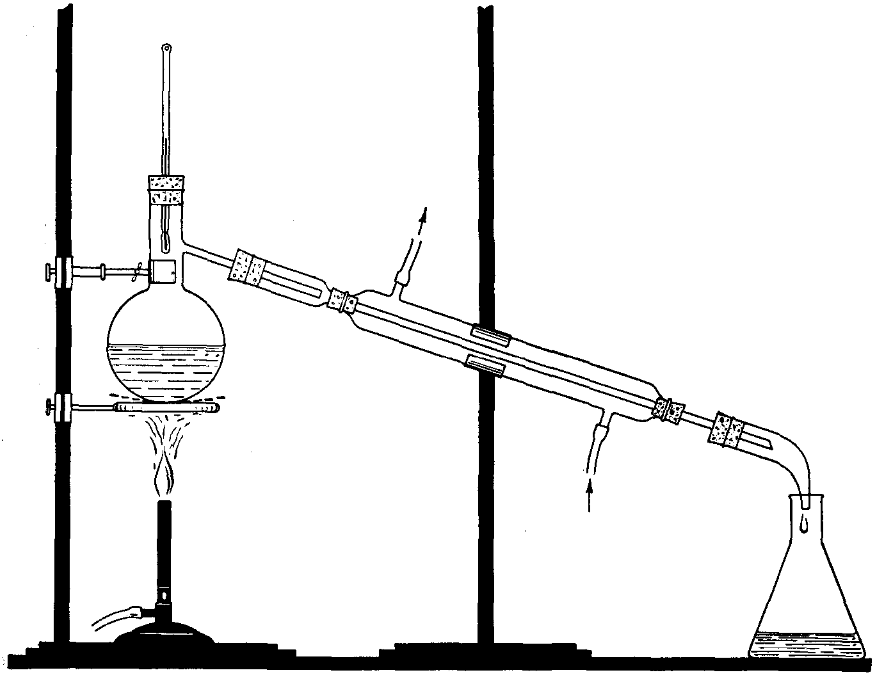

Fig. 24. Macro apparatus for simple distillation

For boring, the corks are first rolled in the cork press until they are softened, and then they are bored. Two general methods are used for boring corks. Select a cork borer which is nearly two sizes smaller than the tube to be fitted. Sharpen the borer, using the tool for this purpose. Moisten the borer with water or dilute sodium hydroxide solution and bore into the small end of the cork, using a continuous rotary motion. When the borer is half-way through, withdraw it and force the cork core out; place the cork on a board or an old cork, wet the borer again, and bore from the large end of the cork until the opening is complete. If the opening is smaller, use a round file to enlarge it. In the second method the borer is heated. Select the borer as above, and sharpen it well. Place the cork on a table, the large end down. Now heat the borer in the flame until it is too hot to touch. Place it on the smaller end of the cork, and while the latter is kept firmly fixed on the table rotate the borer, slowly pressing gently downwards into the cork. When the borer is half way through remove it and reheat it in the flame. Reverse the cork and start boring from the other end until the opening is complete. The student should follow the method indicated by the instructor.

Care should be exercised in fitting the cork to the thermometer or the side arm of the flask. The glass is first lubricated with water or a soap solution; hold both glass and cork with towels, and rotate gently. *Avoid pushing the glass too hard,* as breakage will occur. The thermometer is adjusted so that the mercury bulb is a little below the opening of the side tube. When the apparatus is assembled, it should be on the back part of the desk and in a straight line. The rubber tubing which serves as inlet and outlet for water should not form more than a 90° angle, lest the bending of the rubber tubing lead to pressure within the jacket which will force the water out.

Place in the flask two small boiling stones and 25–50 ml of the "liquid for distillation" obtained from the shelf or from the instructor. Adjust all corks and inspect the apparatus. The water is connected if the liquid boils below 150°. Above this temperature the water is not connected, or an air condenser (a straight glass tube without a water jacket) is used. Heat with a small flame until boiling begins; note the temperature at which the first drop falls in the receiver. Regulate the flame so that the drops of the distillate can be counted at the rate of about 2–3 drops per second. When the temperature as indicated by the thermometer fails to rise as distillation proceeds, remove the flame and place as a receiver a tared flask or bottle. Continue the distillation and note the temperature at regular intervals, and record it in your notebook as the observed boiling point. Discontinue the distillation when the temperature begins to rise. Determine the weight of the distillate. Cork and label the bottle, giving the observed boiling point and yield of the pure liquid. Disconnect the apparatus and wash the flask.

(B) Semimicro Distillation. Read the general directions given for simple distillation above, particularly on boring corks. Arrange apparatus as shown in Figure 25. The distillation tube is an ordinary six-inch (20 × 150 mm) or eight-inch (25 × 200 mm) tube with a side arm. The distilling tube is fitted with a cork holding the thermometer; the latter is so adjusted that it is 5 mm below the side-arm opening. The side arm is connected by a small piece of rubber tubing (3–4 mm) to the delivery tube. Both the delivery tube and the condenser should be fitted through a cork into an

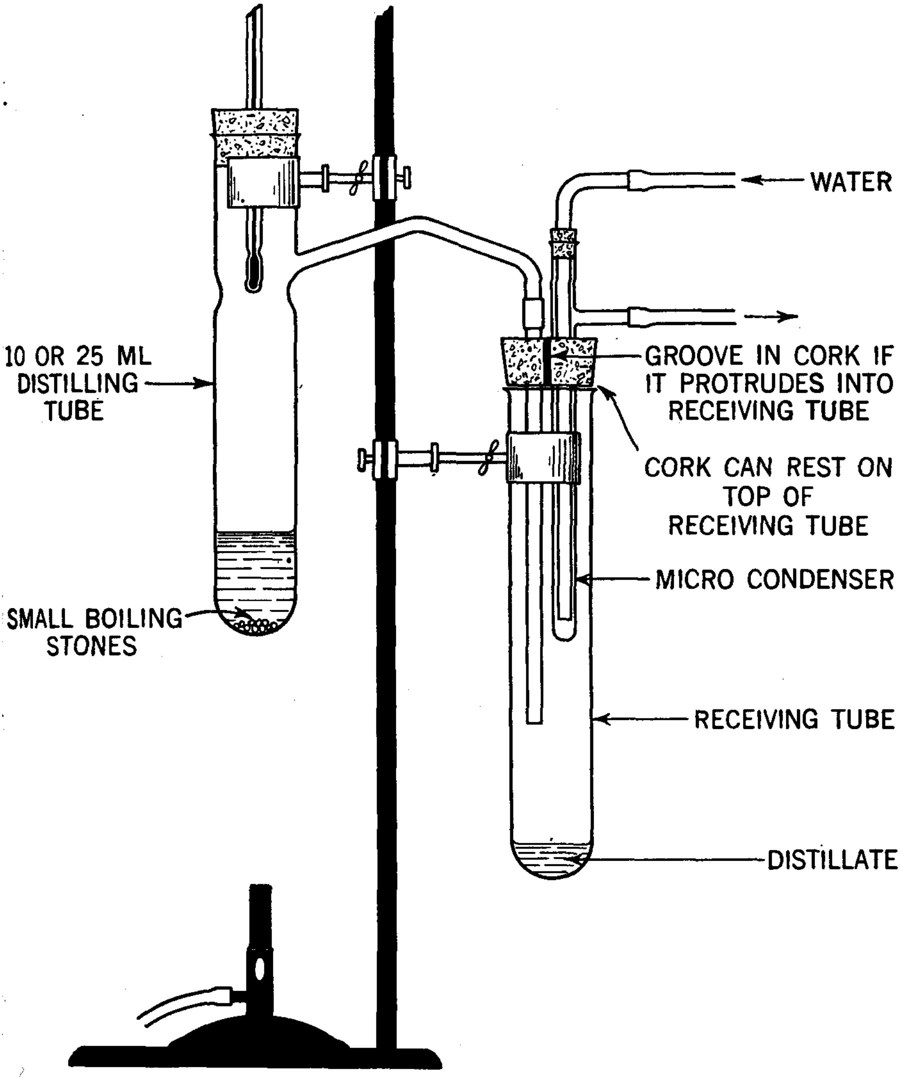

Fig. 25. Semimicro apparatus for distillation

ordinary six-inch test tube which acts as a receiver. The opening for the condenser is larger than the diameter of the condenser tube, so that it fits loosely; it is held in place by inserting a match or small stick, and in this manner the system is not closed. A test tube of any size may serve as a receiver, provided its diameter is sufficient to hold the delivery tube and the condenser. The cork need not fit into the receiving tube but may be adjusted to rest on top of its mouth. Another method of keeping the system open is to cut a groove on the side of the cork as shown in the diagram. In such a case the cork may be inserted into the receiving tube.

Obtain 5–7 ml of liquid from the instructor for simple semimicro distillation. Place the liquid in the distilling tube and add two small boiling stones about the size of grape seeds. Inspect all connections and adjust the receiving tube so that the condenser and the delivery tube reach to about two-thirds of the depth of the tube. Begin heating with a burner, moving the flame to and fro. As the liquid begins to boil the vapor condenses on the sides of the distilling tube and returns to the boiling portion. The flame is adjusted so that the vapors ascend very slowly and reach the thermometer bulb at least one minute before they pass through the side tube. In this manner the thermometer is heated to the temperature of the vapor. The vapor passes into the receiving tube, condenses on the micro condenser, and runs to the bottom of the tube. Thus the progress of distillation is determined by the amount of liquid in the receiving tube.

Note and record the temperature at which the liquid appears in the receiving tube. Continue the distillation slowly until the mercury column in the thermometer remains nearly stationary. Remove the flame and change the receiving tube. Resume the heating, and when distillation begins, adjust the flame so that the liquid in the receiving tube increases slowly. A little experience is necessary before the technic is mastered. Note the temperature at regular intervals and record it as the observed boiling point. Toward the end manipulate the flame by hand, moving it to and fro in order to avoid superheating. Discontinue the distillation when 0.5 ml are left in the distilling tube. Cork the receiving tube and determine the weight of the distillate; record it and label the tube. Disconnect and clean the apparatus. It will be found advisable to allow the cork to remain in place on the delivery tube and condenser. The delivery tube and condenser are cleaned by rinsing with a little acetone or denatured alcohol, wiped, and placed in a small cardboard box.

Experiment 6

PURIFICATION BY FRACTIONAL DISTILLATION

GENERAL CONSIDERATIONS

Vapor pressures of two miscible liquids. When the organic liquid to be purified contains impurities which are volatile and which are miscible with it the boiling point of the mixture and the composition of the distillate depend on the vapor pressures of the components in the mixture. For the purpose of discussion we will consider the distillation of two volatile substances which are miscible with each other. If this mixture, or solution, is placed in a flask and heated, each substance will exert its own partial pressure in proportion to the mole fraction of each. When the vapor pressure of the solution reaches the atmospheric pressure, the vapor will be pushed into the condenser tube to form the first distillate. The composition of the distillate depends on the vapor pressure of each component at that temperature. Since the vapor pressure at the temperature of boiling is the sum of the two partial vapor pressures it is evident that the distillate will contain the lower boiling substance along with some of the substance boiling at a higher temperature. In practice it is not possible to separate by simple distillation a mixture of two substances that boil 40° to 50° or less apart. The temperature is not constant at any particular point, but rises slowly during the distillation from the boiling point of one component to the boiling point of the other.

Assume that the two components of the solution are *A*, which boils at 110°, and *B*, which boils at 50°. The composition of this mixture is 60 per cent (in moles) of *A* and 40 per cent of *B*. As the flask is heated the partial vapor pressure exerted by each is 60 and 40 per cent, respectively, of the vapor pressure that each would have exerted at that particular temperature if it were alone in the flask. At 70° the total pressure of *A* if it were alone would be 300 mm, and therefore the partial pressure is $300 \times 0.6 = 180$ mm. The pressure of *B* would be 1450 mm, and therefore the partial pressure of *B* is $1450 \times 0.4 = 580$ mm. The sum is 760 mm, and consequently the liquid boils. The vapor that comes out will have a composition of 580 molecules of *B* and 180 molecules of *A*, or 76 per cent (mole) of *B* and 24 per cent of *A*. The vapor, and hence the distillate, is richer in *B* than the original boiling mixture. But as *B* is removed faster than *A*, this disturbs the state of the boiling mixture; and since the mixture becomes richer in *A*, the higher boiling constituent, the boiling point rises.

Figure 26 represents the boiling-point–composition diagram of

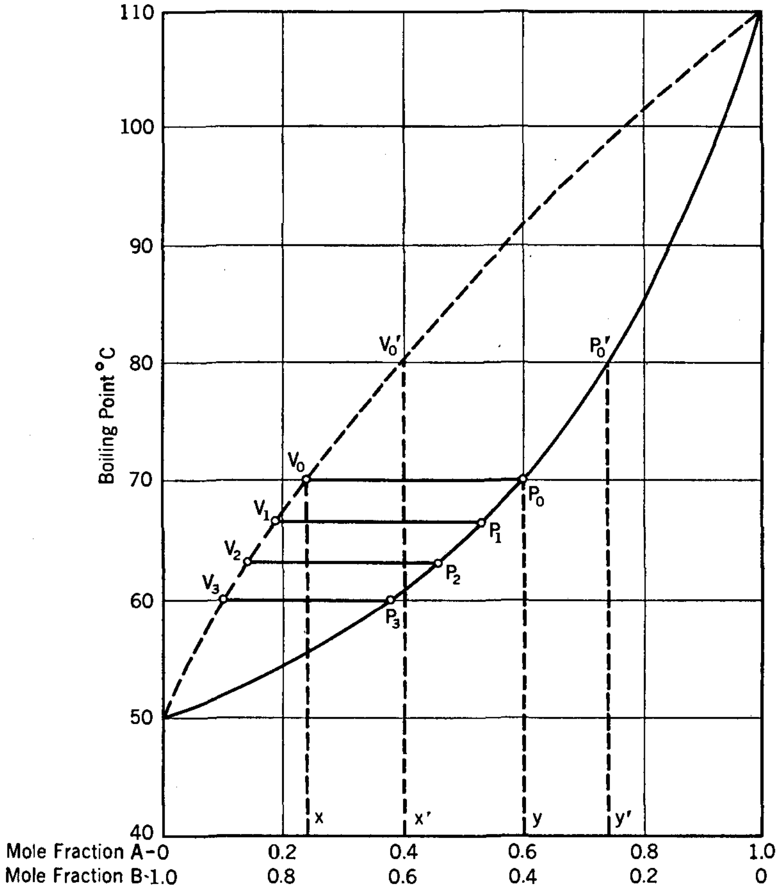

Fig. 26. Boiling-point curve of a mixture of two liquids. The vapor-pressure curve does not have maximum or minimum

A and *B*. The dotted curved line gives the composition of the vapor which results by the distillation of any particular composition; the heavy continuous line represents the boiling points of various compositions. Point P_0 represents the boiling point of a solution which has a composition given by the dotted line P_0y and corresponding to 60 mole per cent of *A* and 40 mole per cent of *B*. The temperature at which this solution boils is 70°. The composition of the vapor distilling at this temperature is given by the dotted line V_0x, and corresponds to 25 mole per cent of *A* and 75 per cent of *B*. Thus from a solution with an initial concentration of 40 mole per cent of *B* we obtain a distillate of 75 mole per cent of this component. As the boiling proceeds the solution in the flask becomes richer in *A*, the higher boiling constituent, and the temperature of boiling rises to 80°. The composition of the solution in the flask has changed to $P_0'y'$ which corresponds to 75 mole per cent of *A* and 25 mole per cent of *B*; the composition of the distillate has changed to $V_0'x'$ which corresponds to 40 mole per cent of *A* and 60 mole per cent of *B*. If the distillate is collected in separate fractions, for example, fraction I: distillate which comes over between 70° and 75°; fraction II: distillate which comes over between 75° and 80° and then a fraction for every 10°; the first fraction will be richer in *B* and the last fraction richer in *A*. Each fraction can be redistilled, and with each fractionation the separation of the two components becomes more nearly complete. It is possible by repeated fractionation to obtain a portion of the liquid which is pure *A* and a portion which is pure *B*. This process is laborious and, though it is often used, it is more convenient to employ a fractionating column.

Fractionating column. The simplest kind of fractionating column is a tube filled with broken glass or stones as shown in Figure 27. The upper end has the usual side arm of the distilling flask, while the lower end fits through a stopper on any type of flask. The principle of the operation of the fractionating column can be understood by referring to the diagram of Figure 26. Assume that the vapor of composition V_0, from the solution in the flask which has the composition P_0, rises in the column, where it strikes the walls and glass of the column and partially recondenses. In the process of condensation the higher boiling component *A* of the vapor will condense to a greater extent than the lower boiling component *B*. As a result of this partial condensation the remaining uncondensed vapor has the composition V_1, which is richer in *B*. As the vapor V_1 passes upwards in the column it acquires by partial condensation the composition V_2 and then V_3; therefore at the top of the column the vapor is nearly pure *B*. The ascending vapor of composition V_0 on changing to the vapor V_1 forms by partial condensation a liquid of composition P_0. Similarly the vapor V_1 partially recondenses to a liquid of composition P_1 and changes to a vapor of composition V_2. As the liquid produced by partial condensation trickles through the broken glass it meets ascending vapors which do not have the same composition and hence are not in equilibrium with each other. An exchange takes place and *B* passes from the liquid P_1 to the ascending vapor V_0 while *A* passes from the ascending vapor to the liquid. In other words, the ascending vapor V_0 vaporizes part of the lower boiling constituent from the liquid P_1 which trickles down the column. In this manner the interchange between the liquid trickling down the glass packing and the as-

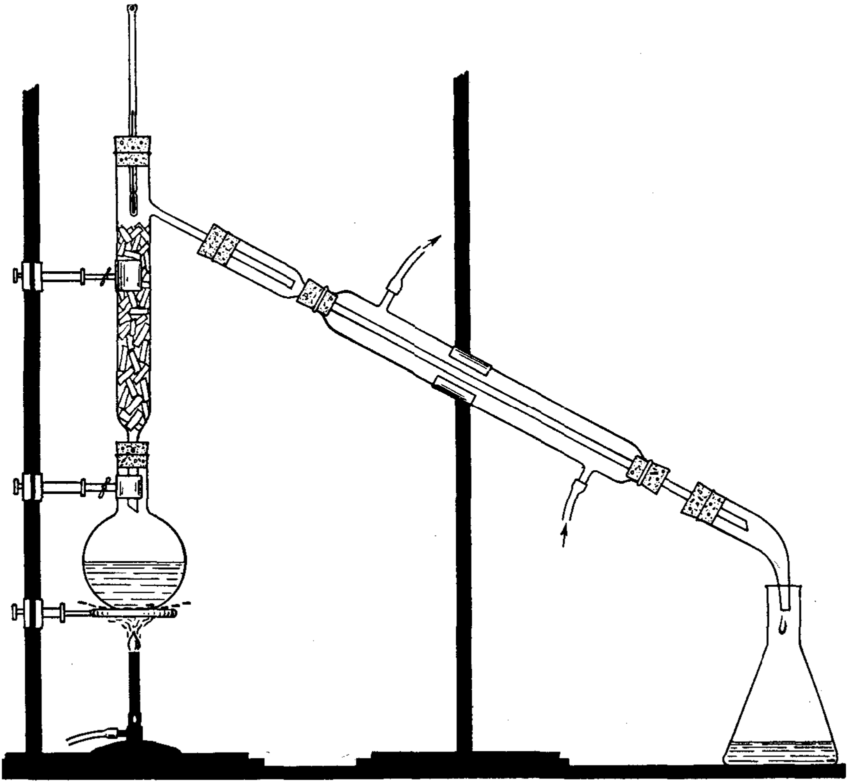

Fig. 27. Macro apparatus for fractional distillation

cending vapors is actually a series of partial vaporizations and condensations; the ascending vapor becomes richer in *B*, and, if the process is repeated a sufficient number of times, it is possible to obtain vapor composed of pure *B* emerging from the side arm of the column. For such purposes it is necessary to have a very long column, and packing that will provide a large surface for contact of liquid and vapor. This, of course, means that a considerable amount of liquid must always be kept in the column and the distillation must be carried out slowly. In usual laboratory practice, however, it is found more practical to use a column of medium size and to redistill the fractions once or twice. Figures 28, 29, and 30 represent three types of fractionating columns used in elementary organic laboratories.

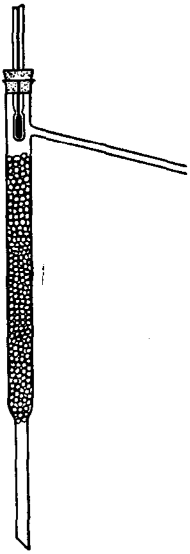

Fig. 28.
Hempel column

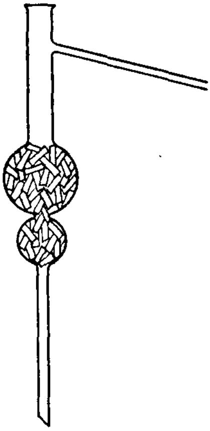

Fig. 29.
Wurtz column

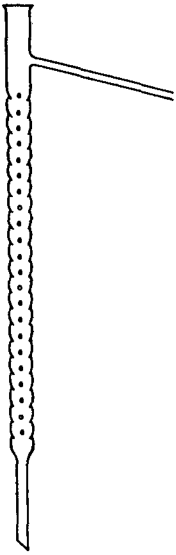

Fig. 30.
Vigreux column

Azeotropic mixtures. A number of liquids when mixed in certain proportions boil higher or lower than either component. Such mixtures are known as *azeotropic mixtures*, or constant boiling mixtures. Table 3 shows a few common azeotropic mixtures.

The most common example of an azeotropic mixture is hydrochloric acid, for which the azeotropic mixture boiling at one atmosphere pressure contains 20.22 per cent (by weight) of hydrogen

Table 3

BINARY AND TERNARY AZEOTROPIC MIXTURES

Components and Boiling Points Thereof				Azeotropic Mixture	
Component	(° C)	Component	(° C)	Composition by Weight	Boiling Point (° C)
Water	100.0	Ethyl alcohol	78.26	Water 95.6 Alcohol 4.4	78.15
Water	100.0	Hydrogen chloride	−84	Water 79.76 Hydrogen chloride 20.24	110
Water	100.0	Nitric acid	86	Water 32.0 Nitric acid 68.0	120.5
Ethyl alcohol	78.26	Carbon tetrachloride	76.8	Alcohol 15.8 Carbon tetrachloride 84.2	65.1
Ethyl alcohol	78.26	Benzene	80.2	Alcohol 32.4 Benzene 67.6	68.2
Ethyl acetate	77.1	Water	100	Ethyl acetate 93.9 Water 6.1	70.4
Benzene	80.2	Water Ethyl alcohol	100 78.26	Water 7.4 Benzene 18.5 Alcohol 74.1	64.9
tert-Butyl alcohol	82.6	Water Carbon tetrachloride	100 76.8	Water 3.1 Alcohol 11.9 CCl_4 85.0	64.7

chloride. A solution of very dilute hydrochloric acid, when distilled, gives off more water vapor than hydrogen chloride until the constant-boiling composition is reached. It will be observed fron inspection of Table 3 that the constant-boiling mixtures of wate and hydrochloric acid, and of water and nitric acid, boil at highe temperatures than either component. Such mixtures are known a *maximum-boiling mixtures,* while those which boil at lower ten peratures than either component are known as *minimum-boilin mixtures.* The latter are more common.

The behavior of azeotropic mixtures indicates that many solutions of liquids do not follow the general principle developed in the preceding section, namely: the vapor pressure of a solution at a given temperature is the sum of the vapor pressures of the components at that temperature multiplied by the mole fraction of each present in the solution. This statement is one way of formulating Raoult's law. However, a large number of solutions of liquids deviate from this principle. The sum of the vapor pressures may be either higher or lower than those calculated on the basis of Raoult's law. If the vapor pressure is higher, the vapor pressure curve will show a maximum and the boiling point curve will pass through a minimum, as shown in Figure 31. Conversely, a solution of two liquids whose vapor pressure curve shows a minimum will have a boiling point curve which will pass through a maximum, as shown in Figure 32.

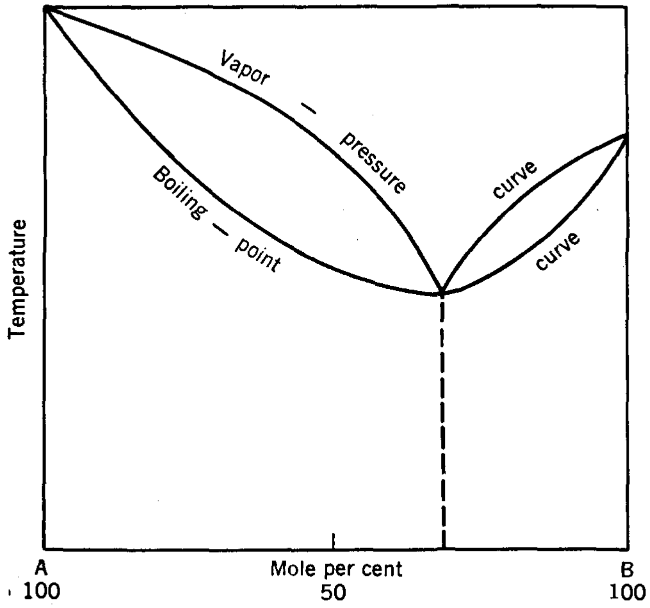

Fig. 31. Boiling-point curve of a solution of two liquids, *A* and *B*, whose vapor-pressure curve shows a maximum. The boiling point curve shows a minimum.

Binary azeotropic mixtures cannot be separated by fractional distillation. A mixture of two components which form maximum-boiling or minimum-boiling mixtures may be separated into portions of different compositions, but cannot be separated into pure components by repeated fractionation. For example, repeated fractionation of a sample of wine which contains 12 per cent of ethyl alcohol will give an alcohol fraction having the composition of the azeotropic mixture: 95.6 per cent alcohol and 4.4 per cent water. Pure ethyl alcohol cannot be obtained by fractional distillation of a water-alcohol mixture. It is possible, however, under certain conditions, to obtain pure ethyl alcohol by distillation of a water-alcohol-benzene mixture. Inspection of Table 3 shows that this three-component (ternary) mixture has a boiling point of 64.9° if it contains 74.1 per cent (by weight) of benzene, 18.5 per cent of ethyl alcohol, and 7.4 per cent of water. When the water has been removed, a binary mixture of benzene and ethyl alcohol will form when the composition is 67.6 per cent of benzene and 32.4 of ethyl alcohol; this binary mixture boils at 68.2°. Then when the benzene has been removed, the remaining liquid is practically pure (absolute) ethyl alcohol and distills at 78.3°. Generally in the fractionation of binary azeotropic mixtures the minimum-boiling mixture will appear as a distillate, and the maximum-boiling mixture will remain as a residue in the flask.

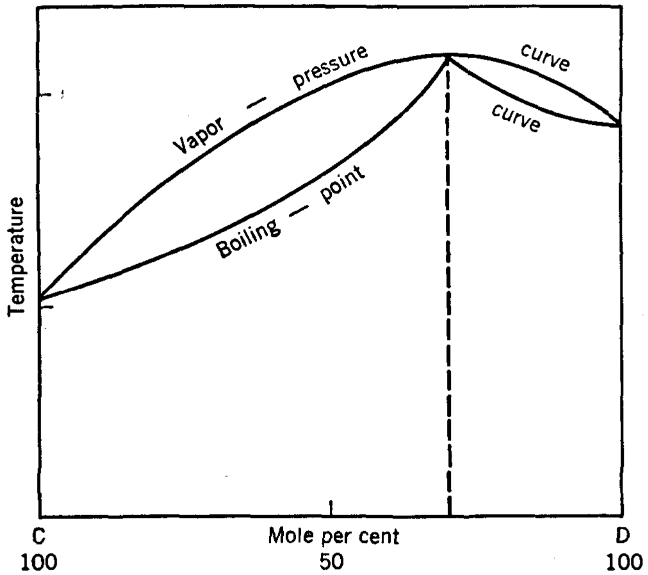

Fig. 32. Boiling-point curve of a solution of two liquids, *C* and *D*, whose vapor-pressure curve shows a minimum. The boiling point curve shows a maximum.

SPECIFIC DIRECTIONS

Purification by Fractional Distillation (M.). Arrange an apparatus for simple distillation as shown in Figure 24. Obtain from the instructor 100 ml of a mixture of equal amounts of methyl alcohol and water. Transfer the liquid to the distilling flask by using a funnel whose stem reaches below the opening of the outlet tube. Place two boiling stones in the flask, and use a 100 ml graduated cylinder as a receiver. Before the distillation is begun, make sure that all cork connections are tight. Heat the flask slowly on an asbestos-centered wire gauze with a small flame until warmed, then increase the flame so as to cause the liquid to distill at the rate of 2–3 drops per second from the end of the condenser. Do not remove or alter the flame during the remainder of the distillation. Note and record the temperature when the first drop is observed in the condenser. Continue the distillation, and record the temperature when the volume of the distillate reaches 5 ml, 10 ml, 15 ml, and so on until the distillation is complete. Make a graph in which the volume of the distillate is plotted against the temperature.

Set up an apparatus for fractional distillation as shown in Figure 27, using a 200 ml round-bottom flask or a 250 ml Florence flask and a fractionating column filled with glass beads or pieces of glass tubing about 10 mm in length. Obtain from the instructor 100 ml of a mixture of equal amounts of methyl alcohol and water,[1] and subject the mixture to distillation, observing all the precautions mentioned in the preceding experiment. For receivers prepare five clean dry flasks or bottles (about 50 ml), and number them consecutively from 1 to 5. Collect successively the five fractions which boil between the following temperatures: I, from 65° to 70° inclusive; II, from 70° to 80°; III, from 80° to 90°; IV, from 90° to 95°; V, residue. Measure each fraction in a graduated cylinder. Record the data, in tabular form, thus:

FRACTION	I	II	III	IV	V
Temperature	65–70°	70–80°	80–90°	90–95°	Residue
Volume 1st distillation					
Volume 2nd distillation					

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[1] The distillate obtained in the simple distillation described above may be used. If the volume is not exactly 100 ml, add sufficient water.

When the flask has cooled, pour in the contents of flask I, add one small boiling stone, and distill until the thermometer reaches 70°; allow apparatus to cool to 60° and add the contents of flask II. Resume distillation and collect again in flask I the fraction from 65° to 70°. Place flask II as receiver and collect the distillate from 70° to 80°. Remove the flame and allow to cool to 65° and then add the contents of flask III. Resume the distillation and collect the fraction from 65–70° in flask I; from 70–80° in flask II; and 80–90° in flask III. Allow to cool to 65° and then add the contents of flask IV, and again collect the fraction I, II, III, IV. At 95° the distillation is again discontinued, the contents of flask V are added. The distillation is resumed and the various fractions are collected as before. When the distillation is complete, the volume of the various fractions is again measured and the results are tabulated. From the tabulated results a graph is made on the same paper as for the experiment for purification above, by plotting the volume of the distillate against the temperature. The graphs may be placed on the space provided in the question section below. If a refractometer is available, determine the refractive index of fractions I and V of the last distillation.

Other mixtures for fractional distillation. (1) A mixture of toluene and carbon tetrachloride may be separated by the procedure described in the preceding section. Use a mixture of equal volumes of the two substances. Collect fractions as follows: I, from 76° to 81°; II, from 81° to 90°; III, from 90° to 98°; IV, from 98° to 108°; V, residue.

(2) A mixture of chloroform and toluene may be separated by fractional distillation, using the following temperature ranges to collect the various fractions: I, from 62° to 70°; II, from 70° to 85°; III, from 85° to 95°; IV, from 95° to 108°; V, residue.

Semimicro Fractional Distillation. Figure 33 shows an arrangement of apparatus for semimicro fractional distillation. The fractionating column is about 180 mm in length and 9–10 mm in diameter; the upper end is 20 mm in diameter to permit insertion of the thermometer. Inside the column is placed a spiral of nichrome wire or iron wire. The spiral is made by winding the wire around a glass rod (6 mm) of such diameter that it can be inserted into the column. The wire spiral is preferred to packing with glass beads, as in the latter case considerable refluxing takes place at the upper end of the column. A greater efficiency is obtained if two spirals are used and one is inserted into the other. For this purpose the first spiral is made by winding the wire around a tube 6 mm in diameter and the other by winding it around a tube 4 mm in diameter. When the spiral has been inserted, the column is covered with a piece of asbestos 40 × 110 mm, which is rolled around the tube. The edges of the asbestos covering are moistened with water and pressed together so that the asbestos forms a tight jacket around the column. A piece of thin wire or string is tied around the covering to hold it in place. The column is fitted through a cork placed in the mouth of an eight-inch test tube which serves as the boiling vessel. The thermometer is placed

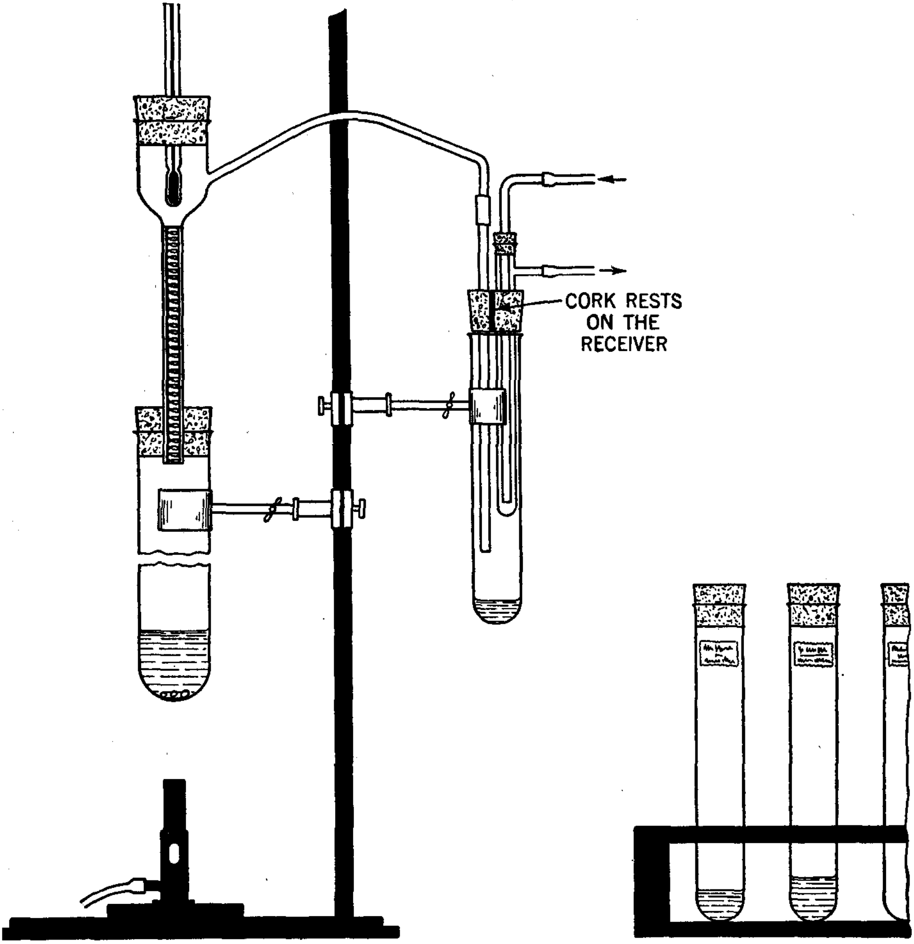

Fig. 33. Semimicro apparatus for fractional distillation

so that the lower end is just above the opening of the narrow tube. The delivery tube is connected with the receiver, and the condenser is arranged as usual.

A semimicro column with a Podbielniak Heli-Grid packing may be obtained[2] to demonstrate the importance of the type of packing in the fractionation of liquids. This column has the same dimensions as the one described above but contains a special type of packing which gives 3–4 times higher efficiency in fractionation. In other words, a single distillation with the Heli-Grid packing is equivalent to three or four distillations with the ordinary spiral.

Place 20 ml of a mixture of equal amounts of methyl alcohol and water in the distilling tube, and add two boiling stones the size of grape seeds. Make sure that all connections are adjusted. Heat slowly by means of a micro burner, moving the flame to and fro. In the beginning there will be a certain amount of refluxing in the column, but if the heating is very slow, distillation will begin without any difficulty. For receiver use regular 6-inch test tubes. The first receiver is calibrated at 0.5 and 1 ml mark as follows: By means of a small 10 ml cylinder (or pipette), measure into the test tube marked I, 0.5 ml of water, and place a thin strip of gummed paper or label paper at the level of the water. Add 0.5 ml more and mark as before.

Collect successively the five fractions which boil between the following temperature ranges: I, from 65° to 70°; II, from 70° to 80°; III, from 80° to 90°; IV, from 90° to 95°; V, residue. It is very important that the fractionation should be done *very slowly* and *carefully*, otherwise the amount of the first fraction will be negligible. The first fraction is collected in the calibrated test tube, and the volume is read directly, since it is usually less than one milliliter. If a graduate is used to measure it, most of the fraction is lost in the transfer. Each succeeding fraction is measured carefully by the use of a 10 ml cylinder and is replaced immediately in the original test tube. Care should be taken in allowing the cylinder to drain completely, as losses of even small amounts in semimicro work are of importance. The residue is measured in the same manner and placed in tube V. Record the data in tabular form as shown on page 73.

When the distilling tube has cooled pour in the contents of receiving tube I, allow it to drain completely, and then add a tiny boiling stone. Distill until the thermometer reaches 70°. Allow apparatus to cool to 60° and then add the contents of tube II.

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[2] Podbielniak Centrifugal Super-Contactor Co., Chicago, Ill.

Add another tiny boiling stone and resume distillation, collecting in tube I the fraction which boils at up to and including 70°. Replace tube I with tube II, and collect the distillate from 70° to 80°. Allow to cool to 65° and then add the contents of tube III. Resume distillation and collect the fraction from 65° to 70° in tube I, the fraction from 70° to 80° in tube II, and the fraction from 80° to 90° in tube III. Allow to cool to 65°, add contents of tube IV, and resume distillation. Collect again fractions I, II, III, and IV in their respective tubes. At 95° the distillation is discontinued, the tube is allowed to cool, and the contents of tube V are added. The distillation is resumed and the various fractions are collected as before. When the temperature reaches 95°, the distillation is discontinued and the tube is allowed to cool while permitting the liquid in the fractionating column to drain back into the distilling tube. The residue is measured directly and placed in tube V. The volumes of the other fractions are likewise determined, and the results tabulated. From the tabulated results a graph is made in which the volume of the distillate is plotted as the abscissa and the temperature as the ordinate.

Experiment 7

MICRO DETERMINATION OF BOILING POINTS

Introduction. The boiling point of an organic compound which can be distilled without decomposition may be used as a criterion for its purity. Since the boiling point varies with the atmospheric pressure in the laboratory, the observed boiling point is not as reliable a criterion as the melting point. For very accurate work a correction is applied to the observed boiling point to reduce it to corrected standard boiling point. For small deviations from 760 mm pressure the correction is a fraction of a degree. The rise in boiling points per millimeter increase in atmospheric pressure is approximately one ten-thousandth of the boiling point expressed in absolute degrees. The boiling point of benzene at 760 mm is 80.09°. The correction, therefore, for every millimeter deviation from 760 mm will be: $(273 + 80) \times 0.0001 = 0.0353°$. Assume that a sample of benzene boiled under a pressure of 750 mm gives 79.7° as the observed boiling point. The correction is $(760 - 750) = 10$ mm $\times\ 0.0353° = 0.35°$. The corrected boiling point is $79.7° + 0.35° = 80.05°$. It should be noted that this rule is only approximate and that it does not apply to pressures which are far removed from 760 mm.

The method for determining boiling points which was outlined in the two previous experiments is satisfactory for all ordinary purposes. The liquid is boiled gently so that distillation proceeds slowly without superheating. It is advisable to use a thermometer which has been calibrated by the manufacturer for stem immersion of 65°. Such a thermometer when placed in an average distilling flask has about 65° of the stem immersed in the vapor, which extends from the top of the neck to the opening of the sidearm. It should be noted that from a rigorous standpoint the actual boiling point of a liquid is not the temperature of the vapor at the side arm of the distilling flask but the temperature of the boiling liquid itself, provided there are no errors from superheating. This condition is difficult to satisfy in ordinary distillations with the common distilling apparatus. Special apparatus for accurate determination of boiling points using macro methods are described in the literature.[1] The micro method requires no special apparatus, is fairly accurate, rapid, and can be employed even if only a few drops of the liquid are available. Three procedures will be described.

Procedure A. The apparatus used is shown in Figure 34(*B*). It consists of a thermometer and a 3-inch tube in which is inserted a capillary tube 4–5 mm in diameter and 80–100 mm in length. The capillary is made as follows: Take a piece of glass tubing 4–5 mm in bore and cut it in two, about one-third the distance from one end. Seal the end of the larger piece. Heat the side of this tube about 10 mm from the end with as pointed a flame as it is possible to obtain. When a small spot has become red hot, blow until the bubble bursts, leaving a hole in the side of the tube. Heat the end of the small piece as well as the large one, and when they are closed and soft, push them together and align. Cool in the luminous Bunsen flame. This tube is shown diagrammatically in Figure 34(*A*). Cut the small glass tube at about 4–5 mm from the joint, using a sharp file and being careful not to break the fragile joint.

To determine the boiling point, use a three-inch test tube provided with a bored cork to insert the boiling-point tube. Arrange the boiling-point tube as shown in Figure 34(*B*). Place the boiling-point tube so that the end of the short piece is 3 mm from the bottom of the three-inch test tube. Put in ten drops of the liquid whose boiling point is to be determined and insert the boiling-point tube. Fasten the three-inch tube to a thermometer by means of a rubber band. Heat slowly and watch the air trapped in the chamber formed by the short piece of the boiling-point tube bubble out as the temperature rises. Heat slowly until all the air has bubbled out. To make sure, stop heating momentarily; if the liquid completely fills the inverted chamber, all the air has been removed. Raise the temperature slowly until the vapor of the liquid fills the cavity and begins to bubble out. Stop heating, and observe the temperature at which the liquid begins to recede into the capillary chamber. Record this temperature, and again heat very slowly until the gas bubble fills the entire chamber and grows neither smaller nor larger. Record this temperature as the boiling point of the liquid.

Procedure B. Use a tube about 90 mm in length and 4–5 mm in diameter sealed at one end. Place in the tube 4–5 drops of the liquid. Take a melting-point tube about 120 mm in length, heat it

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[1] A. A. Morton, *Laboratory Technique in Organic Chemistry* (New York: McGraw-Hill, 1938), p. 51.

very carefully about 30 mm from the end and push inward gently from the ends so that the walls collapse and a seal is made. Cut the open end of the tube about 10 mm from the seal, and place it with the open end downward in the large capillary tube containing the liquid. The complete setup attached to a thermometer is shown in Figure 34(*C*). Place the whole in an oil bath, as in the determination of melting points, and proceed as directed for Procedure A.

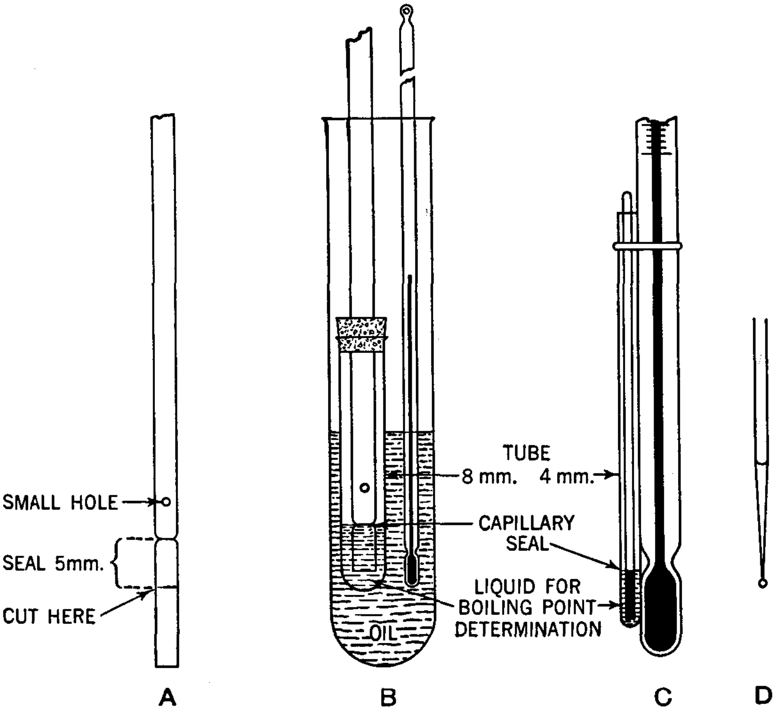

Fig. 34. (*A*) Capillary for boiling-point determination (enlarged)
(*B*) Boiling-point setup using capillary (*A*)
(*C*) Boiling-point setup using modified melting-point capillary
(*D*) Capillary for boiling-point determination, according to Emich

Procedure C. This method, devised by Emich,[2] is particularly useful when the amount of liquid for the determination is less than one drop. Prepare a capillary shown in Figure 34(*D*). Select a clean

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[2] A. A. Benedetti-Pichler and W. F. Spikes, *Introduction to the Microtechnique of Inorganic and Qualitative Analysis* (Microchemical Service, Douglaston, N. Y., 1935.)

piece of soft glass tubing 6–8 mm in diameter. Heat it above the blue cone of the flame, rotating it continuously around its axis. When the tube is soft, remove it from the flame and draw it out slowly so that a capillary pipette is obtained. Make several of these pipettes. Select one which is about 100 mm in length, with a 0.5 mm diameter and tapering at the narrow point to 0.1 mm in diameter. The length of the narrow point should be about 10 mm. Insert the narrow point of the capillary pipette into the liquid whose boiling point is to be determined. The capillary attraction forces the liquid to rise within the pipette. When the liquid has risen just above where the narrow point begins, remove the pipette and hold it near the flame of a burner, with the tapered end pointing slightly upwards so as to draw the liquid away from the narrow point. Heat the point momentarily at the edge of the burner so as to seal it. A small air bubble is formed and fills most of the fine point of the capillary. Examine the bubble with a magnifying glass to make sure that it does not extend into the tapered portion of the pipette.

Attach the capillary pipette as a melting-point tube and heat it slowly in the bath. Observe the air bubble through a magnifying glass, using a light if necessary. When the bubble begins to show signs of upward motion, remove the flame. The temperature at which the bubble reaches the surface of the bath liquid is recorded as the boiling point of the liquid. Allow the bath to cool to 10° below the recorded temperature, heat slowly again and make a second observation.

Micro determination of the boiling point of an unknown substance. It is advisable to become familiar with the technic by first determining the boiling point of a known substance which can be obtained in a state of high purity. The following compounds are suggested: benzene, chlorobenzene, and aniline. Select one of the procedures and determine the boiling point of the known substance until you have obtained a satisfactory value.

Hand a small test tube to the instructor and obtain 0.5 g of an unknown substance. Determine the boiling point, and note the barometric pressure in the laboratory. Report the observed and corrected boiling point.

Experiment 8

DETERMINATION OF REFRACTIVE INDICES

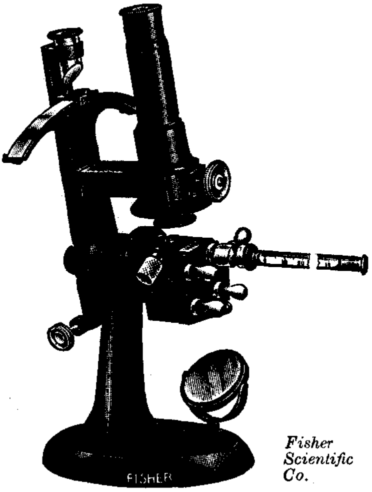
GENERAL CONSIDERATIONS

Introduction. When light passes from air into a denser medium, such as water or glass, its velocity changes, and as a consequence the light undergoes bending or *refraction*. When light passes from air into a denser medium at an angle, a relation is found to exist between the angle of incidence and the angle of refraction. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a characteristic constant for each substance and is called the *refractive index*. Since refraction depends on the difference in the velocity of light in the two media, the refractive index represents the ratio of the velocities. By definition the absolute refractive index of a substance represents the ratio of the velocity of light in a vacuum to that in the substance. For the refractive index as commonly determined air is used as the standard of comparison. The index is denoted by the letter n with a superscript indicating the temperature of observation, and a subscript denoting the wave length of light used. Thus, the refractive index of water $= n_D^{20} = 1.3330$ and $n_D^{50} = 1.3290$. The refractive index decreases as the temperature rises. The variation due to the temperature effect is different with various substances, but it can be approximated by taking the variation as 0.0004 per degree Centigrade.

The refractive index is one of the important physical constants of organic compounds and can be determined accurately. As a criterion of purity it is more reliable than the boiling point. The determination of refractive indices is useful for the identification of an unknown pure liquid. It is also used in analytical work for the determination of the relative amount of a substance in solution.

Refractometers. There are several types of refractometers used for determining the refractive indices of liquids. The Abbe refractometer is widely used because it employs only a few drops of the material and requires but a few minutes for the determination. The Fisher refractometer has been introduced recently and is particularly adapted to the student's use.

The Abbe refractometer, shown in Figure 35, consists of (*a*) a pair of rotating water-jacketed prisms hinged together; (*b*) an observing telescope above the prisms for observing the border-line of the total reflection which is formed in the prism; (*c*) a sector on which the telescope is fastened. The sector is graduated from 1.300 to 1.710 and permits direct reading of the index of refraction; it is adjusted to the sodium D line of the spectrum.



Fisher Scientific Co.

Fig. 35. Refractometer (Abbe). Permits determination of refractive index of the fourth decimal place. For higher accuracy, use is made of the dipping refractometer.

To operate the refractometer, adjust the thermometer in place, and connect the base of the prism enclosure with a reservoir containing water at 20°. Place the left thumb on the sector and use the right hand to open the double prism by pulling down the screw-head which is fastened on the lower prism. Wipe off the prisms carefully with a sheet of lens paper.[1] If the liquid is a kind that does not evaporate rapidly, place two drops on the face of the lower prism and close immediately, clamping it by means of the screw head against the upper prism. If the liquid is volatile, close the prism, then slacken the screw and by means of a pipette dropper pour a few drops of the liquid into the depression on the side of the prism which leads through a narrow channel into the space between the two prisms. Tighten the screw, and rotate the prism by moving the arm at the side of the sector. Adjust the mirror to obtain maximum illumination, and bring the cross hairs sharply into focus. As the prism is rotated the illuminated field is partly darkened by a shadow moving across it. The boundary between the dark and the light field is called the *dividing line* or *border line*. If the dividing line is not sharp but is hazy with a band of colors, move the compensator wheel, which is at the lower part of the observing telescope, until the dividing line becomes sharp and colorless. Move the arm of the prism until the dividing line coincides

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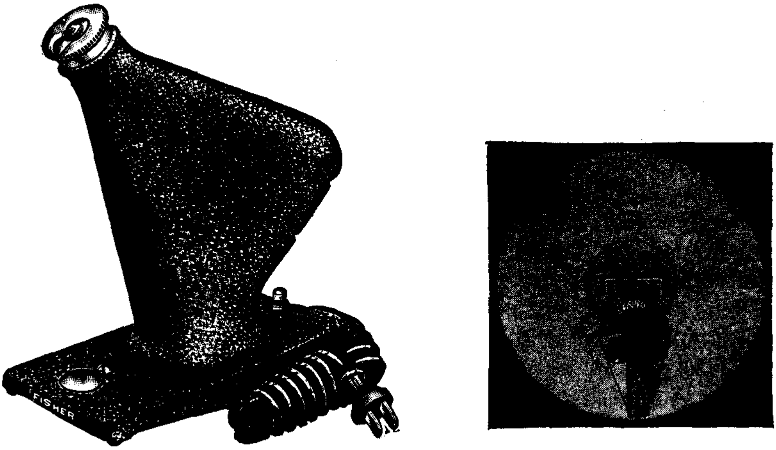
[1] Facial tissue paper, such as Kleenex, Handies, Sitroux, are well adapted for the same purpose.

with the intersection of the cross hairs. Read the refractive index by looking through the small eyepiece over the sector. The pointer indicates the last three figures of the refractive index. The first two are read on the left side of the scale a small distance below the pointer. Open the double prism and clean by means of a piece of lens paper and a few drops of acetone.

The Fisher refractometer is shown in Figure 36(*a*). A small glass slide with a beveled edge is fitted on the glass plate of the eyepiece, as shown in Figure 36(*b*). A small clamp holds the glass slide down so that a prism-shaped well is formed between the plate of the eyepiece and the glass slide. The instrument has a cord by which it is attached to an electrical outlet. If the push-button on the base of the instrument is pressed, and observation is made through the aperture of the eyepiece, an illuminated scale appears. The graduations on the scale are divided at 1.516 by an arrow. This point corresponds to the refractive index of the glass in the eyepiece.



Fisher Scientific Co.

(*a*) (*b*)

Fig. 36. (*a*) Refractometer (Fisher). Low cost renders instrument suitable for student use. Range: $n = 1.30$ to $n = 1.90$; permits estimation of refractive index to $n = 0.002$.

(*b*) Eyepiece of Fisher refractometer, with wedge-shaped well in which is placed a drop of liquid for the refractive-index determination.

When a very small drop of a liquid is placed in the well formed by the glass slide and glass plate of the eyepiece, the refraction of light passing through the prism of the liquid sample produces a secondary or virtual image of the arrow on the scale. A liquid which has a refractive index less than that of the glass employed will cause the light to bend downwards and the secondary image will appear above 1.516 on the scale. Conversely, if the refractive index is higher, the bending is upwards and the secondary image appears below 1.516.

To operate the Fisher refractometer, remove the small glass slide from the box and clean it with lens paper. Likewise wipe off the plate of the eyepiece. Place the glass slide, with the beveled edge downwards, over the plate so that the beveled edge just covers the aperture. Connect the plug of the instrument to an electrical outlet. Press down the push-button and examine the scale. Using a capillary pipette dropper, add a very small amount 0.01–0.05 ml)of the liquid at the edge of the glass slide directly over the aperture. The minute droplet spreads by capillary attraction over the beveled edge and fills the well. Press the push-button and observe the second arrow either above or below 1.516 on the scale. This is the refractive index of the liquid. If the liquid evaporates rapidly, add the droplet with one hand and push the button with the other, observing the secondary image immediately. When the determination is completed, clean the glass slide and replace it in the proper box. If it is desired to make several determinations, the glass slide and eyepiece are cleaned with lens paper between operations.

SPECIFIC DIRECTIONS

(A) **Liquids for Refractive-Index Determinations.** Table 4 lists a number of liquids which are commercially available[1] in uniform 25-ml glass-stoppered bottles and are suitable for refractive-index determinations. Obtain from the instructor a few drops of two or three known liquids and determine the refractive index of each. Tabulate the observations.

(B) **Determination of the Refractive Index of an Unknown Substance.**

(1) Hand in one or two clean vials or three-inch tubes and obtain a few drops of one or two unknown liquids. Determine the refractive index of each. Obtain from the instructor the refractive index of the unknown and calculate the per cent of error.

(2) Consult in Lange's Handbook the tables of refractive indices

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[1] Eastman Kodak Company, Rochester, N. Y. The selection of liquids was based partially on cost. For example, methylene iodide, with a refractive index of 1.74, is not included, since the cost of $4.80 per 25 g is prohibitive for the student's use. The total cost of 25 ml of each of the liquids listed in Table 4 is about $6.00.

Table 4
LIQUIDS FOR REFRACTIVE INDEX DETERMINATION

SUBSTANCE	n_D^{20}	SUBSTANCE	n_D^{20}
Methyl alcohol	1.3288	Toluene	1.4957
Water	1.3330	Chlorobenzene	1.5250
Acetone	1.3592	*o*-Nitrotoluene	1.5466
Ethyl acetate	1.3727	Bromobenzene	1.5602
n-Heptane	1.3872	*o*-Toluidine	1.5725
n-Butyl alcohol	1.3991	Quinoline	1.6272
n-Butyl chloride	1.4022	α-Bromonaphthalene	1.6585
Methylcyclohexane	1.4235		
Ethylene chloride	1.4453		
Cyclohexanol	1.4678		

arranged in the order of increasing values and ascertain the various possibilities as to the nature of the compound.

Experiment 9

IDENTIFICATION OF ELEMENTS IN CARBON COMPOUNDS

GENERAL CONSIDERATIONS

Introduction. The elements that may be present in organic compounds are comparatively few. Ten elements combined in various forms make up the greater part of the enormous number of organic compounds. The majority of organic compounds contain only three elements: carbon, hydrogen, and oxygen. Nitrogen, sulfur, and the halogens are less common, and a still smaller number of compounds contain phosphorus, arsenic, mercury, and other elements.

Most carbon compounds when heated in air will burn. In many cases carbon compounds can be detected by heating them. The evolution of combustible gases, or charring, or both, indicate the presence of carbon. Some carbon compounds, however, volatilize on heating without decomposition. Therefore, more reliable methods are employed for the systematic detection of the elements present in an organic compound. The object of the present experiment is to illustrate the various qualitative tests which are usually employed for detecting the presence of carbon, hydrogen, nitrogen, sulfur and halogens in organic compounds.

Detection of carbon and hydrogen. The detection of carbon and hydrogen is based upon the formation of *carbon dioxide* and *water* when compounds containing these elements are heated with copper oxide. The formation of carbon dioxide is detected by passing the gases produced through a solution of barium or calcium hydroxide, whereby barium or calcium carbonate is precipitated. The formation of water is detected by the appearance of droplets in the upper (cool) part of the ignition tube.

Detection of halogens. Very few organic compounds contain halogen atoms which form halide ions in aqueous solutions and so can be detected by the addition of silver ion. It is necessary, therefore, to convert the organic halogen to a metallic halide by fusion with metallic *sodium* or calcium oxide. By such decomposition nitrogen and sulfur, if present, form ions which can be detected by the usual methods of qualitative inorganic analysis.

The presence of halogens can be demonstrated by the *Beilstein Test.* A small amount of the sample is placed on a copper wire and burned in the Bunsen flame. The copper halide which forms imparts a green color to the flame. This test, though sensitive, must be confirmed through fusion and detection by means of silver halide.

Sodium fusion for detection of halogens, nitrogen, sulfur. When an organic compound is heated with metallic sodium, decomposition occurs. Free carbon is deposited, and some carbon monoxide and dioxide are formed. The halogens forms halides (NaCl, NaBr, and NaI). Nitrogen in presence of carbon and sodium gives sodium cyanide, NaCN; sulfur forms sodium sulfide, Na_2S.

The residue obtained by fusion is warmed with a small amount of alcohol to decompose the unreacted metallic sodium and is extracted with water. Portions of the filtered alkaline solution are used for the detection of halide, cyanide, and sulfide ions.

Detection of cyanide ion and other tests for nitrogen. The cyanide is converted first to ferrocyanide ion by boiling with ferrous sulfate, then to ferric ferrocyanide, or Prussian blue, by addition of ferric chloride and addition of acid. The Prussian blue is detected by its blue color, which is intensified by addition of fluoride ion:

$$2\ CN^- + Fe^{++} \longrightarrow Fe(CN)_2$$

$$4\ CN^- + Fe(CN)_2 \longrightarrow \underset{\text{(Ferrocyanide ion)}}{Fe(CN)_6^{=}{}^{=}}$$

$$3\ Fe(CN)_6^{=}{}^{=} + 4\ Fe^{+++} \longrightarrow \underset{\text{(Prussian blue)}}{Fe_4[Fe(CN)_6]_3}$$

A number of nitrogen compounds, for example, proteins, do not yield cyanide ions easily with sodium fusion. It is advisable to perform the soda lime test for nitrogen if the sodium fusion shows absence of cyanide ion.

Soda lime and magnesium fusion for nitrogen. Magnesium metal or soda lime may be used for the fusion of substances which do not decompose easily. About 0.2 g of the substance is mixed with 0.5 g of magnesium and heated strongly in an ignition tube. Nitrogen forms magnesium nitride, which on addition of water forms ammonia:

$$Mg_3N_2 + 6H_2O \longrightarrow 3\ Mg(OH)_2 + 2\ NH_3$$

The presence of ammonia is detected either by moist litmus paper or by Nessler's solution. If a mixture of equal parts of magnesium powder and anhydrous sodium carbonate is used, sodium cyanide is formed and may be tested by the formation of Prussian blue in the same manner as described for the solution from the sodium fusion. The soda lime fusion is applicable to compounds which contain the amino ($-NH_2$) group, such as amines, amino acids, proteins, and urea derivatives. When such compounds are heated with soda lime (a fused mixture of sodium and calcium hydroxides), ammonia is given off which can be detected by the methods described.

Detection of sulfide ion and other tests for sulfur. The alkaline solution from the sodium fusion is treated with lead acetate in presence of acetic acid. The formation of brownish-black lead sulfide indicates the presence of sulfide ion. Another test for the sulfide ion is the formation of a violet-red color upon addition to the solution of a few drops of sodium nitroprusside ($Na_2Fe(CN)_5NO$). The test is very sensitive but the color produced is not stable and fades.

Detection of halide ions. The alkaline solution from the sodium fusion is first treated with dilute nitric acid and boiled in the hood to remove cyanide and sulfide ions that may be present. These ions form insoluble precipitates with silver ion and interfere with the detection of halide ions. On boiling with dilute nitric acid they are volatilized as hydrogen cyanide and hydrogen sulfide; hence care should be exercised, and the hood must be used in heating the test solution. The addition of silver ion forms a precipitate of silver halide which varies in color from yellow (iodide) to white (chloride and bromide). If it is necessary to identify the halide present, a portion of fresh solution is acidified with a few drops of dilute sulfuric acid and a thin layer of chloroform (2–3 ml) is added, followed by a drop of freshly prepared chlorine water. On shaking, the chloroform layer becomes colorless if the ion is chloride, brown if it is a bromide, and violet if it is iodide.

Oxygen. The presence of oxygen is usually made known by the presence of groups such as the hydroxyl (OH), carboxyl (COOH), and other oxygen-containing functional groups. It is then necessary to determine quantitatively all the other elements present. The difference from 100 per cent is assumed as the amount of oxygen present. In many cases it is possible to detect oxygen by passing the vapors of the compound over heated charcoal in an apparatus from which air and moisture have been removed. The oxygen, if present, is converted to carbon dioxide, which is detected by passing it through a solution of barium hydroxide.

SPECIFIC DIRECTIONS

(A) Combustibility of Organic Compounds. Place a very small amount (0.1 g of solid or 2 drops of liquid) of each of the following substances in an evaporating dish or a crucible cover: *benzene, ethyl alcohol, sodium acetate, sugar.* Ignite each one, first applying a match to it; if it does not ignite, use the burner. Note whether there is an ash or residue; if so, add a few drops of distilled water to the residue, transfer to a test tube, add a drop of universal indicator, and note the *p*H by comparing the color with the chart. The dish is cleaned after each test.

(B) Tests for Carbon and Hydrogen. Use a dry 6-inch hard-glass ignition tube and attach to it a cork and bent delivery tube made of narrow glass tubing (4–5 mm), as shown in Figure 37. Heat 2 g of fine copper oxide in a porcelain crucible or evaporating dish for a few minutes to drive off the moisture. Cover it with a watch glass and allow to cool.

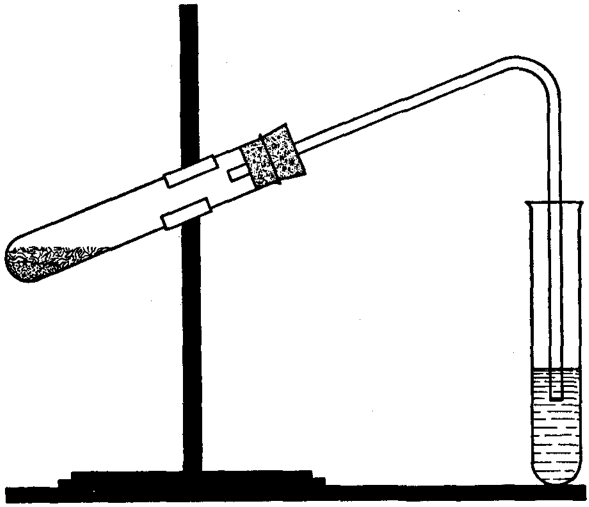

Fig. 37. Apparatus for the detection of carbon and hydrogen

Mix 0.2 g of benzoic acid or sugar with the copper oxide in a mortar. Put the mixture into the tube, and place on top about one inch of copper oxide wire. Fix the tube in a clamp near the cork, and dip the end of the delivery tube under the surface of a small amount of freshly filtered clear barium or calcium hydroxide solution. Heat the granular copper oxide, beginning at the end which is farthest from the sample. When this is red hot, heat the sample and observe the cool part of the tube and also the alkaline hydroxide solution. Note the color of the cupric oxide in the tube. Remove the delivery tube from the alkaline hydroxide solution before allowing the hot tube to cool.

(C) **Sodium Fusion.** Read directions on page 109 for handling sodium. Wear goggles throughout the experiment. Place in a six-inch Pyrex ignition test tube a piece of clean metallic sodium about the size of a pea. Use forceps in handling it, and do not use more than the specified quantity. In cutting sodium, *keep away from the sink.* Replace all small pieces in the bottle and do not throw any into the sink or waste jar. Clamp the tube to a ring-stand in the hood, and heat the lower part of the tube until the vapors of sodium rise about one millimeter within the tube. Remove the flame momentarily and add, all at once, directly upon the molten sodium a small amount of the sample to be tested. Use a few crystals if the sample is solid and 2–3 drops if the sample is a liquid. Care should be exercised to add the sample directly upon the molten sodium, else there may be vaporization and incomplete decomposition. It is advisable to repeat the addition of sample if in doubt. The addition of the sample causes a vigorous reaction. Heat the reaction mixture strongly until all of the compound is decomposed. Allow the tube to cool; when it is *perfectly cold,* add *cautiously* 2 ml of ethyl alcohol, and wait until all the sodium is decomposed. Then add 10 ml of distilled water.

Caution: Keep your face away from the tube, since the decomposition of the encrusted sodium by the alcohol may be incomplete.

Heat to boiling, and filter. (The test tube is to be cleansed immediately and put away.) The filtrate should be clear and colorless. Portions of this stock solution are used to test for cyanide, sulfide, and halide ions.

(1) **Test for Cyanide Ion.** Place 3 ml of alkaline filtrate in a small beaker or a large test tube, and add 5 drops of freshly prepared 10 per cent ferrous sulfate solution, 2 drops of 6 N sodium hydroxide solution and 5 drops 10 per cent potassium fluoride solution, then boil. Add 1 drop of 10 per cent ferric chloride solution and then add dilute sulfuric acid drop by drop until the solution is acid, in order to dissolve the oxides of iron. Allow to stand for five minutes. A clear solution of a yellow color indicates absence of cyanide ion and hence of nitrogen. The formation of a greenish-blue

solution indicates a poor fusion and the presence of some nitrogen. A precipitate of Prussian blue proves the presence of nitrogen.

Sulfur often obscures the test for nitrogen. If sulfur is present, proceed as follows: To a portion of the solution add 5 drops of ferrous sulfate solution and 5 drops of fluoride solution, then add sodium hydroxide until the mixture is alkaline. Heat to boiling, and filter from any precipitate. Acidify with dilute hydrochloric acid, and add a drop of ferric chloride to obtain a precipitate of Prussian blue.

(2) **Test for Halogens.** Acidify 2 ml of the solution with dilute nitric acid, boil in the hood to remove any hydrogen cyanide or hydrogen sulfide which may have been formed, and add 3–4 drops of dilute silver nitrate solution. A white or slightly yellow precipitate indicates the presence of a halogen.

If a halogen has been detected and it is desired to identify the nature of the halide ion, 2 ml of the solution are acidified with dilute sulfuric acid. Add 2 ml of chloroform and one drop of chlorine water prepared by the addition of 0.5 g potassium chlorate to 1 ml of concentrated hydrochloric acid. Shake the mixture. The color of the chloroform layer indicates the nature of the halide ion (see page 89).

(3) **Test for Sulfide Ion.** Add 2–3 drops of lead acetate to 2 ml of the stock solution which has been acidified with dilute acetic acid. A brown or black precipitate denotes the presence of sulfide ion. Add 1–2 drops of sodium nitroprusside solution (0.1 per cent) to 2 ml of the stock solution. A deep red color indicates the presence of sulfide ion.

(D) **Beilstein Test for Halogens.** Heat a copper wire to redness until it no longer colors the flame. Cool, and touch it to a small crystal of *p*-dichlorobenzene; then heat it again. A blue-green flame indicates the presence of a halogen. The color of the flame is due to the vapors of the copper halide.

(E) **Detection of Nitrogen.** (1) **Calcium Oxide Fusion.** Mix 0.1 g of urea or casein with five times its bulk of pulverized soda lime. Place in a small evaporating dish, and cover with a watch glass, on the inner surface of which is laid a strip of moist red litmus paper. Now heat gently to avoid spattering, and observe the litmus paper. Allow the ignition mixture to cool, place a portion in a test tube, and test for sulfide ion.

(2) **Magnesium Fusion.** Arrange a hard-glass tube as in Figure 37. The delivery tube reaches just above the water, which is acidified with 5 drops of dilute hydrochloric acid. Mix 0.1 g of the sample to be tested with 0.2 g of a mixture of equal parts of mag-

nesium and sodium carbonate. Then place about 0.2 g of the magnesium mixture on top of the sample. Heat the fusion mixture, beginning at the end which is farthest from the sample, and when it begins to burn heat the lower end of the tube until it is red hot. Cool, add 10 ml of water, boil, and filter. The filtrate is tested for cyanide ion as directed in paragraph C (1). The acidified water is tested for the presence of ammonia by the addition of 1 ml 6 *N* sodium hydroxide solution and a few drops of Nessler's solution. The presence of ammonia is indicated by a yellow color.

(F) Detection of Elements in an Unknown Substance. Hand a clean test tube to the instructor. The tube should have a label on the upper part. Enough material will be supplied for all tests, but do not waste it. Proceed in accordance with directions to test for *carbon, hydrogen, halogens, nitrogen,* and *sulfur.* When the tests are finished, complete the report and hand it to the instructor.

PART II

PREPARATION AND PROPERTIES OF SIMPLE ORGANIC COMPOUNDS

Experiment 10

PREPARATION OF *n*-DECANE AND *n*-OCTANE

(Semimicro)

NOTE: The preparation of *n*-octane or *n*-decane by the action of sodium on alkyl halides is *recommended only* on a *semimicro scale* for beginners. The macro method involves the use of 10–15 g of sodium and therefore it is not recommended. Even the *semimicro* technic requires the use of 2–2.5 g of sodium, an amount which it is dangerous to use unless the student is very careful and follows directions. The preparation of *n*-decane is preferred for beginners.

Hydrocarbons. The hydrocarbons, as the name implies, are compounds containing carbon and hydrogen. If the carbon atoms lie in the same plane they are known as *open-chain,* or aliphatic hydrocarbons. If the carbon atoms form a ring structure they are known as *cyclic* hydrocarbons. The cyclic hydrocarbons are further differentiated into *benzene* (*benzenoid,* or *aromatic*) and *alicyclic* hydrocarbons. If there is another element present in the ring besides carbon, they are known as *heterocyclic* hydrocarbons.

The aliphatic hydrocarbons are studied first because they serve as a basis for the study of the simpler groups of organic compounds. They are divided into:

(1) *Saturated* (*alkanes,* paraffins, C_nH_{2n+2}); (2) *Unsaturated* (*a*) *Alkenes* (olefins, C_nH_{2n}); (*b*) *Alkynes* (acetylenes, C_nH_{2n-2}). As their molecular formulas indicate, the unsaturated differ from the saturated by containing less hydrogen.

A large number of hydrocarbons are obtained from such mixtures as natural gas, petroleum, and coal tar. It is very difficult for a beginner to isolate in the laboratory a pure hydrocarbon from such mixtures, because a distillate which boils within a range of 10° usually contains many hydrocarbons. The preparation of hydrocarbons in the laboratory serves to illustrate general principles of important reactions, and at the same time provides an introduction to the technics used in the preparation of organic compounds.

The Wurtz-Fittig synthesis. When a monohalogen compound is reduced by sodium under anhydrous conditions, the resulting radical can unite with either a similar or a different radical to give a hydrocarbon with a higher carbon content:

$$2\,R-I + 2\,Na \longrightarrow 2\,R-R + 2\,Na-I$$

$$2\,CH_3CH_2CH_2I + 2\,Na \longrightarrow CH_3CH_2CH_2CH_2CH_2CH_3 + 2\,NaI$$

For the explanation of this reaction it is usually assumed that sodium reacts with the monohalogen, forming an unstable compound in which the sodium is directly attached to the carbon, and that the organo-metallic compound then reacts with a second molecule of the halide to form the hydrocarbon:

$$\underset{\text{(n-Propyl bromide)}}{CH_3CH_2CH_2Br} + 2\,Na \longrightarrow \underset{\text{(Propyl sodium)}}{CH_3CH_2CH_2Na} + NaBr$$

$$\underset{\text{(Propyl sodium)}}{CH_3CH_2CH_2Na} + CH_3CH_2CH_2Br \longrightarrow \underset{\text{(n-Hexane)}}{CH_3(CH_2)_4CH_3} + NaBr$$

The principle of this method was developed by Frankland, who used zinc to effect reduction. Wurtz replaced the zinc with sodium and prepared a large number of aliphatic hydrocarbons. Fittig applied the same reaction to the preparation of benzene hydrocarbons, using a mixture of alkyl and aryl halides. The preparation of hydrocarbons by treatment of monohalogen compounds with sodium under anhydrous conditions is sometimes called the *Wurtz-Fittig* synthesis. The yields of a pure hydrocarbon are seldom above 50 per cent and usually below 30. This is due to the formation of other hydrocarbons, both saturated and unsaturated. Another difficulty is that the reaction does not take place with the same readiness in all cases; for example, when *n*-propyl bromide is added to sodium cuttings no reaction occurs for some time, while *n*-butyl bromide reacts as soon as the first drop comes in contact with the metal. If ether is used as an inert solvent to moderate the reaction by dilution, very little hydrocarbon is obtained, while in the reaction of bromobenzene, C_6H_5Br, and ethyl bromide, C_2H_5Br, to give ethyl benzene, $C_6H_5C_2H_5$, the reaction does not take place unless ether is present.

The above discussion emphasizes the fact that very often a general method has to be adapted to each particular case. The student is reminded that it is usually easy to write and balance equations representing reactions of carbon compounds, but rather difficult to find the same simplicity in the laboratory. In practically all reactions between any two organic compounds there is more than one direction and more than one possible set of products and therefore it is necessary not only to consider the nature of the reactants, but many other factors such as temperature, rate and method of addition, presence of impurities, presence or absence of solvent, etc. The following should be read carefully.

Directions for the use of sodium. Sodium is a very active and dangerous metal; it must be kept under an inert liquid such as kerosene or toluene, and must be handled away from water. To prepare sodium cuttings, the required amount is weighed rapidly in a small evaporating dish which contains a little kerosene. A piece of sodium is removed by means of rubber finger-stalls or handled with paper, and is cut rapidly into small pieces with a knife. The cuttings are put back into the dish as they are cut, so that they are kept covered with kerosene. Sodium must not be left in contact with air any longer than necessary, as a coating of oxide forms on it immediately. When the cuttings have been prepared, they are dried by pressing rapidly between filter paper and placed in the tube as directed. All the papers and vessels that have been used in handling sodium are carefully examined for adhering pieces, then are placed in a beaker in the hood and washed with denatured alcohol before disposal.

Caution: Be sure that you wear goggles throughout all the experiments in which sodium is used.

(A) **Preparation of *n*-Decane.** Arrange an eight-inch Pyrex tube with a micro condenser as shown in Figure 38. The cork has three openings; through one is fitted the condenser, through another a micro calcium chloride tube, and through the third opening a glass tube 150 mm in length and 8 mm in diameter. To this latter opening is fixed a medicine dropper. Place in the large tube 2.5 g of sodium cuttings; the cork holding the condenser is replaced after wiping off the condenser with a dry cloth. The large tube is immersed in a small beaker containing cold water, since the action of halide and metal is violent. Weigh 10 g of *n*-amyl bromide or *n*-amyl chloride in a small beaker. The chloride is commercially available at a lower cost than the bromide and gives good results. With the dropper add *slowly* five drops of the halide and wait until the reaction starts. The beginning of the reaction is shown by the appearance of fumes. Continue to add the halide dropwise at the rate of about one drop per second, and shake the tube gently from time to time. If at any time the reaction appears to proceed with violence due to local super heating, the addition of the halide is stopped. When all the halide has been added (10–15 minutes) and the vigorous reaction appears to be over, the tube is removed, wiped dry on the outside, and the solid mass at the bottom stirred with a dry rod. Be sure that you wear goggles and that the tube rests on a dry place while you are stirring the solid mass. There is a tendency for the sodium halide to deposit on the unreacted so-

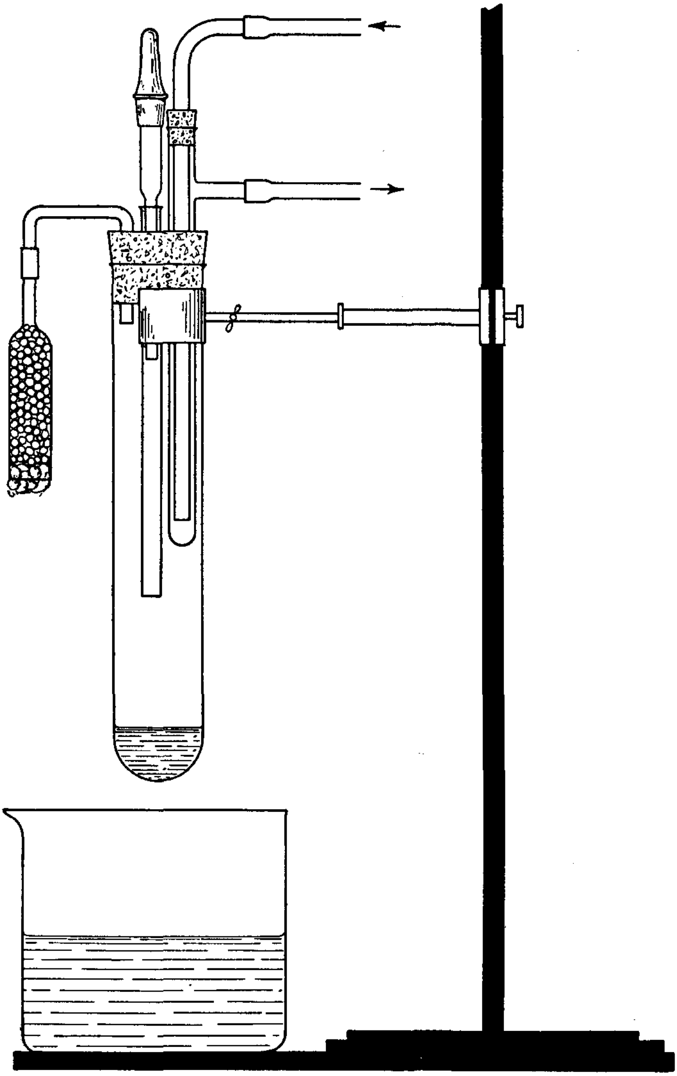

Fig. 38. Semimicro apparatus for Wurtz-Fittig reaction

dium and form a cake, and therefore stirring helps to expose fresh surface and prevent the encrusting of the sodium metal. After stirring, the cork and condenser are replaced, and the tube is heated in the bath to about 80° for 20 minutes.

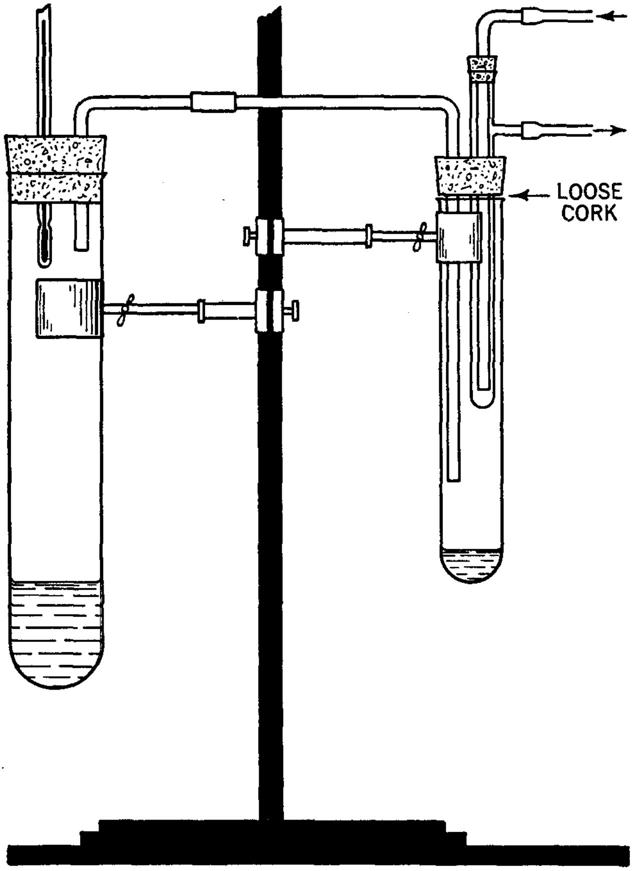

Fig. 39. Semimicro distillation apparatus for distilling directly from an ordinary eight- or six-inch test tube

Remove the water bath and arrange for distillation as shown in Figure 39. Wipe the tube with a cloth to remove the adhering water and then heat the tube slowly with a small semi-luminous flame. To obtain the semi-luminous flame reduce the amount of air entering the lower part of the small Bunsen burner. Continue heating until no more distillate passes over and the solid mass in the tube appears perfectly dry.

The distillate in the tube contains the hydrocarbon and some unchanged halide. To remove the latter, arrange the tube containing the distillate for reflux as shown in Figure 5, page 30. Add 0.5 g of sodium cuttings and warm cautiously. The reaction of the unchanged halide sometimes does not begin until after a few minutes of refluxing. If there is considerable unchanged halide the reaction may be vigorous; in such case the water bath is removed at once and the tube cooled. After 10 minutes the liquid in the tube is poured from the sodium cuttings into a distilling tube, arranged as shown in Figure 25 and fractionated carefully. A small boiling stone is added, and heat is applied by means of a very small (partially luminous) flame, which is moved to and fro. The fraction which boils at 165–175° is collected. The boiling point of pure *n*-decane is 174°. The yield is about 3 g. If a refractometer is available, determine the refractive index. The refractive index of pure decane is 1.411. The tubes containing sodium cuttings are treated in the hood with 1 ml of alcohol at a time, until the reaction ceases. A few milliliters of water are added cautiously to dissolve the sodium halide, and the tube is cleaned.

(B) Preparation of *n*-Octane. Use the same arrangement of apparatus as in the preparation of *n*-decane (see section preceding). Place 2.5 g of sodium cuttings in the tube and observe all the directions given above for the handling of sodium. Weigh 10 g of *n*-butyl bromide in a small beaker. By means of the dropper add slowly 5 drops of the halide. The reaction begins immediately after the addition of the first drop; then follow the same directions as given in the preparation of *n*-decane. In the final fractionation collect the fraction which boils at 123–130°. Determine the weight of the distillate and its refractive index if a refractometer is available. Pure *n*-octane boils at 125.5° and its refractive index is 1.3988. The yield is about 1.5–2 g.

Experiment 11

PREPARATION OF ETHYLBENZENE

Introduction. The principle of the method used for the preparation of ethylbenzene is discussed in the introduction to Experiment 10. A mixture of aryl and alkyl halides, when treated with sodium under anhydrous conditions, forms alkyl-substituted aromatic hydrocarbons:

$$\underset{\substack{\text{Bromo-}\\\text{benzene}}}{C_6H_5Br} + \underset{\substack{\text{Ethyl}\\\text{bromide}}}{C_2H_5Br} + 2Na \longrightarrow \underset{\substack{\text{Ethyl-}\\\text{benzene}}}{C_6H_5C_2H_5} + 2\ NaBr$$

The use of two different halides increases the possibility of side reactions. In the preparation of ethylbenzene, two molecules of ethyl bromide, or two molecules of bromobenzene may react:

$$2\ C_2H_5Br + 2\ Na \longrightarrow \underset{n\text{-Butane}}{C_4H_{10}} + 2\ NaBr$$

$$2\ C_6H_5Br + 2\ Na \longrightarrow \underset{\text{Biphenyl}}{C_6H_5 - C_6H_5} + 2\ NaBr$$

The macro method gives fairly good yields (40–55 per cent of theory), but involves the disadvantage of having the reaction mixture stand in the laboratory, as it cannot be finished in a single laboratory period. The yield when the semimicro method is employed is somewhat less.

(A) **Semimicro Method.** The arrangement of apparatus is somewhat similar to that used in the preparation of *n*-decane (Figure 38). The cork which fits in the eight-inch Pyrex tube has two openings, one for the condenser and the other for a micro calcium chloride tube. *Be sure you wear goggles.* To a mixture of 4 g of bromobenzene, 4.5 g of ethyl bromide, and 10 ml of dry ether are added 1.5 g of sodium cuttings. The water is shut off after one hour so that it does not circulate in the condenser and the tube is allowed to stand over night.

The mixture is filtered into a distilling tube through a very small funnel provided with a plug of glass wool or of cotton. The reaction tube is rinsed with 2 ml of ether and the washings are filtered through the funnel. The solid material on the funnel is pressed with a cork and, after all the liquid has been pressed out, the solid residue is placed in a vessel designated by the instructor. The ether is distilled off by means of a water bath. The water bath is removed and the distilling tube is heated with a free flame. The portion boiling at 133–140° is collected. The yield is 1.1–1.4 g. Pure ethylbenzene boils at 136°.

NOTE: *n*-Propylbenzene and *n*-butylbenzene may be prepared by the same method and with the same quantities of bromobenzene and alkyl bromide. The fraction which is collected in the preparation of *n*-propylbenzene boils at 156–162°. For *n*-butylbenzene the fraction collected is 180–186°. The yield of *n*-butylbenzene is about 50 per cent of theory.

(B) Macro Method. Read directions regarding the handling of sodium on page 99. Arrange a 250 ml or 500 ml Erlenmeyer flask as shown in Figure 40. Be sure that you wear goggles. Place 40 ml of dry ether in the flask, with 9 g of sodium cuttings, and connect immediately with the reflux condenser, the top of which has a calcium chloride tube. Weigh in a small beaker 20 g of dry bromobenzene and 17.3 g of ethyl bromide. Lift the calcium chloride tube and add the halides to the sodium-ether mixture. The reaction begins within five to ten minutes. After about an hour the circulation of water through the condenser jacket may be discontinued, and the two pieces of rubber hose may be joined by means of a short piece of glass tubing, thus leaving water within the jacket. The apparatus is set aside until the next laboratory period.

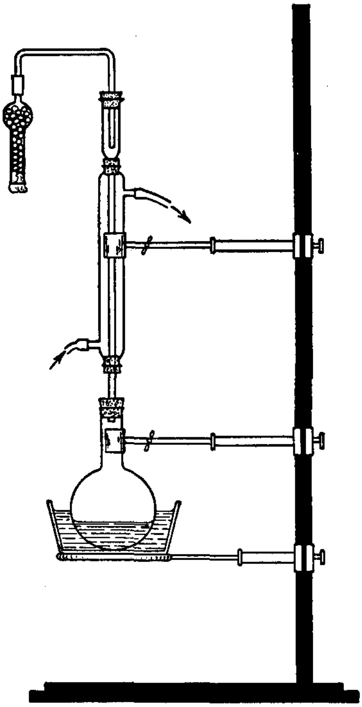

Fig. 40. Macro apparatus for Wurtz-Fittig reaction

The reaction mixture is then filtered through a funnel into a 125 ml distilling flask. A small piece of cotton or glass wool is used in place of filter paper. The reaction vessel is rinsed out with a small amount of ether, (10 ml) and the washings are filtered through the same funnel. The sodium bromide and unreacted sodium cuttings are pressed with a cork, and, after all the liquid has been squeezed out, the residue is placed in a vessel designated by the instructor. The unreacted sodium is disposed of by adding small portions of denatured alcohol. Obtain further directions from the instructor.

The ether is distilled off from a water bath. The water bath is removed, the flask is dried with a cloth and then heated directly with a small semi-luminous flame. The portion boiling between 125–140° is collected separately, and redistilled, when the fraction which boils at 133–138° is collected separately. Ethylbenzene boils at 136°.

Experiment 12

PREPARATION OF A HYDROCARBON BY DECARBOXYLATION OF AN ORGANIC ACID

Introduction. If the alkali salt of an organic acid is heated with soda lime, carbon dioxide is removed and a hydrocarbon is obtained having one carbon atom less than the original acid. The general equation for the reaction is:

$$RCOONa + NaOH \longrightarrow RH + Na_2CO_3$$

In this reaction one carbon atom is oxidized from the carboxyl stage to carbon dioxide. It is to be noted, therefore, that the carboxyl group cannot be directly reduced to the hydrocarbon without the loss of one carbon atom. The method is not practical. It is a traditional experiment, as it illustrates the difficulty in reducing the carboxyl group. The elimination of the carboxyl group is also effected by electrolysis of concentrated solutions of the alkali salts. The products in the case of sodium acetate are ethane and carbon dioxide:

$$2\ CH_3COONa \xrightarrow{E} CH_3CH_3 + 2\ CO_2 + 2\ Na^+$$

The preparation of benzene (part B) is preferred.

(A) **Preparation of Methane.** Grind thoroughly in a mortar 5 g of anhydrous sodium acetate[1] and 5 g of soda lime. Place the mixture in a Pyrex ignition tube fitted with a cork and with a delivery tube which leads into a trough arranged for collection of gases by water displacement. The delivery tube projects about 5 mm into the test tube beyond the stopper. The tube is inclined so that it is almost horizontal. The collection bottles are filled with water containing 10 ml of lime water. The tube is heated and three 25–30 ml bottles of gas are collected. One of the bottles which contains the gas is brought near the flame and the cover removed. To the second bottle 1 ml of a 1 per cent solution of bromine in carbon

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[1] For the preparation of anhydrous sodium acetate see p. 354.

tetrachloride is added; the bottle is shaken, covered with glass, and set aside. To the third bottle add 5 drops of 1 per cent alkaline permanganate, and shake.

(**B**) **Preparation of Benzene.** Prepare benzene by heating a mixture of 5 g of sodium benzoate with 4 g of soda lime in an ignition tube fitted with a cork and with a delivery tube leading into a test tube immersed in cold water. Note the characteristic odor of the distillate. Devise a test for proving the presence of benzene. Consult the instructor and perform the test.

Experiment 13

UNSATURATED HYDROCARBONS (ALKENES) PREPARATION OF CYCLOHEXENE AND AMYLENE

Introduction. When a saturated hydrocarbon like ethane, CH_3CH_3, is passed over a nickel oxide catalyst heated to 800°, hydrogen is removed (dehydrogenation) and ethene, CH_2CH_2, is one of the products:

$$\underset{\text{Ethane}}{H_3C{-}CH_3} \xrightarrow{-H_2} \underset{\text{Ethene}}{H_2C{=}CH_2} + H_2$$

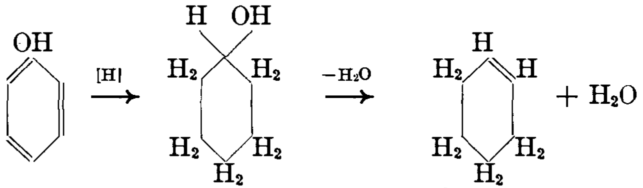
Although the dehydrogenation proceeds further and ethene cannot be prepared by this reaction, it illustrates the generic relations. Ethene contains less hydrogen atoms than the saturated hydrocarbon ethane and therefore is considered as *unsaturated.* Further, ethene is the first member of *alkenes* or *olefins,* a class of unsaturated hydrocarbons represented by the general formula C_nH_{2n}.

The dehydrogenation of saturated hydrocarbons to yield alkenes is not easily accomplished under ordinary laboratory conditions. A general method which can be used is the dehydration of alcohols:

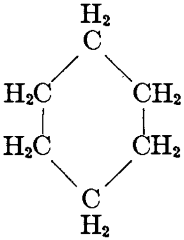
$$CH_3CH_2OH \xrightarrow[\text{Heat}]{\text{Catalyst}} CH_2{=}CH_2 + H_2O$$

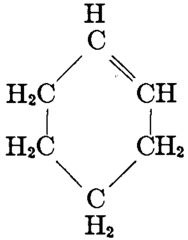
For the preparation of small amounts of olefin, sulfuric acid, phosphoric acid, or zinc chloride may be used as catalysts. For larger amounts of olefins the alcohol is dehydrated by passing it over alumina heated at 200–300°. The use of sulfuric acid as a dehydrating agent involves the possibility of a number of side reactions, of which oxidation is the most important, and causes troublesome frothing. Phosphoric acid is preferred when it is desired to keep oxidation at a minimum. Ordinary (syrupy) phosphoric acid contains 15 per cent of water; hence it must be first dehydrated by heating in an open vessel.

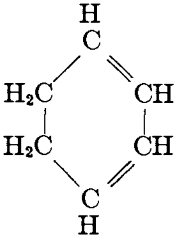
Primary alcohols, RCH_2OH, dehydrate at higher temperatures than secondary, R_2CHOH, and tertiary, R_3COH. The present experiment illustrates the preparation of olefines from cyclohexanol (a secondary alcohol) and *tert*-amyl alcohol. Cyclohexanol is a cyclic alcohol which may be considered to be derived from cyclohexane by replacement of one hydrogen atom by a hydroxyl group. Industrially it is prepared by hydrogenation of phenol:

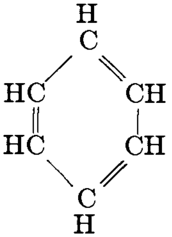

Cyclohexene

The preparation of cyclohexene is of interest because it is related to cyclohexadiene and cyclohexatriene (benzene). The structural relationships are shown by the following formulas:


Cyclohexane

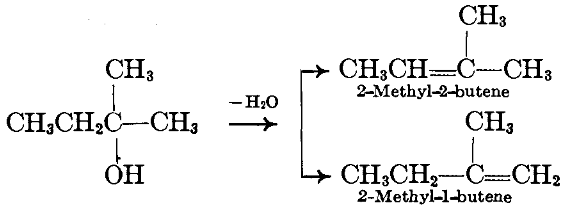

Cyclohexene


Cyclohexadiene


Cyclohexatriene (Benzene)

Cyclohexane can be dehydrogenated to benzene and also benzene can be hydrogenated to cyclohexane, but these reactions cannot be controlled to give the intermediate olefin and diene. Cyclohexene and cyclohexadiene exhibit the characteristic addition reactions of unsaturated hydrocarbons. Cyclohexatriene, or benzene, shows unexpected properties in that it exhibits saturated properties under ordinary conditions and gives some of the addition reactions of unsaturated hydrocarbons with extreme difficulty.

The dehydration of *tert*-amyl alcohol gives at least two isomeric pentenes (amylenes):


2-Methyl-2-butene

2-Methyl-1-butene

Other isomeric pentenes may be formed by isomerization of the two olefins. If the heating is slow and careful the main product is 2-methyl-2-butene.

Drying agents. When the alcohol is distilled slowly with a small amount of sulfuric acid, the condensate consists of olefin, unchanged alcohol, water, and small amounts of impurities. An inorganic salt, usually sodium chloride, is added to decrease the solubility of the organic compounds in the water present and to inhibit the formation of an emulsion. The crude olefin separates on top of the aqueous layer, and by use of the proper apparatus the latter is withdrawn. If an attempt is made to distill the olefin, the distillate will be milky or cloudy; it can be shown by appropriate tests that the turbidity is due to the presence of small amounts of water dispersed in the olefin. Addition of a small piece of fused calcium chloride to the distillate will remove the water. Since the presence of water during the distillation may give rise to reactions, the practice is to dry organic liquids before distillation.

The selection of the drying agent involves consideration of the chemical properties of the organic substance and of the inorganic compound used to remove the water. For example, in the case of the olefin, calcium chloride was used, but this drying agent cannot be employed to remove water from an alcohol since it combines with alcohols. Calcium chloride acts as a drying agent only if it is in anhydrous form. In such state, if it is brought in contact with an organic liquid which contains a small amount of water it will remove it to form a hydrate (ultimately the hexahydrate $CaCl_2 \cdot 6\,H_2O$). In the same manner calcium chloride combines with alcohols to form molecular compounds. For example, with methyl and ethyl alcohols it forms the compounds $CaCl_2 \cdot 4\,CH_3OH$ and $CaCl_2 \cdot 4\,C_2H_5OH$.

The common drying agents and their uses are listed in the Appendix, pages 357–358. Suffice it for the present discussion to state briefly the factors which must be taken into consideration in selecting a drying agent. These are: (1) The drying agent must not combine chemically with the organic compound. (2) It should not have any catalytic effect in promoting reactions of the organic compound—for example, polymerizations, auto-oxidations, and other similar reactions. (3) It should have a quick and effective drying capacity—for example, the alkali and alkaline earth sulfates (particularly Na_2SO_4, $MgSO_4$, and $CaSO_4$) have good drying capacities. Of these magnesium sulfate is most efficient. This may be due to the fact that magnesium sulfate forms a heptahydrate below 48° and sodium sulfate a dihydrate below 33°. (4) The drying agent should be inexpensive—for example, one drying agent may cost seventy cents and another twenty cents per pound.

Beside anydrous calcium chloride and the anhydrous sulfates, a number of other inorganic compounds are used for drying agents. Among the more common are the solid alkali hydroxides, NaOH and KOH, the alkali carbonates, particularly potassium carbonate, and the oxides of barium and calcium. The student should read the section on drying agents on pages 357–358.

(**A**) **Cyclohexene** (**Sm.**). Arrange a distilling setup as shown in Figure 25. Put 5 ml of cyclohexanol and 10 drops of concentrated sulfuric acid into the distilling tube and mix by rotating. Place the thermometer so that it reaches nearly to the bottom of the tube, and add 2 small boiling stones the size of grape seeds. The receiving test tube (six-inch), is immersed in a beaker of cold water. Heat with a small micro burner until the temperature reaches 130°. By moving the burner to and fro, the temperature is held at 130–140°, until the end of distillation. Add 2 ml of saturated salt solution and 1 ml of 10 per cent sodium carbonate solution directly to the contents of the receiving tube, and rotate to mix the contents. Read carefully the directions given at the end of the experiment for the separation of two immiscible liquids. Use the semimicro technic. Prepare a separatory stopper to fit the six-inch test tube. Insert it and remove the lower aqueous layer. The crude cyclohexene remains in the tube with about a drop of aqueous solution of salt.[1] Add 0.5 g of anhydrous calcium chloride and allow tube to stand for ten minutes. Distill directly from the same tube and collect the portion which boils at 80–85°. The yield is about 2.5–3.0 g.

(**B**) **Cyclohexene** (**M.**). Place 50 ml of cyclohexanol and 5 ml of concentrated sulfuric acid in a 250 ml distilling flask, and rotate it so as to mix the contents. Connect the flask with a condenser attached to a well-cooled receiver (ice-bath). The stopper of the distilling flask is provided with a thermometer which reaches almost to the bottom of the flask. Two boiling stones are added, and heat is applied until the temperature reaches 130°. The reaction mixture is maintained at a temperature of 130–140° (preferably 130–135°) until the end of distillation.

To the distillate add 10 ml of saturated salt solution and 2 ml of 10 per cent solution of sodium carbonate. Shake thoroughly and transfer to a separatory funnel. Separate the lower aqueous layer

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[1] The last drop of the aqueous layer may be removed by a pipette with a capillary thread. See appendix, "Pipette for Semimicro separation of immiscible liquids," pp. 359–360.

and pour the crude olefin through the mouth of the funnel into a small flask. Add about 4–5 g of calcium chloride and allow to dry for about 15–20 minutes, shaking the flask from time to time. Pour the dry hydrocarbon into a distilling flask and allow the solid layer of calcium chloride to remain back. Add two boiling stones and distill from a water bath. Collect the fraction which boils at 80–85° in a tared bottle. The yield is 25–30 g.

(C) **2-Methyl-2-Butene (Amylene) (Sm.).** Add a few drops of *tert*-amyl alcohol to 2 ml of bromine solution in carbon tetrachloride or bromine water. Shake, and note if there is any immediate decolorization.

Place 6 ml of the alcohol in an eight-inch tube, immerse in a beaker of cold water, and add *carefully* 1 ml of concentrated sulfuric acid. Rotate the tube so as to mix the contents. After a minute add another milliliter of the acid. Rotate the tube as before. Take the tube out, and allow it to stand for a few minutes. Note the layer that separates out on the top. By means of a pipette dropper or capillary pipette, remove a few drops and test with 2 ml of bromine solution and also with potassium permanganate solution. The olefin formed in this test tube experiment may be separated and purified. For this, insert the separatory stopper in the tube as directed in the section on separation of two immiscible liquids at the end of this experiment. Separate the lower acid layer and allow the olefin to remain in the tube. Raise the stopper cautiously, and add 3 ml of saturated salt solution and shake for a minute. Close the clamp of the separatory stopper, and pressing the stopper with one finger invert the tube, allow to settle, and withdraw the aqueous layer. Repeat the washing, using 3 ml of 5 per cent sodium carbonate solution. Withdraw the aqueous layer and add the olefin directly to a distilling tube. Add 0.5 g of anhydrous calcium chloride; shake tube for one minute; then arrange thermometer, and delivery tube for distillation. Allow to stand for ten minutes, and then heat carefully by means of a water bath, collecting in a weighed tube the portion which boils at 36–40°. It is well to have the receiving tube in a small beaker containing ice water. The hydrocarbon is very volatile and *inflammable* and therefore *care* must be exercised.

(D) **2-Methyl-2-Butene (Amylene) (M.).** Arrange the apparatus as for fractional distillation, as shown in Figure 27. Place 20 ml of water in a 200–250 ml flask and add slowly 15 ml of concentrated sulfuric acid, cooling in tap water after each addition. When the temperature of the acid mixture is 30°, add slowly 40 ml (32.4 g) of *tert*-amyl alcohol. Add two boiling stones and connect the flask for distillation. Place a small burner under it and regulate the flame so that the temperature at the top of the column does not exceed 40°. The receiving flask is immersed in an ice-water mixture. When toward the end the temperature rises to 50° discontinue the distillation. Treat the distillate with about 10 ml of five per cent sodium carbonate solution, shake thoroughly and transfer to a separatory funnel. Separate the lower aqueous layer and pour the crude olefin through the mouth of the funnel into a small Erlenmeyer flask. Add about 2 g of anhydrous calcium chloride and allow to dry for about 15 to 20 minutes, shaking the flask from time to time.

Transfer the dried hydrocarbon into a distilling flask so that the solid layer remains in the Erlenmeyer flask. Add two boiling stones and distill from a water bath. Collect in a weighed flask or bottle the portion boiling at 36–40°. The hydrocarbon is very volatile and *inflammable*, and *care* must be exercised.

(E) Tests for Unsaturation. (1) To 0.2 ml (2–3 drops) of cyclohexene or amylene add 1 ml of 0.05 per cent aqueous potassium permanganate solution and shake. Repeat, using the same amount of a saturated hydrocarbon (cyclohexane, hexane or pentane). Assume that the unsaturated hydrocarbon in decolorizing the permanganate underwent oxidation to a dihydroxy derivative and then to a carboxylic acid. The last stage involves fission of the carbon-to-carbon bond. Insert in your note book the equations for these changes, giving the names for all products.

(2) To 2 ml of one per cent solution of bromine in carbon tetrachloride add 0.2–0.3 ml (3–4 drops) of cyclohexene or amylene. Repeat the test, using a saturated hydrocarbon. Explain the results and insert in your notebook the equation for each reaction.

(F) Separation of Two Immiscible Liquids (Sm.). The separation of two immiscible liquids is a common procedure in the organic laboratory, since most organic liquids are immiscible with water. For the separation of small quantities (semimicro) a *separatory stopper* is used. Stoppers are made by each student to fit six- and eight-inch test tubes, in accordance with the following directions:

(1) Separatory Stopper for 6-Inch Tube. Cut a piece of 4-mm glass tubing 220 mm long and rotate each end over the flame until the opening is reduced to a fifth of the original size. Insert the tube through one of the holes of a No. 2 rubber stopper so that the latter fits tightly in the mouth of the tube, and the end of the glass tubing just fails to touch the bottom. Insert the other end into a 30-mm piece of 3-mm rubber tubing. Through the other hole of the rubber stopper insert a piece of glass tubing 40 mm long, so that it just reaches the other side of the hole but does not protrude through it. This short glass tube is connected through a piece of 3-mm rubber tubing 30 mm in length with the delivery tube. The delivery tube is a piece of glass tubing 35 mm in length

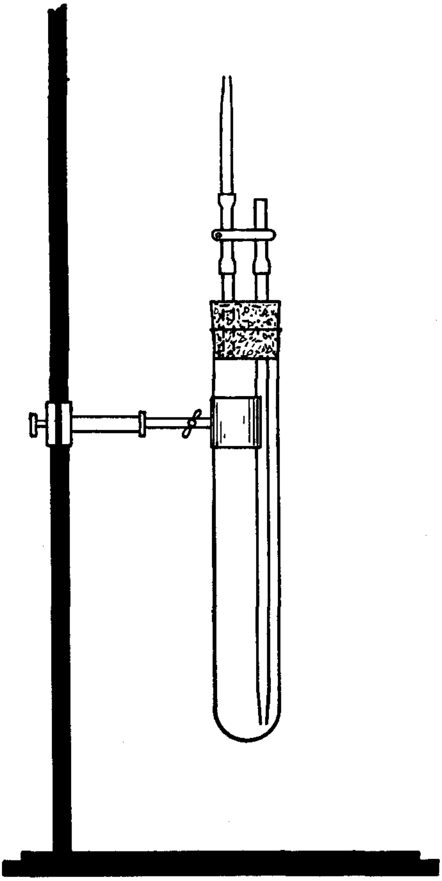


Fig. 41. Semimicro apparatus for separation of two immiscible liquids

and drawn out into a capillary, similar to that used for washing bottles. Finally a screw clamp is placed at the middle of two pieces of rubber tubing. A pinchcock clamp may be used, if the capillary of the delivery tube is drawn out so that the opening is smaller. The complete assembly of the separatory tube is shown in Figure 41.

(2) **Separatory Stopper for 8-Inch Tube.** Use glass tubing 4 mm in diameter. The long piece of glass tubing is 280 mm in length. The short pieces are about 40 mm in length. A two-hole No. 5 rubber stopper is used. The other directions are the same as those for the separatory stopper for six-inch tubes.

(3) **Separation by Means of Separatory Stopper.** Figure 41 shows diagrammatically the separatory stopper inserted into a tube, thus

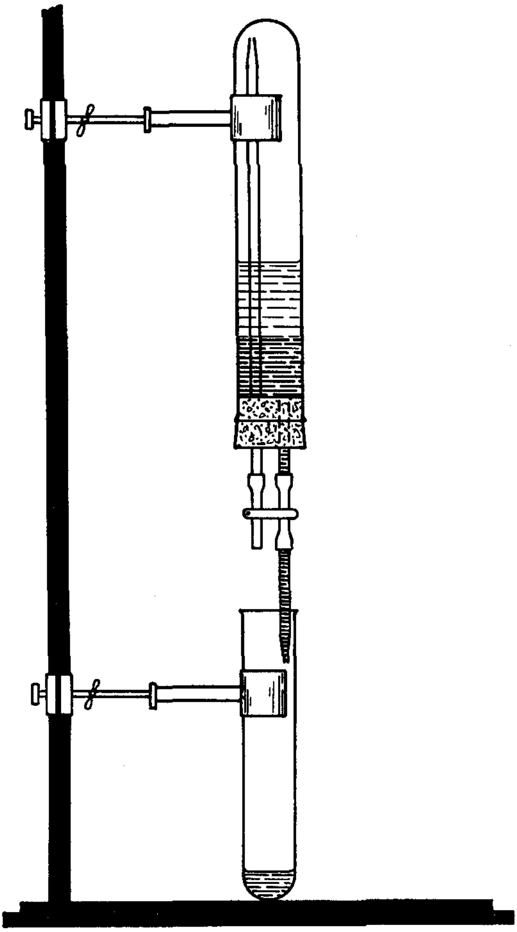


Fig. 42. Semimicro separatory tube in use

completing the separatory tube. Figures 42 and 43 show the separatory tube in use for the separation of two immiscible liquids. The separatory stopper may be inserted in any tube which contains two immiscible liquids to be separated. In order to separate the two layers the screw clamp is closed tightly and the tube is inverted and so held that the rubber stopper rests between two fingers of the left hand with the thumb pressing lightly upward upon the lip of the tube. The delivery capillary tube is placed inside a clean test tube, and the screw clamp is operated with the right hand. When the interface of the two layers nearly reaches the rubber stopper, the flow is diminished, and when the junction of the two layers appears in the capillary tube the flow is stopped. The separatory tube is placed in an upright position, still pressing on the rubber stopper. With a slow sidewise motion loosen the stopper so as to release any pressure. Raise the stopper about

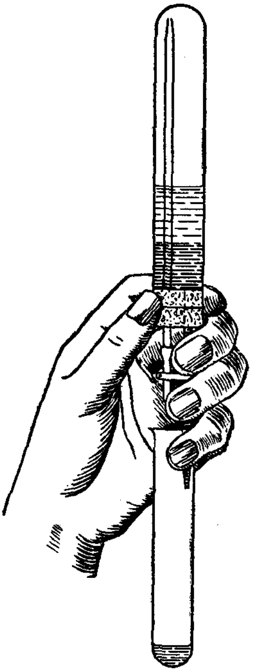


Fig. 43. Operation of semimicro separatory tube with one hand

1 mm, and loosen the screw clamp so as to return the liquid in the delivery tube to the liquid within the test tube. Care should be exercised not to raise the stopper too far and not to tilt it so the liquid within the capillary tube will fall outside of the test tube. Since the amounts handled in semimicro work are small, loss of a few drops is serious. It is suggested that the student practice a little with 3 ml each of water and benzene, or water and kerosene. The separatory stoppers, after use, are cleaned and placed in a box so they may be always ready.

(G) **Separation of Two Immiscible Liquids** (M.). For the separation of liquids in volumes of 25 ml and above, separatory funnels shown in Figure 1(*b*) (page 9) are used. For small volumes a funnel with a short stem cut obliquely is advised. For larger volumes the 125 ml and 250 ml sizes are most generally used by beginners. The liquid is poured into the separatory funnel with the aid of an ordinary (Bunsen) funnel. The funnel is stoppered and allowed to stand for some minutes until the two layers have separated. The stopper is removed or loosened so as to allow air to enter, then the stopcock is slowly turned and the lower layer is allowed to run into the receiver below the funnel. The stopcock is closed when most of the lower layer has been removed. The funnel is closed by replacing the stopper and then given a gentle rotatory motion so as to force downward such drops of the heavier layer as adhere to the sides. The stopcock is turned slowly until the last drop of the heavier layer has been removed. The lighter layer is then poured through the mouth of the funnel into another flask. If care is used, any drops of the heavier layer which may have been missed will remain in the separatory funnel. The separatory funnel is cleaned, the stopcock is carefully taken out, dried, greased with a very small amount of stopcock grease or vaseline, and replaced.

Experiment 14

THE PREPARATION OF ACETYLENE
(Ethyne)

Introduction. Acetylene has the empirical formula C_2H_2. It shows a greater unsaturation than ethylene, in that it can add four univalent groups to each carbon atom. This unsaturation is indicated by a triple bond between the two carbon atoms: $HC\equiv CH$. Acetylene is produced in the thermal decomposition of many hydrocarbons. Of theoretical interest is its formation from hydrogen and carbon in the electric arc. It is prepared industrially by the pyrolysis of methane, and by the action of water on calcium carbide. The last method is employed for preparation of small quantities in the laboratory:

$$CaC_2 + 2\,H_2O \longrightarrow Ca(OH)_2 + HC\equiv CH$$

The carbides of the metals of Group I and Group II in the Periodic system (except beryllium) also react with water to give acetylene. Beryllium and aluminum carbides, Be_2C and Al_4C_3, and a few carbides of group IV yield methane on hydrolysis. A number of carbides, such as those of iron, manganese, and other heavy metals, do not hydrolyze. Recall the relation of iron carbide (cementite) to the properties of cast iron and steel. Commercial calcium carbide contains small amounts of phosphides, sulfides and other impurities, and therefore the acetylene produced by hydrolysis of the carbide is impure. Pure acetylene may be obtained by the action of an alcoholic alkali on ethylene bromide. This method is useful in the preparation of the higher homologs of acetylene:

$$\underset{\text{1, 2-Dibromopropane}}{CH_3CHBrCH_2Br} + 2\,KOH \longrightarrow \underset{\text{Propyne}}{CH_3C\equiv CH} + 2\,KBr + 2H_2O$$

Although acetylene adds four monovalent atoms while ethylene adds only two, it does not follow that the greater unsaturation is accompanied by a more rapid rate of addition. As a rule, the activity of the *triple bond*, measured by the rate of addition, is lower than the activity of the double bond. Acetylene forms explosive mixtures with air, and care should be exercised by the student to **keep the generator away from all flames.**

(A) **Generation of Acetylene.** Place 10 g of technical calcium carbide in a 125 ml distilling flask. Insert into the neck of the flask a rubber stopper through which passes a dropping funnel. An eight-inch separatory tube, described on page 115, can be used in place of the separatory funnel. This arrangement is shown in Figure 51, page 184. Connect the side tube of the flask for the collection of gas by water displacement. A bottle may be used instead of a tube. Disconnect the side arm rubber connection and allow four to five drops of water to fall from the funnel on the lumps of calcium carbide. After the acetylene generated has displaced all or most of the air from the flask, the generator is ready for use. Connect the side arm with the delivery tube and allow water to fall drop by drop until all the water has been displaced from the tube. Disconnect the tube, cork it, and place it aside. Use the delivery tube in order to pass acetylene into the following solutions contained in test tubes.

(B) **Action of Acetylene on Permanganate.** Pass acetylene (not too rapidly) through 5 ml of 0.05 per cent potassium permanganate solution which has been acidified with 1 ml of dilute sulfuric acid. Note change in color. Insert in your note book the probable changes undergone by acetylene and the permanganate ion.

(C) **Action of Acetylene on Bromine.** Pass acetylene through 5 ml of bromine water. Note the changes. Aside from the color change, what other evidence is there for the reaction?

(D) **Formation of Metallic Acetylides.** Pass acetylene gas for one minute into 5 ml of each of the solutions of ammoniacal silver nitrate and ammoniacal cuprous chloride, prepared according to directions given below. Note the character of the precipitate. Disconnect the flask, and dispose of the material in the flask, according to directions given by the instructor.

Wash each precipitate once with water by decantation. Filter a small portion, and place a pinch of the solid acetylide on the end of a wire or spatula and heat it in the flame. Punch a hole in the filter paper, and wash the remaining metallic acetylide into a test tube. Flush the filter paper with tap water before throwing it into the residue jar. Silver and copper acetylides are *very explosive* when dry. The suspension of acetylides is allowed to settle and the water is decanted. Add 5 ml of dilute nitric acid in each tube. Warm gently and note the gas evolved. Replace the tube in the rack until all the acetylide is decomposed.

The ammoniacal silver nitrate is prepared by the addition of ammonium hydroxide to 2 ml of 0.1 N silver nitrate until the precipitate which forms just redissolves. Sufficient water is added to bring the volume of the solution to 5 ml. The ammoniacal cuprous chloride is prepared by dissolving 0.1 g of the copper halide in 1 ml of concentrated aqueous ammonia and sufficient water to bring the volume of the solution to 5 ml. If cuprous chloride is not available, heat for two minutes 0.1 g copper oxide with 0.1 g copper turnings and 2 ml dilute hydrochloric acid. Pour off the liquid into another test tube, and cork. Cool and then add 3–4 ml of a mixture of equal volumes of concentrated ammonia and water.

(**E**) **Odor and Combustion of Acetylene.** Observe the odor of the acetylene in the tube which was set aside in part (A). Ignite the sample at a burner, keeping the tube downwards so as to prevent the soot from getting out of the tube.

Experiment 15

THE STUDY OF AROMATIC HYDROCARBONS

Introduction. Benzene is obtained commercially by the fractional distillation of coal tar, derived from the carbonization of coal. Commercial benzene contains small amounts of water, toluene (methyl benzene), and thiophene (a heterocyclic compound having sulfur in the molecule). It was shown in Experiment 12 that benzene is formed by decarboxylation of benzoic acid. Its relation to cyclohexene and cyclohexadiene has been pointed out in Experiment 13. The dehydrogenation of cyclohexane to benzene establishes its cyclic structure. It would follow, then, that benzene as a cyclohexatriene should exhibit extraordinary reactivity and lack of stability. Although cyclohexadiene is unstable and undergoes addition reactions, the removal of two hydrogen atoms from its molecule is accompanied by some change and a *stability*, characteristic of saturated hydrocarbons, results. Benzene does not show under ordinary conditions the characteristic addition properties expected from its unsaturated structure. With bromine, nitric acid, and sulfuric acid, benzene forms *substitution* products. Benzene and its derivatives react with nitric acid at slightly higher than room temperature to give oily or crystalline compounds. In the same manner, benzene and other aromatic hydrocarbons react with sulfuric acid to give substitution products easily soluble in water. These two reactions may be used to distinguish benzene and its homologs from the other hydrocarbons. The object of this experiment is to illustrate some of the characteristic aromatic properties.

(A) **Purity of the Sample of Benzene.** If a refractometer is available, determine the refractive index of a sample of commercial benzene from the shelf. Devise a test to prove presence or absence of water.

The presence of thiophene is made known through a color reaction with isatin, a compound related to indigo. The isatin reagent is prepared by dissolving 1 g of isatin in 100 ml of concentrated sulfuric acid. It is best to prepare a smaller amount of solution as needed. Add to 3 ml of commercial benzene 1 ml of isatin reagent.

Shake for a minute and allow to stand. A blue-green color indicates the presence of thiophene.

(**B**) **Tests for Unsaturation.** (1) Add 1 ml of benzene to 2 ml of 1 per cent solution of bromine in carbon tetrachloride and allow to stand for a few minutes. (2) Shake 1 ml of benzene with 2 ml of 0.05 per cent potassium permanganate solution and allow to stand for 5 minutes.

(**C**) **Nitration Test.** Place in a 30 or 50 ml Erlenmeyer flask 6 ml of a mixture of equal volumes of concentrated nitric acid and concentrated sulfuric acid. Add 2 ml of benzene and shake for a minute. In another flask treat in the same manner 2 g of naphthalene. Place flasks in a water bath and warm at 50° for 10 minutes. Shake the mixture frequently, using care that no acid is splattered. *Wear your goggles.* After the mixtures are heated pour each into 50 ml of water and note whether any yellow oil or solid separates out. The nitro compound is separated and handed to the instructor. Compare the nitronaphthalene with the original compound. Record in your note book the observations and explanation.

(**D**) **Sulfonation.** Place 2 ml of concentrated sulfuric acid in each of two test tubes. To the first add one gram of benzene, and to the second add one gram of naphthalene. Heat slowly both tubes in an oil bath so that the temperature of the bath rises to 150° after 30 minutes. Allow to cool, and then add each mixture to 25 ml of water contained in a small beaker. Note whether the product dissolves. Record in your note book your observations and their explanation.

Experiment 16

PREPARATION OF HYDROCARBONS BY THE USE OF THE GRIGNARD REAGENT

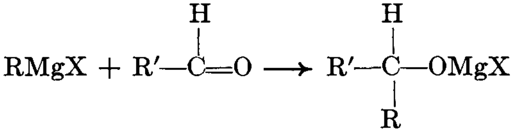
(Toluene from Benzyl Chloride)

NOTE: This experiment is better adapted to semimicro technic. The macro method may be used but difficulties are encountered by beginners. The use of Grignard reagent by the macro method is described in Experiment 36. The semimicro technic permits the introduction of the Grignard reagent early. Besides its use for the preparation of a hydrocarbon in the present experiment, it is used in Experiment 23 for the preparation of carbinols and Experiment 36 for the preparation of carboxylic acids.

Introduction. The preparation of a hydrocarbon by use of the Grignard reagent illustrates one application of reactive compounds having a metallic atom directly attached to the carbon. The preparation of the Grignard reagent involves the reaction of magnesium metal in the presence of dry ether with an organic compound containing a halogen. The magnesium attaches itself to the carbon, while the halogen which was previously attached to the carbon becomes attached to the magnesium:

$$\mathrm{RCH_2X + Mg \xrightarrow{(C_2H_5)_2O} RCH_2MgX}$$

The Grignard reagent is very reactive. The group MgX can be replaced by a hydrogen atom giving a hydrocarbon, by a hydroxyl group, OH, to give an alcohol, and by a carboxyl group to give an acid. Generally the Grignard reagent, RMgX, reacts as R and as an MgX group. The radical of the Grignard reagent attaches itself to the carbon atom of the functional group with which it reacted, while the MgX attached itself to atoms more negative than carbon:



$$\mathrm{RMgX} + \mathrm{R'{-}\overset{H}{\overset{|}{C}}{=}O} \longrightarrow \mathrm{R'{-}\underset{\underset{R}{|}}{\overset{H}{\overset{|}{C}}}{-}OMgX}$$

In the present experiment the addition of water is sufficient to generate the hydrocarbon. The MgX group unites with a hydroxyl ion to form basic magnesium halide. The hydrocarbon passes into the ether layer. In order to separate the layers, it is advisable to dissolve the basic magnesium halide. This is accomplished by addition of dilute hydrochloric acid:

$$\mathrm{RMgX} + \mathrm{HOH} \longrightarrow \mathrm{R{-}H} + \mathrm{Mg(OH)X}$$

The preparation of the Grignard reagent involves extraordinary cleanliness and care. In particular, all substances and apparatus used must be free from moisture. Absolute ether must be used. For its preparation commercial ether is first shaken with calcium chloride to remove part of the water and alcohol. The ether is then filtered into a flask containing metallic sodium and allowed to stand overnight. The next day the ether is distilled from the excess sodium into a flask protected from moist air by a calcium chloride tube. For details see pages 156–157.

(A) **Preparation of Toluene** (Sm.). Clean an eight-inch tube well, dry it by heating over a flame to drive all the moisture out. Cork the tube while hot, and allow to cool.

Place 0.7 g of magnesium in the tube and arrange apparatus as shown in Figure 44. The micro condenser is wiped off with a perfectly dry cloth; then the cork, which holds the condenser and the calcium chloride tube, is inserted in the mouth of the tube. The cork has two holes and fits tightly into the mouth of the tube. Add 4.2 g of benzyl chloride in 10 ml of absolute ether and a crystal of iodine, by raising the cork momentarily. The reaction starts within a few minutes, and it requires 10–15 minutes for completion. If the reaction is too slow in starting, raise a small beaker containing warm water (50–60°) over the outside of the tube for about a minute. If, after the color of iodine disappears, the reaction proceeds very slowly and requires constant heating, moisture is present in the apparatus or in the reagents.

When the reaction has ceased and practically all the magnesium has reacted, immerse the tube in a beaker containing water and ice. Add very slowly 5 ml dilute hydrochloric acid prepared by the addition of 3 ml concentrated acid to 5 g of ice. The dilute acid can be added by means of a pipette dropper, by removing the calcium chloride tube and using the opening to insert the dropper. When the decomposition of the reagent is complete, the aqueous layer should be clear. If it is milky or cloudy, or if undissolved magnesium is present, add a few drops of concentrated hydrochloric acid and allow the reaction to proceed for a few minutes.

Insert the separatory stopper in the reaction tube. *Be sure* that

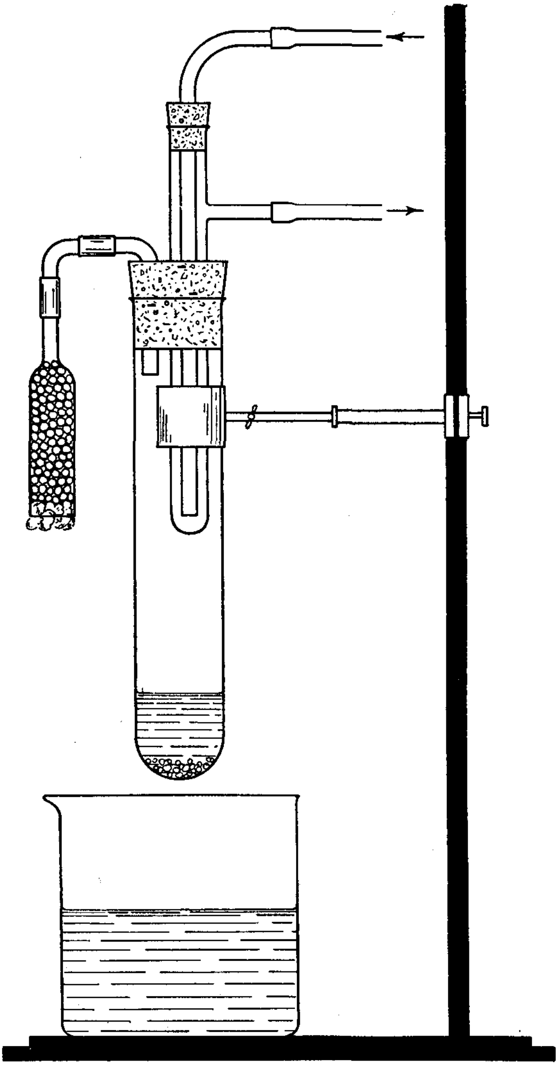


Fig. 44. Semimicro apparatus for Grignard reaction

(The calcium chloride tube is slightly enlarged; the actual diameter being one-third that of the large test tube.)

all the magnesium is dissolved, else the hydrogen evolved will force the stopper out during the separation. The ether layer should have about the volume of 10 ml. Since some ether is lost by evaporation it is advisable to add 5 ml of ordinary ether before separation. Close the screw clamp, place the index finger on the stopper and shake the tube gently. While the stopper is held in place, release the pressure slowly by turning the clamp.

Caution: Keep away from flames, and point the delivery tube away from your face, since any droplets that may be in the delivery tube will be thrown upwards.

Close the screw clamp, invert the tube and separate the ether layer as directed on pages 115–117. The ether layer is allowed to remain in the reaction tube. Add about 0.2 g of calcium chloride to the ether mixture and allow to stand for 15 minutes. Most of the ether is removed by distilling directly from the large tube (see Figure 39). When the amount of liquid in the tube is about 5 ml, it is transferred to a regular small distilling tube and fractionated (Figure 25). The fraction which boils at 108–112° is collected. The yield is 1.0–1.3 g. If a refractometer is available determine the refractive index of your product.

Experiment 17

THE REACTIONS OF HYDROCARBONS

NOTE: This experiment may be used as a laboratory demonstration by the instructor. The use of molecular bromine in section (2) of part (B) and of fuming sulfuric acid in section (2) of part (D) is recommended only when students are working under strict supervision.

Introduction. Some of the general methods used for the preparation of hydrocarbons were illustrated in experiments 10 to 16. The present experiment is designed to study a number of the characteristic reactions of hydrocarbons and differences in their rates of reaction towards the same reagent. The student should try to record the data of his observation after each test and later write the explanation and equations for each reaction.

The hydrocarbons are classified into three subgroups on the basis of their reaction properties. These subgroups are: *saturated, unsaturated,* and *aromatic* (benzene) hydrocarbons. The unsaturated hydrocarbons exhibit the greatest reactivity. They form addition compounds with many reagents, are easily oxidized, and form complex compounds by self-addition (polymerization). Saturated hydrocarbons are inert to most reagents at room temperature and require, as a rule, high temperatures for reactions involving the replacement of hydrogen atoms with a functional group such as SO_3H, NO_2, etc. Aromatic hydrocarbons undergo substitution more easily than do saturated hydrocarbons, particularly with nitric and sulfuric acid.

(A) **Oxidation by Aqueous Permanganate.** To 100 ml of water in an Erlenmeyer flask add 0.05 g of potassium permanganate and 5 g of sodium carbonate. Warm until solution is complete. Cool to room temperature and add to each of 11 test tubes 5 ml of the alkaline permanganate solution. Ten of the test tubes are marked (by marking pencil or label) each with a number corresponding to the number of the following hydrocarbons to be added: n-*pentane, isopentane, amylene,* n-*hexane, cyclohexane, cyclohexene, benzene, toluene, naphthalene,* and *triphenylmethane*; the eleventh tube, to which nothing is added, serves as a control. Add 0.4 ml (5–6 drops) if the hydrocarbon is a liquid. For naphthalene and triphenylmethane add 0.3–0.4 g of the solid. Shake the tube vigorously for 5 seconds and observe any fading within one minute in the color of the permanganate by comparing it to the eleventh tube. Shake the tubes which did not show decolorization of the permanganate solution 3–4 times in the period of ten minutes and examine the color at the end of this period. Enter the data in your notebook in tabular form (see Questions at the end of this experiment).

(B) Action of Bromine. *Use goggles throughout this part.*

(1) Prepare 11 test tubes as above and fit each with a cork. Place in each the proper amount of each hydrocarbon as directed in section (A); then add to each 2 ml of one per cent bromine solution in carbon tetrachloride. Examine after one minute. Expose to the light by arranging the tubes in a test tube rack and placing it near a window or electric light bulb. Allow to stand for 15 minutes in the light, then examine the color of the bromine solution again, comparing the color of each with the control.

(2) For this test, use *n*-hexane, cyclohexane, benzene, and naphthalene. Place in separate test tubes 1 ml of each of the hydrocarbon and add **carefully** one drop of bromine and a very small piece of iron wire or a few pieces of clean iron filings. Place the tubes in a water bath at 60° in the hood. Observe after ten minutes. Blow across the mouth of the test tube to detect hydrogen bromide, and add 5 ml of water. The organic halide will settle in the bottom of the tube.

(C) Action of Nitric Acid. *Use goggles throughout this part of the experiment.* In ten separate test tubes place 0.5 ml of each of the hydrocarbons as in section (A). Place the test tube rack holding the tubes in the hood or at the end of the bench near the water trough, so that it is away from you as well as from other students.

In an eight-inch test tube place 5 ml of concentrated nitric acid, and then add very slowly, with cooling, 5 ml of concentrated sulfuric acid. Cool to room temperature and pour carefully into a small beaker.

Use a calibrated pipette dropper to withdraw about 1 ml of the mixture and add it all at once to the tubes containing the hydrocarbons.

Caution: When adding the acid mixture to the samples of the unsaturated hydrocarbons, *step back at once,* since a vigorous reaction takes place.

Place the tubes which do not show any apparent reaction within one minute in a bath at 40–50° for 15 minutes. Shake the contents of the tubes cautiously, keeping the mouth of the tube away from you and other students. Add the contents of the tubes to 25 ml of water in a beaker. Note any evidence of nitration, and record your observations.

(D) **Action of Sulfuric Acid.** (1) In each of 10 test tubes place the proper amount of hydrocarbon as in section (A). Add to each tube 1 ml of concentrated sulfuric acid. Use the same *precautions* as in section (C) in adding the acid to unsaturated hydrocarbons. Shake those tubes that do not show any apparent sign of reaction and note whether the hydrocarbon has dissolved. Heat in a bath at 60–70° for 10 minutes and examine again. Record your data.

(2) **Sulfonation by Means of Fuming Sulfuric Acid.** (Demonstration) Use *n*-hexane, cyclohexane and benzene. Place 0.5 ml of each hydrocarbon in separate marked test tubes. Add about 1 ml of fuming sulfuric acid (20–25 per cent SO_3), and shake *cautiously* from time to time over a period of 15 minutes. Add the contents of each tube *very slowly and carefully* to a 150 ml beaker containing 25–30 ml of water. When all the acid mixture has been added stir the contents of the beaker, and then note whether a layer of hydrocarbon separates on the top of the diluted acid. If the hydrocarbon is completely sulfonated, the product is soluble. Record your data.

(E) **Hydration of an Unsaturated Hydrocarbon.** For this experiment use either amylene or cyclohexene. Recall how these hydrocarbons were prepared by dehydration of the alcohol. In the present experiment the reaction will be reversed. Note that the same catalyst is used but under different conditions, which permit the displacement of the equilibrium in the desired direction:

$$C_2H_5(CH_3)_2COH \rightleftharpoons (CH_3)_2C = CHCH_3 + H_2O$$

Place in an eight-inch tube 5 ml of the unsaturated hydrocarbon and 5 ml of cold 70 per cent sulfuric acid. Cool the mixture in tap water, place a solid rubber stopper in the mouth of the tube, and shake with cooling until the hydrocarbon dissolves and a clear liquid results. Add 6 g of ammonium sulfate dissolved in 8 ml of water. Insert the separatory stopper, and remove the aqueous acid layer. The liquid which is left in the reaction tube can be tested with bromine water or alkaline permanganate to show that it is not an olefin. If it is desired to purify the alcohol, add 1 g of anhydrous calcium sulfate and shake from time to time over a period of fifteen minutes. Pour the crude alcohol into a distilling tube. Heat with a small flame and collect the proper fraction. If amylene is used, and the water is not completely removed by the drying agent, a constant boiling mixture will be formed which boils at 87°.

The fraction which boils at 96–104° is collected. For cyclohexanol the fraction which boils at 157–164° is collected.

(F) Polymerization of an Unsaturated Hydrocarbon. Place 8 ml of amylene in an eight-inch test tube provided with a solid rubber stopper. Place the tube in an ice-salt mixture and cool until the temperature falls below −5°. Similarly cool in another tube 6 ml of 75 per cent sulfuric acid. Add the acid to the olefin, stopper the tube, remove it from the ice bath and shake for five seconds, then immerse the tube again in the ice bath. Repeat until a homogeneous solution is formed. Remove the tube and arrange for reflux as shown in Figure 5. Immerse the tube in warm water until it acquires the temperature of the room. Add two boiling stones, wipe the tube dry and heat by a small flame for 10 minutes. Cool and, using the separatory stopper, remove the lower aqueous layer. Wash first with 5 ml of 5 per cent sodium carbonate and then 5 ml of water. Dry the hydrocarbon with 0.5 g of calcium chloride for 10 minutes, and then transfer to a distilling tube for distillation. The fraction which boils at 150–160° is the crude *dimer* of amylene, 2,3,4,4-tetramethyl-2-hexene.

Experiment 18

PREPARATION OF BUTYL CHLORIDES

Monohalogen compounds. The monohalogen derivatives of the hydrocarbons are among the most important groups of organic compounds. Their ready reactivity and the replacement of the halogen by other functional groups leads to their frequent use in organic synthesis. The practical preparation of the alkyl monohalides in the laboratory involves the application of the law of mass action to the reaction between an alcohol and a halogen acid:

$$ROH + HX \rightleftharpoons RX + HOH$$

The reaction reaches equilibrium rapidly if the hydroxyl group is attached to a reactive radical, as in tertiary alcohols. In such cases, excess of the halogen acid is shaken with the alcohol, and the monohalogen compound is separated. With primary and secondary alcohols, equilibrium is reached more slowly, and a catalyst (such as zinc chloride in the case of hydrochloric acid, and sulfuric acid in the case of hydrobromic acid) is used. On account of its cost, hydriodic acid is not used, but iodine and phosphorus, which react as follows:

$$2\ P + 3\ I_2 \longrightarrow 2\ PI_3$$

$$3\ ROH + PI_3 \longrightarrow 3\ RI + P(OH)_3$$

The preparation of iodides by this method requires special precautions, if extensive side reactions are to be avoided. The direct action of bromine and chlorine on saturated open-chain hydrocarbons in the presence of catalysts results in the formation of isomeric monohalides, and in the laboratory the separation of these is difficult. In industry, however, this method is practicable.

The direct halogenation of aromatic hydrocarbons in the laboratory is feasible. Chlorination or bromination of benzene gives one monohalogen, C_6H_5X, and by proper control of temperature and concentration of the halogen, the formation of dihalogen compounds, $C_6H_4X_2$, can be kept at a minimum:

$$C_6H_6 + Cl_2 \longrightarrow C_6H_5Cl + HCl$$

The halogenation is usually performed in the presence of catalysts. A great variety of so-called *halogen-carriers* can be used. Iron, phosphorus or its halides, and sulfur and its halides are among the most common.

Butyl chlorides. As stated in the preceding paragraphs, tertiary alcohols react rapidly with halogen acids. If excess of hydrochloric acid is used, the tertiary halide is formed at room temperatures. *n*-Butyl and *sec*-butyl alcohols require heating with a mixture of concentrated hydrochloric acid and fused zinc chloride in order to yield appreciable amounts of the normal and secondary chlorides. It should be noted that the ease of formation of the halide corresponds to the ease of hydrolysis. This should be expected if we consider the following equation:

$$C_4H_9OH + HCl \rightleftharpoons C_4H_9Cl + H_2O$$

For a given temperature the same equilibrium point is reached from either side of the equation.

(A) **Rate of Formation of the Butyl Halides.** In each of three test tubes place 5 ml of concentrated hydrochloric acid. To the first, add 2 ml of *n*-butyl alcohol; to the second, 2 ml of *sec*-butyl alcohol; and to the third, 2 ml of *tert*-butyl alcohol. Shake at intervals for 5 minutes. If a halide has been formed, it will appear as a separate layer.

(B) **Preparation of *tert*-Butyl Chloride (Sm.).** Place 6 ml of *tert*-butyl alcohol and 15 ml of concentrated hydrochloric acid in an eight-inch tube. Close the tube with a solid rubber stopper and shake at intervals for five minutes. After each shaking loosen the stopper. Towards the end of the mixing period add 2 g of solid calcium chloride and shake until the chloride has dissolved. Insert the separatory stopper and withdraw the aqueous layer. Add 3–4 ml of five per cent sodium bicarbonate solution and shake cautiously. Withdraw the aqueous layer immediately after shaking. Add 2 g anhydrous calcium chloride and dry for 15–20 minutes. Transfer to a distilling tube, add two boiling stones, and heat with a very small flame. The portion boiling at 49–52° is collected. The yield is 3.0–3.5 g.

(C) **Preparation of *tert*-Butyl Chloride (M.).** Place in a 250 ml Erlenmeyer flask 30 ml *tert*-butyl alcohol, 90 ml of concentrated hydrochloric acid, and 8 g of solid calcium chloride. Follow the general procedure described in section (B). Shake for ten minutes, and use a separatory funnel to remove the aqueous layer. Wash the halide with 20 ml of 5 per cent sodium bicarbonate and then with 20 ml of water. Add 5 g of anhydrous calcium chloride and shake for a few minutes. Allow to stand for 10 minutes. Arrange a 125 ml distilling flask with a well-cooled condenser. Place the halide and two boiling stones in the distilling flask and heat with a water bath. Collect the fraction which boils at 49–52°. The yield is about 25 g.

(D) **Preparation of *n*-Butyl Chloride (Sm.).** Arrange an eight-inch tube for heating under reflux (See Figure 45, page 141). The micro condenser fits through a cork which has an outlet tube connected with an absorption tube, half-filled with water to absorb the gaseous hydrogen chloride which is evolved. Place in the tube 6 ml of *n*-butyl alcohol, 12 ml of concentrated hydrochloric acid, and 18 g of fused zinc chloride, prepared as described below. Boil the mixture for an hour, using a small flame. Cool the tube, and separate the two layers through the separatory stopper. The halide, which forms the upper layer, is left in the reaction tube while the acid mixture is withdrawn. Add 3 ml of concentrated sulfuric acid and heat in the water bath under reflux for 15 minutes. Remove the reflux micro condenser and arrange for distillation, using the eight-inch tube as a distilling tube. Collect the fraction which boils at 76–79°. The yield is about 2.5–3.0 g.

NOTE: *sec*-Butyl chloride is prepared from *sec*-butyl alcohol, using the same quantities of reagent and the same method. Collect the fraction which boils at 65–69°. For the preparation according to *macro method*, use five times the quantities indicated above. The reaction mixture is boiled for 2.5 hours. The yield is about 20 g.

Preparation of fused zinc chloride. It is advisable to prepare the fused zinc chloride required by several students at one time. If the powdered zinc chloride is placed in a wide-mouth bottle fitted with a Bakelite screw cap and the latter kept tight, the anhydrous chloride keeps for a long time. Use a round-bottom iron dish 200 mm in diameter and 100 mm in depth. If the amount of zinc chloride to be fused is 200–300 g, use an iron dish 160 × 70 mm. Place in the dish 300–500 g of technical powdered zinc chloride. Put the dish on a tripod and heat with a strong flame. Stir the fused mass with a long screw driver while holding the iron dish by means of a pair of pliers. It is best to use a pair of canvas gloves. Scrape the material which solidifies on the sides and push it toward the center. When the whole has melted and no bubbles arise from the melt, discontinue heating. Hold the dish firmly by the lip with the pliers and remove it from the tripod on to an asbestos mat. Stir the melt with the screw driver as it cools. When the melt begins to solidify scrape it away from the sides of the dish. In this manner the zinc chloride solidifies in a dough-like consistency which does not adhere to the sides. Keep stirring the dough-like solid until it begins to crumble. At this point use a large pestle and, holding the dish down firmly with the pliers, pulverize the lumps to a fine powder. If the solid is still dough-like, use the screw driver again to stir for a minute or so, then use the pestle. The zinc chloride pulverizes into a freely-running fine powder which is still hot. Empty the dish on a large piece of paper and transfer the powder rapidly into a dry bottle which has been previously warmed. Close the bottle, using a tightly fitting bakelite screw cap. When needed the chloride is weighed rapidly and added to the reaction mixture. The stock bottle should not remain open more than a few seconds at any time. If there is considerable solid adhering tightly to the sides of the dish, it is remelted, cooled and pulverized. The dish is cleaned by soaking with water and then dried. Rust does not interfere with the activity of zinc chloride.

Experiment 19

PREPARATION OF BUTYL BROMIDES

Introduction. The method used for the conversion of butyl alcohols into butyl bromides is generally the same as that used in the case of chlorides. When using *n*-butyl alcohol it is necessary to heat it with an excess of hydrobromic acid in the presence of a catalyst, such as sulfuric acid. The grades of commercial hydrobromic acid are 34 per cent and 48 per cent. The latter is preferred, as it gives a better yield. Instead of hydrobromic acid, a mixture of sodium bromide and sulfuric acid may be used. This is more economical, although the yield is somewhat diminished. In either case the first step is to consider the amount required. The equation for the reaction is written and balanced, and the molecular weights are placed under each formula, thus obtaining the required amounts for one mole. In the case of hydrobromic acid, the amount is divided by the fraction indicating the percentage of the acid (.48). An excess (about 25 per cent) of acid is used to convert the alcohol to the bromide as completely as possible. The amount of sulfuric acid used varies from 0.5 to 0.7 mole of acid for every mole of alcohol. When sodium bromide is used, an additional mole of sulfuric acid is used to react with the salt. The calculations of the amounts are made in accordance with the following:

$$\underset{\text{1 mole}}{C_4H_9OH} + \underset{\text{1.25 mole}}{HBr} + \underset{\text{0.65 mole}}{(H_2SO_4)} \longrightarrow C_4H_9Br + H_2O + (H_2SO_4)$$

$$\underset{\text{1 mole}}{C_4H_9OH} + \underset{\text{1.25 mole}}{NaBr} + \underset{\text{1.90 mole}}{H_2SO_4} \longrightarrow C_4H_9Br + NaHSO_4 + H_2O$$

(A) *n*-Butyl Bromide (Sm.). Enter in your note book the calculated amounts of 1-butanol, hydrobromic acid (48 per cent), and sulfuric acid required for the preparation of *n*-butyl bromide, starting with 0.1 mole of the alcohol. If the instructions in your laboratory are to use the sodium bromide method, calculate the amount as shown in the equation above and use 10 ml of water to dissolve the sodium bromide. *Have the instructor approve the amounts* before you begin the experiment.

Place the reagents except the sulfuric acid in an eight-inch test tube. Add the sulfuric acid slowly, and cool the tube. Fit the top of the tube with a two-hole cork stopper having a micro condenser and an outlet tube arranged for absorption of gases. (See Figure 45, page 141, or Figure 53, page 213.) Add two boiling stones, and heat for 30 minutes so that the mixture refluxes. Remove the condenser and arrange for distillation (Figure 39, page 101), using a six-inch tube for receiver. Distill the reaction mixture until no more butyl bromide passes over. Add 3 ml of water to the receiving tube and shake; then remove the aqueous layer by means of the separatory stopper. Place in another six-inch test tube 4 ml of cold concentrated sulfuric acid and add to it the butyl bromide, being very careful that no drops of water which may adhere to the tube are added to the sulfuric acid. Fit a separatory stopper to the tube, close the clamp, and shake gently. The sulfuric acid removes any unchanged alcohol and also any olefin which may be present. Remove the acid layer, and wash the bromide first with 5 ml of water and then with 5 ml of five per cent sodium, bicarbonate solution. Remove the aqueous layer and add 1 g of calcium chloride. After 15 minutes transfer to a distilling tube and distill. The portion which boils from 100–104° is collected. The yield is 4–5 g.

(B) ***n*-Butyl Bromide (M.).** Enter in your notebook the calculated amounts of alcohol, hydrobromic acid, and sulfuric acid required for the preparation of *n*-butyl bromide, starting with 0.5 mole of *n*-butyl alcohol (1-butanol). If the sodium bromide method is to be used, calculate the amounts as shown in the introduction, and use 50 ml of water to dissolve the sodium bromide. Have the instructor approve the calculations.

Place in a 500 ml flask (round-bottom or Florence) the alcohol and the hydrobromic acid or sodium bromide solution. Add very *slowly* the calculated amount of sulfuric acid, and two or three boiling stones. Arrange a condenser for reflux. Place in the top of the condenser a cork bearing a delivery tube bent twice at right angles, as shown in Figure 46, page 142. Connect the end of the glass tube by a short rubber tube to a small filter funnel inverted over water contained in a large beaker. This arrangement provides for the absorption of hydrogen bromide and sulfur dioxide which may be evolved, during the heating of the mixture. Boil the mixture gently on a wire gauze for two hours. As the reaction proceeds the halide separates out, forming a layer at the top of the acid mixture. Discontinue heating, cool slightly, and arrange for downward distillation. Distill the reaction mixture until no more oily drops come over. Transfer the distillate to a separatory funnel and remove the halide which forms the lower layer. Wash the halide with 20 ml of water, and when it settles into a lower layer withdraw it into a dry flask. Cool and add carefully 20 ml of *cold* sulfuric acid and shake gently. Wash the funnel and dry it, then add the acid-halide mixture. Shake the mixture (*carefully*) and allow the layers to separate. Remove the acid and wash with 20 ml of water, then with 20 ml of five per cent sodium bicarbonate solution and again with water. Place the halide in a flask with 5 g of anhydrous calcium chloride and allow to stand for one half hour with occasional shaking. Decant the clear liquid through a funnel containing a small plug of cotton into an 125 ml distilling flask and distill. The portion boiling from 100–104° is collected.

(C) ***tert*-Butyl Bromide (Sm.).** Place in an eight-inch test tube 6 ml of *tert*-butyl alcohol and 15 ml of 48 per cent hydrobromic acid. Shake at intervals for 5–10 minutes. Separate the upper layer by means of the separatory stopper and wash successively with 5 ml of water and 5 ml of 5 per cent sodium bicarbonate solution. Dry the halide with 1 g calcium chloride, and after 15 minutes distill it from a micro distilling tube. The portion which boils at 72–75° is collected. The yield is about 4 g.

Experiment 20

PREPARATION OF ALKYL IODIDES

Introduction. When phosphorus trichloride reacts with an alcohol, a chloride is formed. In the same manner when iodine is added to a mixture of red phosphorus and an alcohol, phosphorus triodide is first formed which reacts with the alcohol to give the halide:

$$3\ CH_3OH + PI_3 \longrightarrow 3\ CH_3I + P(OH)_3$$

The reaction between alcohol and phosphorus halide may proceed in another direction:

$$3\ CH_3OH + PI_3 \longrightarrow P(OCH_3)_3 + 3\ HI$$

The compound formed may be called methyl phosphite by analogy to sodium phosphite, or better, phosphorus methoxide. In order to keep the rate of side reactions as slow as possible, it is necessary to add the iodine in small portions and to keep the temperature in the beginning below 20°.

(A) **Methyl Iodide** (**Sm.**). Place 5 g (6.3 ml) of pure methanol and 1.4 g of red phosphorus in an eight-inch tube. The cork which fits into the mouth of the test tube is provided with a micro condenser protruding inwards as far as possible, and an air condenser tube going outwards. The air condenser tube is a piece of glass tubing about 250 mm in length and 4–5 mm in diameter; it serves as an additional trap for the volatile alkyl iodide. Immerse the reaction tube in a small beaker containing cold water and add 14 g of iodine in very small amounts over a period of 15–20 minutes. In adding the iodine, the cork is momentarily raised. After all the iodine has been added, reflux the mixture for half an hour. Arrange the tube for distillation and distill from a water bath. The distillation is stopped when no more iodide passes over. Shake the distillate gently with 4 ml of 3 per cent sodium hydroxide, and withdraw the lower iodide layer into a dry test tube. Add 0.7 g of calcium chloride, shake gently from time to time and allow to stand for 15 minutes. Transfer the dry halide to a distilling tube and distill, collecting the portion which boils at 40–44°. The yield is

12–12.5 g. Add a minute drop of mercury to keep the product colorless.

(B) **Ethyl Iodide** (Sm.). The same procedure is used as in the preparation of methyl iodide. The amounts of the reagents used are: ethanol (95 per cent), 5 g (6.5 ml); red phosphorus, 1.4 g; and iodine, 14 g. The fraction which boils at 69–73° is collected. The yield is about 8–10 g.

(C) **Methyl and Ethyl Iodides** (M.). Place 20 g (25 ml) of alcohol and 5 g of red phosphorus in a 250 ml flask. Place a cork loosely on the mouth of the flask and immerse in a small pail in which tap water circulates. Over a period of one half-hour, add iodine in portions of 2–3 g until a total of 50 g has been added. Shake well after each addition, keeping the flask immersed in water, and keep the cork loose on the top to minimize the evaporation of the volatile iodide. When all the iodine has been added, remove the flask from the cold bath, stopper tightly, and allow to stand at room temperature for one-half to one hour. Heat the mixture under reflux in a water bath for one hour and then arrange for downward distillation. Distill by heating on the water bath until distillation ceases. Transfer the distillate to a separatory funnel and wash with 20 ml of 3 per cent sodium hydroxide solution. Remove the lower iodide layer into a small flask, add 4–5 g of anhydrous calcium chloride, and shake from time to time over a period of 15–20 minutes. Decant the halide, through a funnel containing a small plug of cotton, into a small distilling flask. Distill from a water bath and collect the fraction which distills at 40–44° for methyl iodide, and from 69–73° for ethyl iodide. Most iodides when freshly distilled are colorless, but become colored by standing due to liberation of iodine. A small drop of mercury added to the iodide keeps it clear.

Experiment 21

PREPARATION OF BROMOBENZENE

NOTE: The macro method is not recommended for beginners, due to the danger involved in handling bromine in a separatory funnel over a reaction vessel. The macro experiment is suitable for advanced work and for demonstration by the instructor. The semimicro method involves the use of 3 ml of bromine, and with suitable precautions the experiment can be assigned to beginners.

Introduction. The action of halogens on saturated open chain hydrocarbons, as for example, pentane or hexane, gives several monohalogen derivatives. Since the separation of the isomeric monohalides is difficult in the laboratory, they are usually prepared from alcohols. Direct halogenation is used industrially. The cyclic hydrocarbons, such as cyclohexane and benzene, yield only one monohalide. The present experiment illustrates direct bromination of a hydrocarbon. Chlorination is more difficult; it is described in the latter part of the text (page 229). The catalyst used for bromination is iron; other substances which can be used for the same purpose are anhydrous aluminum chloride and pyridine.

Caution: Bromine quickly produces severe burns if it comes in contact with the skin. *Wear goggles*, and become familiar with method of treating bromine burns (page 348).

(A) **Preparation of Bromobenzene** (**Sm.**). Arrange apparatus as shown in Figure 45. Provide an eight-inch test tube with a cork having three openings. Through one is fitted the condenser, and through another the outlet tube leading to the absorption vessel. The third opening is fitted with glass tubing, 150 mm in length and 8 mm in diameter, closed by a stopper made of rubber tubing fitted to a small piece of glass rod. An eight-inch distilling tube may be used to advantage. The side arm is connected to the absorption tube. The cork which fits in the mouth has two openings, one for the condenser and one for the dropping tube (see Figure 53, page 213).

Place in the tube 4 g (5 ml) of benzene and 0.3 g of iron filings. Measure out 3 ml of bromine (**with caution**) into a small beaker

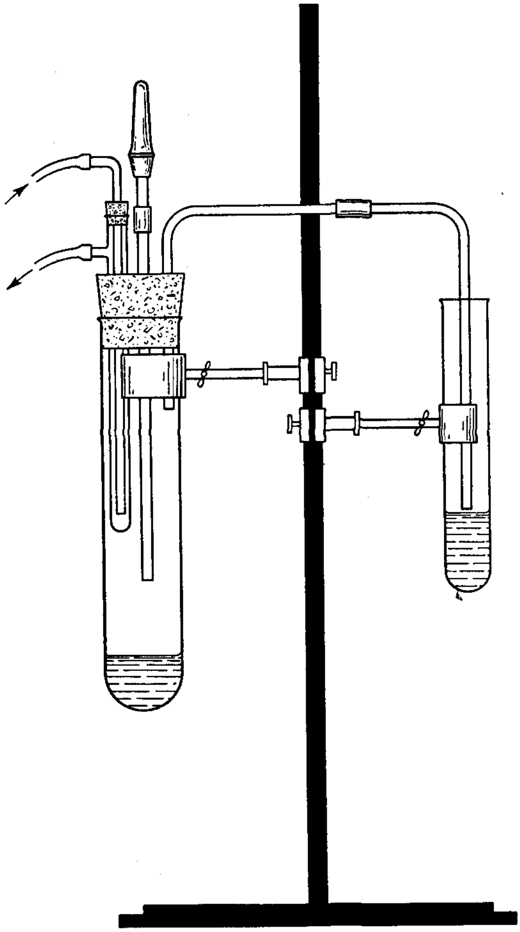


Fig. 45. Semimicro apparatus for bromination (may be used for reactions where gases, soluble in water, are evolved)

and cover it with a watch glass. Remove the plug from the inlet tube, bring the beaker containing the bromine close to the inlet, and add, by means of a pipette dropper, about 0.5 ml of bromine. Use great care in handling the dropper; do not tilt it. Replace the plug, and warm the tube slightly to start the reaction. The remainder of the bromine is added over a period of fifteen minutes. When the reaction has ceased, the tube is warmed at 70° for 15 minutes.

Add 10 ml of water directly to the tube, and after shaking

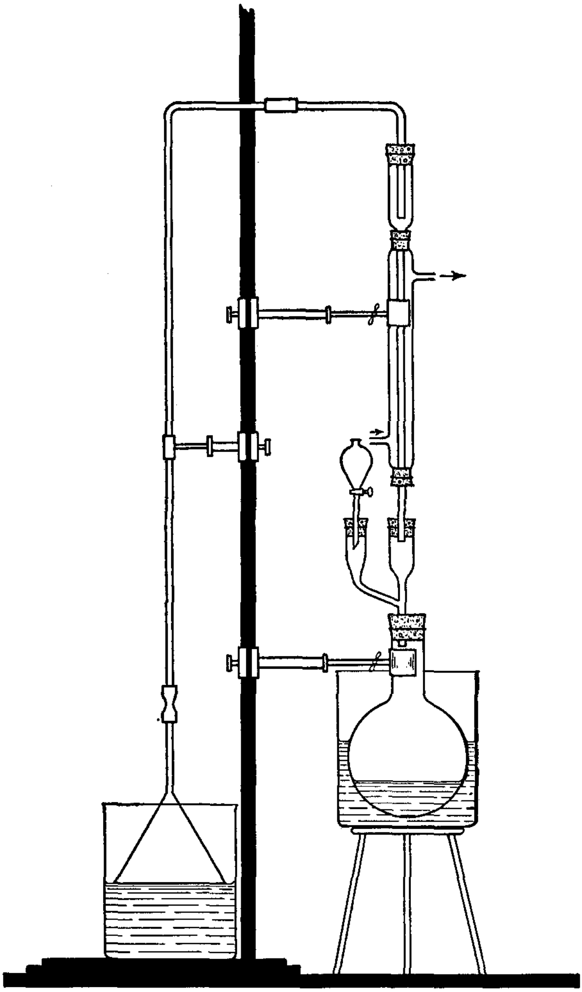


Fig. 46. Macro apparatus for bromination or any reaction where gases soluble in water are evolved

gently, remove the bromobenzene layer by means of the separatory stopper. Wash with 10 ml of water containing 1 ml of 6 *N* sodium hydroxide solution. Withdraw the crude bromobenzene in a dry test tube and add 1 g of calcium chloride. After 15 minutes decant the dry liquid into a distilling tube. Heat with a small flame. The first portion contains benzene. Collect the fraction which boils at

140–165°. Allow the residue in the distilling tube to cool to about 50° and then add 5 ml of methanol to dissolve it. Pour the contents of the tube through a small filter paper into a 50 ml beaker. From the filtrate, on cooling, crystals of *p*-dibromobenzene separate.

The fraction boiling at 140–165° is placed in the distilling tube and redistilled. Collect the portion which boils at 150–160°. The yield is 3–3.5 g.

Preparation of Bromobenzene (**M.**). Arrange a 500 ml Florence flask with a reflux condenser and a small dropping funnel as shown in Figure 46. Place 30 g (38 ml) of dry benzene and 2 g of iron filings in the flask. Make sure that the stopcock of the funnel is well lubricated and fits tightly. Pour with care into the separatory funnel 75 g (24 ml) of bromine which has been dried over concentrated sulfuric acid. Allow a small amount of bromine to run into the benzene in the flask. Warm the flask slightly to start the reaction. Vigorous evolution of hydrobromic acid takes place. Hydrogen bromide carrying small amounts of bromine and benzene passes through the condenser into the absorption beaker. The rest of the bromine is added at a rate that prevents the reaction from becoming too violent. When the evolution of the gas has subsided, the temperature is raised to 70° until the reaction ceases, which is shown by the absence of red bromine vapors in the reflux condenser

Transfer the contents of the flask into a separatory funnel and wash with 50 ml of 5 per cent sodium hydroxide solution. Separate the lower layer into a small flask, add 4–5 g of calcium chloride and allow to stand 15–20 minutes, shaking from time to time. Decant the dry liquid into a small distilling flask and fractionate, collecting the fraction which boils at 140–170°. This fraction is redistilled and the portion which boils at 150–160° is collected. The residue in the distilling flask is poured into a small beaker and cooled, Crystals of dibromobenzene separate out. If it is desired to purify the crude *p*-dibromobenzene, 10 ml of alcohol are added, and the mixture is heated to about 70°, more alcohol being added until solution is complete. About 0.5 g of charcoal is added in small portions, and the solution is filtered and cooled.

Experiment 22

THE PROPERTIES AND REACTIONS OF HALOGEN COMPOUNDS

Introduction. The importance of halogen derivatives is due to the variety of compounds which are produced by the replacement of the halogen with other functional groups such as OH, NH_2, NO_2, etc. The conditions necessary for the replacement of a halogen by another functional group are determined by several factors. One is the nature of the radical attached to the halogen; another is the nature of the halogen—iodides react faster than bromides, and bromides faster than chlorides. The object of the present experiment is to study some of the general reactions of halogen compounds, and to illustrate the effect of the radical on the reactivity of the halogen atom.

A halide that hydrolyzes rapidly in an aqueous solution will increase the hydrogen ion of the mixture owing to the formation of halogen acid. A halide that hydrolyzes rapidly will exhibit change in *p*H more rapidly than a halide that hydrolyzes slowly or not at all. The determination of the *p*H of the aqueous layer resulting when the halide is added to water furnishes evidence of the hydrolysis, and indicates the rate of reaction.

(**A**) **Density of Halides.** To 2 ml of water add two drops of *n*-butyl chloride; note whether it is lighter or heavier than water. Repeat, using *n*-butyl bromide and *n*-butyl iodide.

(**B**) **Hydrolysis of Monohalides.** (1) The following halides are used in this test: n-*butyl chloride,* sec-*butyl chloride,* tert-*butyl chloride,* n-*amyl chloride, cyclohexyl chloride, phenyl chloride* (*chlorobenzene*), and *benzyl chloride.* For the student's use the pure halides are placed in 25 ml bottles provided with droppers which serve also as stoppers to the bottle. The dropper is replaced in the bottle immediately after use.

(**2**) Set up eight tubes on a rack. In each place 5 ml of distilled water and ten drops of Universal indicator[1] (with a *p*H range of 1–13); to each of seven add ten drops of one of the above halides,

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[1] See Appendix, section on reagents.

retaining the eighth as a control. Shake each tube for ten seconds and observe the *p*H of the aqueous layer by comparing the color of the tube with a color chart furnished with the indicator. The tube is then set aside on the rack. Observe the *p*H again in 15 minutes. In the last observation, if necessary, add a few more drops of the indicator before making the comparison with the color charts, as there is a tendency for the color to pass into the halide layer. Record the observations.

(**3**) Apply the same procedure as above, using *n*-butyl chloride, *n*-butyl bromide, *n*-butyl iodide, and bromothymol blue (0.04 per cent) as an indicator. Adjust the *p*H of the water to 7 by the addition of one drop of 0.1 *N* sodium hydroxide to 100 ml of water. To each of three test tubes add 10 drops of indicator and 10 drops of the halide. Observe the *p*H after one, five, and fifteen minutes. The rate of hydrolysis depends not only on the activity of the halogen but also on the solubility of the halide.

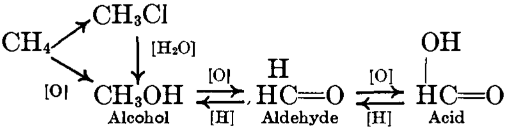
(**C**) **Ammonolysis of Alkyl Halides.** Place 20 ml of a saturated alcoholic solution of ammonia in methanol (90 per cent) in each of two test tubes. To the first add 2 g of *n*-amyl bromide, and to the second 2 g of *tert*-amyl bromide. Cork, shake, label, and set aside until the following laboratory period. Add to each reaction mixture 20 ml of water, and separate the upper layer of amine (and unchanged halide). Test two drops of each product for amylene by shaking with 2 ml of 0.1% potassium permanganate or bromine water. Record the observations. Place the sample of amine in the proper bottle provided by the instructor for future study.

(**D**) **Action of Alcoholic Alkali.** Use alcoholic potassium hydroxide solution containing 30 g of the solid dissolved in 90 ml of 90 per cent methyl or ethyl alcohol. Place 3 ml of the alkali solution in each of three tubes. Add to seperate respective tubes 1 ml of *n*-amyl bromide, *tert*-amyl bromide, and benzyl chloride. Shake gently for a minute, cork, label each tube, and set aside for the next laboratory period. If it is desired to observe the rate at which the halides react, examine after 30 minutes the extent of the reaction as judged by the amount of potassium halide formed. After 24 hours add 3 ml of water, shake, and allow to separate. Note the odor. With a clean dropper or pipette withdraw two drops from each and test with bromine water and dilute permanganate. *n*-Amyl bromide yields a considerable amount of ether, but little olefin. Benzyl chloride yields entirely carbinol. Put the contents of the three tubes into bottles provided by the instructor.

Experiment 23

GRIGNARD SYNTHESIS OF CARBINOLS

Introduction. The general formula for carbinols is ROH. If the radical is aliphatic, they are called *alcohols*; if aromatic, and the functional group (OH) is attached directly to the benzene nucleus, they are called *phenols*. The student already knows that one method of preparation is the hydrolysis of halogen compounds. One way to summarize the preparation of alcohols is to consider the progressive oxidation of the methane carbon atom:



$$\begin{tikzcd} & CH_3Cl \arrow[d, "{[H_2O]}"] & & \\ CH_4 \arrow[ur] \arrow[r, "{[O]}"'] & \underset{\text{Alcohol}}{CH_3OH} \arrow[r, shift left, "{[O]}"] & \underset{\text{Aldehyde}}{\overset{H}{HC{=}O}} \arrow[l, shift left, "{[H]}"] \arrow[r, shift left, "{[O]}"] & \underset{\text{Acid}}{\overset{OH}{HC{=}O}} \arrow[l, shift left, "{[H]}"] \end{tikzcd}$$

The direct oxidation of the hydrocarbon to alcohol is difficult because the oxidation proceeds to the acid stage, thus giving rise to mixtures. In only a very few cases is it possible to develop a practical method. Aside from the hydrolysis of the halogen compounds, the reduction of aldehydes or acids can, according to the above diagram, be used for the preparation of alcohols. Reductions of this type are possible under certain conditions; for these the student should refer to the text.

The Grignard reagent reacts with the carbonyl group (CO) of the aldehydes and ketones to give addition compounds, which upon hydrolysis yield alcohols:

$$R_1CHO + R_2MgX \longrightarrow R_1R_2CHOMgX + H_2O \longrightarrow R_1R_2CHOH + MgOHX \qquad (1)$$

$$R_1R_2CO + R_3MgX \longrightarrow R_1R_2R_3COMgX + H_2O \longrightarrow R_1R_2R_3COH + MgOHX \qquad (2)$$

In the reaction with aldehydes (equation 1) the product is a secondary alcohol, except with formaldehyde, when a primary alcohol is formed.

$$H_2C{=}O + CH_3CH_2MgI \longrightarrow CH_3CH_2CH_2OMgI + H_2O \longrightarrow CH_3CH_2CH_2OH + Mg(OH)I$$

Equation 2 shows that ketones form tertiary alcohols with the Grignard reagent. The objective of the present experiment is to provide an illustration of the use of the Grignard reagent for the synthesis of alcohols.

(A) **Trimethyl Carbinol** (*tert*-**Butyl Alcohol**) (**Sm.**). Prepare the Grignard reagent in accordance with the directions given on page 123. It is advisable to dry all the reagents and to have them stand over fused calcium chloride. Use 5.7 g of methyl iodide (0.04 mole) and 10 ml of ether and 1.0 g of magnesium turnings. The reaction begins within a few minutes and is very vigorous, being completed within 10 minutes. Use a 400–600 ml beaker containing cold water to immerse the tube and thus moderate the reaction, if necessary.

When the magnesium has dissolved almost completely, immerse the reaction tube in an ice-salt mixture and add by means of a dropper, in small portions, a solution of 2.3 g of dry acetone in 5 ml of dry ether. The cork is raised slightly for the addition of the reagent and the tube is shaken gently after each addition. A white addition compound separates. The tube is corked, placed in a beaker of water, and allowed to stand until the following laboratory period.

To decompose the addition compound, immerse the tube in ice-salt mixture and add slowly, by means of a dropper, diluted acid obtained by mixing 5 ml concentrated hydrochloric acid with 5 g of ice. Add only sufficient hydrochloric acid to dissolve the precipitate which forms. Allow to stand until all the residual magnesium has reacted with the acid. The ether layer should have a volume of at least 10–12 ml. If it is less, add ordinary ether to make up this volume. Insert the separatory stopper and remove the aqueous layer. Dry the ether layer by adding 0.5–1 g of anhydrous calcium sulfate. Care must be taken to dry the ether thoroughly, since the carbinol forms an azeotropic mixture with water. Transfer the dry ether mixture to an eight-inch distilling tube, and distill from a water bath until the temperature rises to 70°. Remove the water bath and heat over a small smoky flame. The fraction which boils at 77–84° is collected.

(B) **Ethyldimethyl Carbinol** (*tert*-**Amyl Alcohol**) (**Sm.**). The same apparatus and procedure is used. Prepare the Grignard reagent from 1.0 g magnesium turnings, 4.4 g ethyl bromide (0.04 mole) and 10 ml of dry ether. To the cooled Grignard reagent add as above 2.3 g of dry acetone in 5 ml of ether. The decomposition and isolation of the carbinol is the same as in section (A). Ethyldimethyl carbinol forms an azeotropic mixture with water which boils at 87.4°. The pure carbinol boils at 102.3°. Therefore, after the ether is distilled, collect the fraction which boils at 80–105°. If there is a considerable amount which boils below 95° then add to the 80–105° fraction 0.5 g of anhydrous calcium sulfate, warm, and after one hour decant into a small distilling tube and redistill, collecting the fraction which boils at 98–105°.

(C) **Ethyldimethyl Carbinol** (M.). Arrange a 250 ml flask as shown in Figure 40. All apparatus must be free of moisture, as described in Experiment 16, page 123. All the regents used should be dry and kept over fused calcium chloride.

Place 4.8 g of magnesium turnings and 50 ml of absolute ether in the flask, with 5 g of ethyl bromide. The reaction starts within a few minutes. Remove the calcium chloride tube from the top of the condenser and replace it with a cork holding a dropping funnel. Add through the dropping funnel 18 g of ethyl bromide dissolved in 50 ml of dry ether at such a rate that the reaction proceeds smoothly.

When all the halide has been added and the reaction begins to subside, the mixture is warmed until nearly all the magnesium has dissolved. The warm water in the bath is replaced by an ice-salt mixture, and 11.6 g of acetone, dissolved in 20 ml of ether, is added drop by drop. The mixture is allowed to stand overnight.

Decompose the addition compound by cold dilute hydrochloric acid or cold dilute sulfuric acid. Add acid until all the precipitate has dissolved. Stir for a few minutes, and separate the ether layer. Dry the ether solution with 2 g anhydrous calcium sulfate and 1 g of anhydrous sodium carbonate. When dry, decant the ether into a distilling flask and heat in a water bath. After the ether is removed, the fraction which boils at 80–105° is first collected. This is redistilled (see section [B]), and the portion collected which boils at 98–105°.

(D) **Preparation of Arylalkylcarbinols** (Sm.). The same general procedure as outlined in section (A) is used. The temperature necessary for the distillation of these compounds is high, and water is eliminated with formation of olefin. For this reason it is necessary to distill the carbinol under reduced pressure, as described in Experiment 45. The preparation of two carbinols will be described.

(1) **Ethylphenyl Carbinol.** Employ the same procedure as in section (A). Use ethyl bromide 4.4 g; magnesium 1.0 g; ether 10 ml and benzaldehyde 4.25 ml. The ether extract, after the decomposition of the addition compound, is shaken with 5 ml of saturated sodium bisulfite solution to remove the unreacted benzaldehyde, with which it forms a crystalline compound. The upper layer is

then separated and dried with 0.5 g anhydrous calcium sulfate. After twenty minutes the ether is transferred into the vacuum distillation tube of the apparatus shown in Figure 59. If such a tube is not available, an ordinary tube may be used, with an arrangement as shown in Figure 58. The ether is distilled from a water bath. The bath is then removed, and the outlet from the trap is connected to a vacuum pump. A good water aspirator makes a satisfactory pump. Detailed directions for semimicro distillation under reduced pressure are given in Experiment 45. The fraction which boils at 104–110° at 16 mm pressure is collected. The yield is 0.8–1.0 g. Another method for preparing the same carbinol is to prepare the Grignard reagent from bromobenzene and to add acetaldehyde.

(2) **Isopropylmethylphenyl Carbinol.** Prepare the Grignard reagent, as directed in section (A), from 5.0 g of isopropyl bromide, 1 g of magnesium, 10 ml of ether. To the Grignard reagent add 4.8 g of acetophenone. Decompose and extract with ether. The ether extract is dried with 0.5 g of anhydrous calcium sulfate and the ether removed as described above. It is then distilled under reduced pressure. The first fraction of about 1.0–1.5 g distills at 90–96° at 15 mm pressure. The second fraction, which is the carbinol, distills at 100–106° at 16 mm pressure. The yield is 2.4 g.

Experiment 24

THE REACTIONS OF HYDROXY COMPOUNDS

Introduction. The general reactions of alcohols are divided into two groups. The first includes replacement reactions of the functional group (OH); the second, oxidation-reduction reactions of the carbon atom to which is attached the functional group. The hydroxyl group in compounds of the general type ROH may enter into reactions by replacement either of the hydrogen atom or of the entire group. The ionization of the hydrogen atom is extremely small, unless the hydroxyl is attached to an aryl nuclear carbon. Thus, in C_6H_5OH, the influence of the phenyl group on the ionization of the hydrogen atom is such that phenol has weak acid properties in aqueous solutions. In other reactions the entire hydroxyl group may be replaced. In the oxidation of alcohols the primary are oxidized to aldehydes, and these, in turn, are easily oxidized to acids with the same carbon content as the alcohols. The secondary alcohols are oxidized to ketones, and further oxidation should proceed at a slower rate, since it involves rupture of the carbon-to-carbon bond. Finally, the oxidation of the tertiary alcohols involves, from the very beginning of the reaction, the rupture of the carbon-to-carbon bond; consequently, the tertiary alcohols should have the slowest oxidation rate. The object of this experiment is to illustrate some of these general reactions.

(**A**) **Solubility.** To 4 ml of distilled water add, drop by drop, 10–15 drops of 1-*butanol* until no more dissolves. Save the tube. Repeat, using: *ethanol*, tert-*butyl alcohol*, *cyclohexanol*, and *phenol*. The last is solid, therefore use 0.5 g. Likewise determine the solubility of a nitrophenol if available. Treat solutions as directed in section (B).

(**B**) **Ionization.** To each solution prepared above (section (A)) add 4 drops of a long range indicator[1] and note the *p*H of the solution. Use 4 ml of distilled water as a control. If available, determine the *p*H of a nitrophenol.

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[1] See Appendix section on reagents.

(C) **Reaction with Sodium, Alkoxides.** (1) To 5 ml of absolute ethanol add a small piece of sodium. Collect some of the gas evolved by holding a small test tube over the reaction tube and bringing it near a flame. Evaporate the contents of the tube on a watch glass, dissolve a small amount of the remaining powder in 5 ml of water, and test the *p*H. Explain what was reduced by the sodium.

(2) To tubes containing 1 ml of the following hydroxy compounds, add a very small piece of sodium and note the rate of reaction: *ethanol,* 1-*butanol, benzyl alcohol,* tert-*butyl alcohol,* and *phenol.* Arrange these in the order of increasing reactivity towards sodium.

(D) **Reaction of Alkoxides with Halides.**

(1) **Formation of *n*-Butyl Ethyl Ether.** Place 5 ml of dry pure *n*-butyl alcohol in a test tube. Add 0.5 g of sodium metal in small pieces. Observe all *precautions* given on page 99 for handling sodium. When the metal has dissolved, add 2 g (1.5 ml) of ethyl bromide. Cork, and set aside until the following laboratory period. Add the reaction mixture to 25 ml of water in an eight-inch test tube, and shake. Then withdraw the aqueous layer with the separatory stopper, and repeat the washing with water. The ether layer containing small amounts of the alcohol remains.

(2) **Formation of Methyl-β-Naphthyl Ether.** In a test tube provided with reflux micro-condenser place 0.5 g of β-naphthol, 2 ml of 10 per cent sodium hydroxide solution, and 0.5 ml of methyl iodide. Warm for 20 minutes in a water bath, and then note the odor. Add 5 ml of water and filter the crystals, washing with water. The ether may be recrystallized from alcohol.

(E) **Formation of Esters.** To 5 ml of ethanol in a test tube add, carefully, 2 ml of concentrated sulfuric acid and 3 ml of glacial acetic acid. Warm, and note the odor.

To 2 ml of ethanol in a test tube, with the mouth directed away from you, add 5 drops of acetyl chloride. Note the gas evolved. Add 2 ml of water and note the odor of the product. Can this reaction be of any use for detection of the hydroxyl group? Repeat the test, adding 5 drops of phosphorous trichloride.

(F) **Rate of Oxidation of Monohydroxy Compounds.** (1) Set up 9 tubes in a rack. Place in each 10 ml of 0.05 per cent potassium permanganate solution (neutral); then add to eight of the tubes 10 drops respectively of one of the following: *methanol, ethanol,* 1-*butanol,* 2-*butanol, trimethyl carbinol, cyclohexanol, phenol,* and *benzyl alcohol.* Retain the ninth tube as a control. Shake for ten seconds, observe the color immediately afterwards, and allow to stand. Observe the color of the solution again in five and in thirty minutes.

(2) The use of alkaline and acid permanganate with methanol, ethanol and butanol illustrates the difference in the rate of oxidation with increased complexity of the radical. Recall the changes of permanganate on reduction. Green indicates reduction to manganate, muddy-brown to manganese dioxide, and clear pink to manganous. The reaction is brought about in the same manner as in the above test (1). The acid permanganate is prepared by diluting the stock solution to 0.05 per cent, and adding sufficient sulfuric acid to bring the concentration of hydrogen ion to 1 *N*. Similarly, by the addition of sufficient 6 *N* NaOH to bring the concentration of OH^- to 0.1 *N*, the alkaline permanganate is prepared. First use 10 ml of neutral permanganate, and 10 drops of the alcohol. Observe the color immediately after mixing, and again after 5 and 10 minutes. Repeat with alkaline permanganate. Observe changes after 15 seconds, 30 seconds, and 2 minutes. Repeat with acid permanganate and observe changes in 2, 5 and 10 minutes. Tabulate the observations.

(G) **Identification of Monohydroxy Compounds.** The evolution of hydrogen chloride, when acetyl chloride or phosphorus trichloride is added to a compound, indicates the possible presence of a hydroxy group. For identification purposes a derivative should be prepared. 3, 5-Dinitrobenzoic acid forms crystalline derivatives with hydroxy compounds. The melting points of the esters are utilized for identification.

(1) **3, 5-Dinitrobenzoates.** Place in each of two test tubes 0.4 g of 3, 5-dinitrobenzoyl chloride,[2] and add 10 drops of alcohol. Use ethanol or methanol in one, and *n*-butanol in the other. Cork loosely, and warm at 60° for 10 minutes. Add 10 ml of water, and filter the crystals. The melting point of each ester is determined (after recrystallization).

(2) **Reactions of Phenols.** Phenols and compounds with the hydroxyl group attached to an unsaturated carbon give a coloration upon addition of ferric chloride. Add a drop of ferric chloride to a very dilute solution (1 drop to 10 ml of water) of phenol and cresol. Note the color.

The introduction of the hydroxyl group into the benzene nucleus increases the ease with which its hydrogen atoms can be replaced by substitutions. Add 1 ml of one per cent solution of bromine in carbon tetrachloride to 2 ml of 10 per cent solution of phenol. Recall the formation of bromobenzene.

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[2] See Appendix.

Experiment 25

PREPARATION OF ETHERS

USES OF ETHYL ETHER

NOTE: For semimicro work the student may choose between the preparation of ethyl and *n*-butyl ethers. The macro preparation of ethyl ether is not recommended for beginners, particularly when the group of students is large.

Introduction. In the study of unsaturated hydrocarbons it was shown that there are two directions as regards the dehydration of alcohols:

$$2\ CH_3CH_2OH \longrightarrow \left[\begin{array}{ll} \longrightarrow CH_3CH_2{-}O{-}CH_2CH_3 + HOH & (1) \\ \longrightarrow 2\ H_2C{=}CH_2 + 2\ HOH & (2) \end{array}\right.$$

In the lower primary alcohols, ether formation (1) takes place at lower temperatures than olefin formation (2). With secondary alcohols, the temperature difference is not appreciable; and with tertiary alcohols olefin formation takes place easily on warming.

Reaction (1) is easily applicable to the preparation of the lower simple alkyl ethers which boil below the boiling point of the alcohol. For example, when ethyl alcohol is mixed with sulfuric acid in the cold, ethyl sulfuric acid is formed. When more alcohol is allowed to flow into such a mixture at 140–150°, ether, water, and some unchanged alcohol distill over. The mechanism of the reaction is assumed to involve, first the formation of ethyl sulfuric acid, and then the reaction of this with alcohol to form ether and regenerate the sulfuric acid. The regenerated acid combines with fresh alcohol and repeats the cycle until the water produced in the reaction by dilution diminishes its catalytic activity. Olefin formation takes place even at this temperature and decreases the yield. Further decrease in the yield results from the oxidizing action of sulfuric acid.

$$C_2H_5OH + HOSO_2OH \longrightarrow C_2H_5OSO_2OH + H_2O$$

$$C_2H_5OSO_2OH + C_2H_5OH \longrightarrow C_2H_5OC_2H_5 + H_2SO_4$$

For ethers which boil above the boiling point of the alcohol the procedure is modified. For example, isoamyl alcohol, boiling at 130°, is mixed with sulfuric acid and distilled slowly. Water and unchanged alcohol pass over as distillate. The water is separated, and the alcohol is returned to the reaction mixture. When very little comes over in the distillate the ether formation is regarded as complete and the ether which boils at 172° may be removed by steam distillation.

Ethyl ether is one of the most common solvents used in the laboratory. It is very widely used to extract dissolved organic substances from water solutions. Since it is immiscible with water, the ether solution is easily separated. Removal of the ether by distillation gives the organic substance.

The object of this experiment is to illustrate the general method of the preparation of ethers by dehydration of alcohols, and to discuss the principle of extraction with an immiscible solvent.

Caution: Ether is easily volatilized, is highly inflammable, and forms explosive mixtures with air. Use more than usual precaution when working with ether, and avoid the use of flames near vessels which contain ether.

(A) **Preparation of Ethyl Ether** (**Sm.**). Arrange apparatus as shown in Figure 51, page 184. Provide a 125 ml Erlenmeyer flask with a three-hole rubber stopper. Insert the thermometer so that it is within a few mm from the bottom of the flask. The delivery tube is connected to the outlet of an inverted separatory tube which serves as a dropping funnel. Insert through the third opening an outlet tube which extends 250 mm to the receiving tube. Cool the latter by immersing it in an ice-salt mixture.

Place 10 ml of ethanol (95 per cent) in the flask and add slowly, with constant shaking and cooling, 10 ml of concentrated sulfuric acid. Place 20 ml of ethanol in an eight-inch tube, adjust the separatory stopper tightly, close the screw clamp and invert it as shown in Figure 51, connecting it with the delivery tube leading to the bottom of the flask. Heat the flask until the temperature reaches 140° and then adjust the screw clamp and add the alcohol slowly. Regulate the flow of alcohol to about the same rate as ether distills out, and so that the temperature remains at 140–150°. After all the alcohol has been added continue the heating for about five minutes. Add 5 ml of 10 per cent sodium hydroxide solution to the distillate and insert the separatory stopper. Close the screw clamp, place the index finger on the stopper, shake gently so as to mix the contents, and then carefully release the pressure by opening the clamp. Close the clamp, invert the tube and remove the aqueous layer, and repeat the washing, using 5 ml of a 40 per cent solution of calcium chloride. Separate the ether and pour into a dry six-inch test tube. Add 1–2 g of calcium chloride, close stopper securely with a cork and allow to stand overnight. Transfer to a large distilling tube and distill from a water bath according to the usual procedure. It is advisable to immerse the receiving tube in ice water. Collect the fraction which boils at 33–38° in a tared tube. The yield is about 7–9 g.

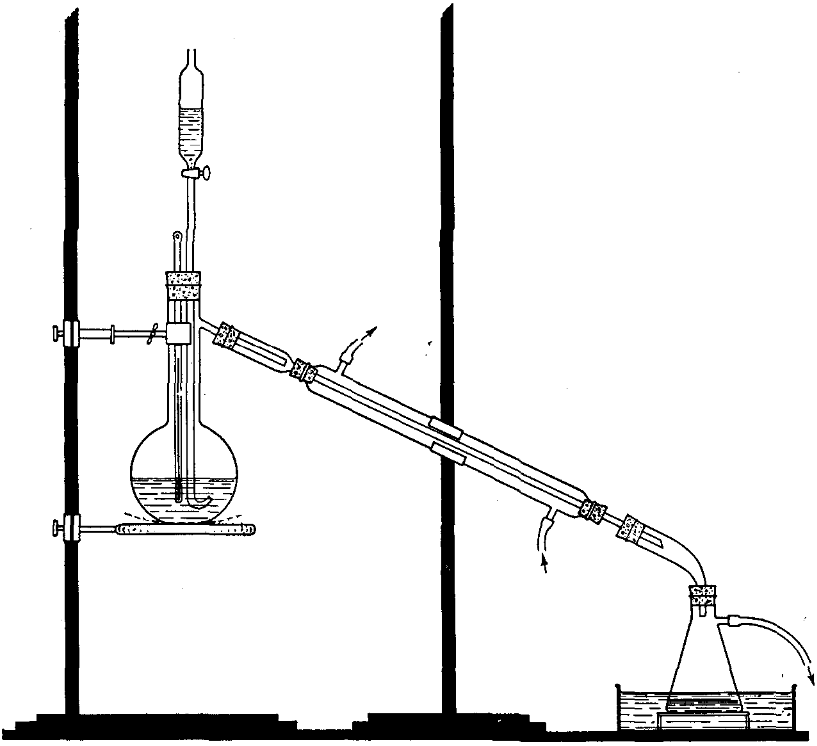

Fig. 47. Macro apparatus for preparation of ether

(B) Preparation of Ethyl Ether (M.). The method is the same as described in section (A). The quantities used are five times those given in the semimicro procedure. The apparatus shown in Figure 47 consists of a 500 ml distilling flask heated on an asbestos-centered wire gauze and provided with a two-hole rubber stopper. The stopper holds the thermometer and the dropping funnel. The lower end of the stem of the funnel is connected by means of a short rubber tube with a piece of glass tubing of sufficient length so that it extends nearly to the bottom of the flask. The side arm of the distilling tube is connected by means of an efficient long condenser to a 250 ml distilling flask immersed in an ice-salt mixture and serving as a receiver. The receiver may be tilted and connected directly to the condenser through a cork or by means of an adapter. The side arm of the receiving flask is connected with a rubber tube extending well below the bench to conduct any uncondensed ether vapors to the floor. As previously mentioned, ether vapors form with air explosive mixtures, which may migrate for ten or more feet along the top of the bench and still be capable of exploding when they reach a flame.

(C) **Preparation of *n*-Butyl Ether (Sm.).** Place 8 ml of *n*-butyl alcohol in an eight-inch tube. Add slowly 1 ml of concentrated sulfuric acid and two boiling stones. Arrange for distillation as in Figure 25, page 63. The thermometer, however, is placed well down in the tube, so that it is immersed in the mixture and reaches to about 5 mm from the bottom.

Heat slowly with a small flame until the temperature reaches 139–140°. Remove the flame and allow the tube to cool, working in the meantime with the distillate. Insert a separatory stopper in the receiving tube and separate the lower aqueous layer. Return the upper layer (chiefly *n*-butyl alcohol and some ether) to the distilling tube. Repeat the heating and separation twice, but discontinue the heating when the temperature reaches 135° instead of 139°.

After the last separation, disconnect the distilling tube and cool it in tap water. Add 8 ml of water, mix carefully, and separate the upper layer. Wash with 5 ml of dilute sodium carbonate, pour the ether into a clean tube, add 0.5–1 g of calcium chloride, and allow to dry overnight. Pour the liquid into a distilling tube and fractionate carefully. Collect the portion which boils at 138–144°. Pure *n*-butyl ether boils at 141°.

LABORATORY USES OF ETHYL ETHER

Pure ether for Grignard reagent. In the preparation of Grignard reagent and other work in the organic laboratory pure dry ether is required. The impurities in commercial ether are water and ethanol. Though ether and water are regarded as immiscible liquids, water dissolves in ether to the extent of 1.35 per cent. The purification of ether may be carried out in quantities of one liter according to the following procedure. Place one liter of commercial ether in a bottle or flask and wash with 200–300 ml of water containing 2 g of ferrous sulphate and 1 ml of sulfuric acid. Separate the ether and place in a dry bottle. Add 30–40 g of calcium chloride, stopper securely and allow to stand for two days with occasional shaking. Calcium chloride removes most of the alcohol and water. Filter the ether through a large fluted filter paper into a dry clean flask or bottle. Add about 10 g of sodium cuttings (see page 99). Close bottle or flask with a paraffined cork holding a calcium chloride tube to allow escape of hydrogen. The tip of the calcium chloride tube is drawn out to a fine point so as to reduce the opening. Allow to stand for 24 hours. Decant into a large distilling flask, attached to a long well-cooled condenser. The receiver is either a flask as described in section (B) of this experiment or the bottle in which the ether is to be stored. In the latter case an adapter is connected with the bottle through a two-hole cork stopper. An L glass tube, inserted through the other opening, is connected with a rubber tubing which reaches well below the bench towards the floor and has a calcium chloride tube at the end. It is advisable to use a well-ventilated hood for the distillation. A laboratory bench may be used, provided no other person is working on either side. Add 2–3 g of sodium cuttings to the flask and distill the ether, heating by means of a water bath. If steam is not available, water is heated (almost to boiling) in another part of the laboratory and added to the bath surrounding the flask until the temperature of the bath water is 60°. The distillation starts within a few minutes. As the water in the bath cools it is partly siphoned off from time to time and more hot water added. Do not use a hot plate for distillation of ether. Discontinue the distillation *before* the residue in the distilling flask becomes dry. Distilling a large quantity of ether, which contains peroxides due to exposure to light and air, involves a danger of explosion if the distillation is allowed to proceed to dryness. The presence of peroxides is detected by adding 2 ml of ether to a mixture of 3 ml of water, 2 ml of starch suspension and 0.5 ml of potassium iodide solution. Shake, and if a blue color does not appear immediately, add a drop of dilute sulfuric acid and shake again. Ether which contains peroxides liberates iodine from an acid solution of potassium iodide. The ether prepared as described above is anhydrous and practically free from other impurities. It is best kept in a dark brown bottle, stoppered with a well-fitting cork covered with metal foil. It is advisable to add a few pieces of fused calcium chloride or better a few clean sodium cuttings. The bottle should be stored in the dark.

Extraction with ether. Ether is often used in the organic laboratory to *extract* from an aqueous solution or suspension an organic substance. Assume that in the preparation of an organic compound, we have 10 ml of distillate which contain 1 g of substance in solution. The usual procedure is to add a certain amount of ether and after shaking the mixture to separate the ether layer and, after drying, distill the ether. A number of questions can be raised about such operation. How much ether should be used? How many times should the extraction be performed in order to remove practically all the dissolved material?

The distribution of a solute between two immiscible solvents depends on its solubility in each and also on the amount of each solvent present. The dissolved substance distributes itself between the two immiscible solvents so that the ratio of its concentration in each solvent remains a constant for any particular temperature. This principle, called the *distribution law*, as applied to aqueous solutions, can be expressed mathematically by the following equation:

$$\frac{C_2}{C_1} = K_d$$

where C_1 is the concentration in the aqueous layer and C_2 the concentration in the ether layer, or any other immiscible solvent, and K_d is the distribution constant. Let us assume that the distribution constant of the substance contained in the distillate mentioned in the introductory paragraph is 4. Suppose we use 10 ml of ether to extract the 10 ml of distillate. If we assume that x g of the substance will pass into the ether layer, then the amount of substance which will remain in the aqueous layer will be the total amount less x, or $1-x$. Then according to the distribution law:

$$\frac{C_2}{C_1} = K_d = \frac{\frac{x}{10}}{\frac{(1-x)}{10}} = 4; = \frac{x}{(1-x)} = 4, x = 0.8$$

After one extraction with 10 ml of ether, 0.8 g of the substance, or 80 per cent, will be in the ether layer while 20 per cent will remain in the aqueous layer. Suppose, however, we used the 10 ml of ether in two 5-ml portions. Then we would have:

First Extraction *Second Extraction*

$$\frac{\frac{x}{5}}{\frac{(1-x)}{10}} = 4; x = 0.666 \qquad \frac{\frac{x}{5}}{\frac{(0.333-x)}{10}} = 4; x = 0.22$$

Total for 10 ml = 0.666 + 0.22 = 0.886 g = 88.6 per cent

In accordance with these considerations, two extractions using 5 ml of ether in each are more efficient than one extraction with 10 ml of ether. Similarly, if the same amount is used in three portions the efficiency will be still better. Actually, in semimicro work it is not practical to work with very small volumes, since losses occur in manipulation. Three extractions using 5 ml of ether each time would remove 0.96 or 96 per cent of the substance dissolved in water. In macro work the problem, although of the same nature, is handled more easily, since the quantities are greater and losses of small amounts are not so significant as in micro work. Assume, for example, that in macro work the quantities involved are 10 times those considered above. The amount of ether used is 100 ml. If the extraction is accomplished by using three portions of ether, 33.3 ml each time, then the amount of substance extracted will be: 5.71 g for the first, 2.84 g for the second, and 0.93 g for the third extraction or 93.8 per cent of the total. Accordingly, 9.38 g of the substance are extracted by ether, leaving 0.62 g in the water layer.

Difficulties are encountered in some extractions with immiscible solvents because of the formation of emulsions which prevent a sharp separation of the layers. Suspension of solid particles tends to stabilize emulsions, and it is advisable, if possible, to filter the solution before extraction and to avoid violent shaking. Emulsions are often "demulsified" by the addition of more solvent, an electrolyte like salt, a few drops of alcohol (in the case of ether extracts), and application of suction to the vessel.

Experiment 26

PREPARATION OF AMINES BY AMMONOLYSIS

Introduction. Amines are organic derivatives of ammonia, with one, two, or three hydrogen atoms replaced by an organic radical. The three types of amines, primary (RNH_2), secondary (R_2NH), and tertiary (R_3N), may be prepared by the reaction of monohalides with ammonia. In the case of reactive halides, like methyl iodide, the reaction proceeds to the formation of the quaternary salt—tetramethylammonium iodide:

$$NH_3 + CH_3I \xrightarrow{NH_3} [NH_3CH_3^+]I^- \xrightarrow{NH_3} CH_3NH_2 + NH_4^+I^-$$

$$CH_3NH_2 \xrightarrow{CH_3I} (CH_3)_2NH \xrightarrow{CH_3I} (CH_3)_3N \xrightarrow{CH_3I} [(CH_3)_4N]^+I^-$$

When one mole of methyl iodide and four moles of ammonia are used, the formation of primary, secondary, and tertiary amines proceeds rapidly, so that within two minutes the formation of tetramethylammonium iodide assumes the dominant role of the reaction. About seventy-five per cent of the methyl iodide is converted to the quaternary salt, while the remainder forms a mixture of the three amines. The formation of the quaternary salt can be inhibited to a large extent by the addition of an ammonium salt, such as ammonium nitrate, which reacts with the free amino group of the amine to form the ion:

$$CH_3NH_2 + NH_4^+ \longrightarrow CH_3NH_2H^+ + NH_3$$

Since the amino group is blocked, the formation of secondary and tertiary amines is inhibited.

The ammonolysis of the alkyl monohalides suffers from the difficulties involved in the separation of the mixture of amines. The reaction is best carried out by adding the halide to a saturated (15–20%) alcoholic solution of ammonia. If a greater proportion of primary amine is desired, 9–10 moles of ammonia and one mole of halide are allowed to stand at room temperature for several days, or ammonium nitrate is added and the amount of ammonia is reduced. The addition of salt reduces the solubility of the halide and the reaction time is lengthened. If shaking is used, the reaction time is greatly shortened.

If secondary and tertiary amines are desired, only 2 to 3 moles of ammonia are used. Aqueous ammonia does not react to any extent at room temperature, owing to the immiscibility of halide and water. Industrially, aqueous ammonia is used and heated in an autoclave under pressure. Tertiary halides, as, for example, *tert*-butyl and *tert*-amyl bromides, do not yield amines, but yield olefines almost exclusively. The object of the present experiment is to illustrate the ammonolysis of alkyl halides. The ammonolysis of aryl halides cannot be easily accomplished in the laboratory, as it involves the use of high pressure, and temperatures of about 200°. Industrially the method is practical.

(A) **Ammonolysis of Methyl Iodide.** In each of two test tubes provided with solid rubber stoppers place 10 ml of a saturated solution of ammonia in 90 per cent methanol. Add to one of the tubes 3 g of ammonium nitrate, stopper, and shake until the salt dissolves. Add to each of the tubes 1 ml (2.3 g) of methyl iodide, shake for a few seconds, and place in a beaker of cold water. Note the time required for the quaternary salt to separate in one of the tubes.

After 10 minutes, filter the contents of the tube which shows a precipitate. Collect the filtrate in a small dish, and wash the crystals with 5 ml of methanol. Use the quaternary salt according to directions given in section (B).

Unite the filtrates with the contents of the tube in which no precipitate was formed. Allow to stand for half an hour. Place the mixture in an evaporating dish and evaporate on a water bath. When the volume has been reduced to 2–3 ml, transfer into a test tube, and wash the dish with a few ml of water which is also added to the tube. Boil off the traces of alcohol, cool for a few minutes and then add 2 ml of $6N$ sodium hydroxide. Note the odor. Heat and light the vapor ascending from the mouth of the tube. Methylamines differ from ammonia in that their vapors are combustible.

(**B**) **Quaternary Base.** Dissolve 0.1 g of tetramethylammonium iodide in 10 ml of water. Use 2 ml to test the *p*H. To another 2-ml portion add a drop of silver nitrate solution. To the remainder add 2 ml of sodium hydroxide solution and heat. Note whether there is any odor of ammonia or amine, and hold moistened litmus over the tube.

To 15 ml of 10 per cent solution of silver nitrate add 4–5 drops of $6N$ sodium hydroxide solution. Shake, and allow the precipitate to settle. Decant, and wash with water 3 times. Filter, and wash the silver hydroxide until free from alkali (test). Make a hole in the filter paper and wash the precipitate into a test tube with 5 ml of water. Add 1.0 g of tetramethylammonium iodide. Shake, and allow to settle. Note the change. Filter through a clean funnel, and test the *p*H of 1 ml of the filtrate. Tetramethylammonium hydroxide is not volatile. Place the filter paper containing silver iodide in a bottle labeled "silver residues."

Experiment 27

PREPARATION OF ANILINE

Introduction. The preceding experiment illustrated the preparation of amines by the replacement of the halogen atom by the amino group. The present experiment illustrates the preparation of amines by the reduction of nitro compounds. The reduction of the nitro compounds is analogous to the reduction of nitric acid to ammonia:

$$HNO_3 + 8\ e + 8\ H \longrightarrow NH_3 + 3\ H_2O$$

$$RNO_2 + 6\ e + 6\ H \longrightarrow RNH_2 + 2\ H_2O$$

In the reduction either tin or iron and hydrochloric acid may be used:

$$2\ C_6H_5NO_2 + 3\ Sn + 12\ HCl \longrightarrow 2\ C_6H_5NH_2 + 3\ SnCl_4 + 4\ H_2O \qquad (1)$$

$$C_6H_5NO_2 + 2\ Fe + 6\ HCl \longrightarrow C_6H_5NH_2 + 2\ FeCl_3 + 2\ H_2O \qquad (2)$$

The use of tin involves a number of difficulties. The chlorides of tin produced in the presence of an excess of hydrochloric acid give chlorostannic acid, which combines with aniline and some other arylamines to form complex double salts as shown in equation (4). In order to decompose these salts alkali is used. A great excess must be employed in order to change the stannic hydroxide, which is formed, to soluble sodium stannate:

$$SnCl_4 + 2\ HCl \longrightarrow H_2SnCl_6 \qquad (3)$$

$$2\ C_6H_5NH_2 + H_2SnCl_6 \longrightarrow (C_6H_5NH_2)_2 \cdot H_2SnCl_6 \qquad (4)$$

$$(C_6H_5NH_2)_2 \cdot H_2SnCl_6 + 8\ NaOH \longrightarrow 2\ C_6H_5NH_2 + Na_2SnO_3 + 6\ NaCl + 5\ H_2O \qquad (5)$$

Comparison of tin and iron as reducing agents. Tin is traditionally used for the preparation of aniline in the laboratory, since it gives good yields. Iron is employed industrially as a reducing agent. The amount of hydrochloric acid used is less than 5 per cent of the amount indicated by equation (2), due to the hydrolysis of the ferric chloride produced to ferric hydroxide and this makes available the necessary concentration of hydrogen ion. The time required for the reduction is much longer than when tin is used. This, of course, is not a serious obstacle in industry. The reaction is started in a pot provided with a stirrer and allowed to proceed without much watching. In the laboratory the time element, particularly in the case of students, is of some importance. The reduction of 0.3 moles of aniline requires about 1–1.5 hours when tin is used. If iron is used without stirring, the reduction is not complete even after 12 hours of boiling. The amount of nitrobenzene used in the semimicro method is 0.03–0.04 moles. The reduction must be complete, since the quantities involved are small and the separation of a mixture of 1.5–2 g of aniline and nitrobenzene is extremely difficult.

The problem of using iron instead of tin in the laboratory and effecting the reduction in 1–2 hours without stirring is solved by considering some of the conditions of the reaction. When tin is used, as soon as some of the nitrobenzene is reduced it is removed in the form of a double salt. (See equations 1, 3, and 4 above.) Iron halides do not form double salts, and since only a small amount of hydrochloric acid is used, some of the aniline remains in the form of free oily aniline. The reaction mixture consists of water, iron powder, nitrobenzene and some aniline, which are immiscible with water. In other words, we have a solid phase and two immiscible liquid phases; since the rate of the reaction depends to a large extent on an intimate contact between the solid, the oily nitrobenzene, and the aqueous acid, the conclusion is that some type of dispersing agent must be used. Stirring, even if it is vigorous, does not accomplish good dispersion, for it breaks the nitrobenzene into droplets. A small amount of colloidal clay called *Bentonite* added to the reaction mixture gives the required dispersion and permits the use of iron in this reduction. The reduction can thus be completed in two hours, whereas without the use of the dispersing clay the reduction is incomplete even after 12 hours of boiling.

After the reduction of nitrobenzene is completed, it is necessary to neutralize any excess of acid present and decompose the aniline salts. When tin is employed as a reducing agent, it is necessary to use about 7–8 moles of sodium hydroxide for each mole of aniline. When iron is employed, a small amount of sodium carbonate is used to neutralize the excess of acid and decompose the aniline salts. After this operation the reaction mixture is subjected to steam distillation to separate the aniline from the mixture.

Steam distillation. The separation of aniline from the mixture of inorganic salts by steam distillation illustrates an important method, often employed in the organic laboratory, of vaporizing organic compounds at temperatures which are far below their boiling points. Thus aniline, which boils at 184° at one atmosphere pressure, is distilled with steam at a temperature below 100°. The topic of steam distillation was briefly mentioned in connection with the discussion of distillation in general (pages 57 to 60). It will be recalled that two liquids which are miscible with each other, and therefore form solutions, lower the vapor pressure of one another. When the combined vapor pressure equals the atmospheric pressure the mixture boils at a temperature intermediate between the boiling points of the two components, unless an azeotrope is formed. But with an immiscible pair of liquids, like water and carbon tetrachloride, neither component lowers the vapor pressure of the other. Therefore if a mixture of these two liquids is heated, boiling will occur when the combined vapor pressure of water and carbon tetrachloride equals one atmosphere. This takes place much below the boiling point of the higher component (water). It is possible to calculate the approximate boiling point of such mixture from vapor pressure data which are listed in handbooks. Table 5 shows data obtained from the literature for water and carbon tetrachloride.

Table 5

VAPOR PRESSURES OF WATER AND CARBON TETRACHLORIDE
(In millimeters of mercury)

	TEMPERATURE				
	60°	65°	66°	67°	70°
I Vapor pressure of water	149	192	196	205	234
II Vapor pressure of carbon tetrachloride	451	531	548	565	622
Combined vapor pressure of I and II	600	723	744	770	856

From these figures it becomes apparent that a mixture of carbon tetrachloride and water will boil at 66–67°, which is 33° below the boiling point of water and 10° below the boiling point of carbon tetrachloride. The exact boiling point can be calculated by interpolation as 66.6°. It should be mentioned that the values for the vapor pressure of carbon tetrachloride at 66° and 67° were also obtained by interpolation. By the same method it can be calculated that *o*-cresol which boils at 190° will distill with steam at 99°; similarly a mixture of toluene and water boils at 85°.

Aniline boils at 184°. A mixture of water and aniline boils at 98.4°. The vapor pressure due to water is 718 mm and that due to aniline is 42 mm. Therefore the distillate will consist of 718 moles of water and 42 moles of aniline. In other words, there will be (718/42) 17 molecules of water for every molecule of aniline in the vapor passing in the condenser, no matter whether there are 3 g of aniline and 1000 g of water in the boiling flask or 100 g of aniline and the same amount of water. The relative ratio of aniline to water of 1 to 17 is a mole ratio. To convert it to weight ratio each figure is multiplied by the molecular weight of the substance which it represents: (1 × 93) to (17 × 18) = 93:306, or 1:3.3. Therefore theoretically it takes 3.3 g of steam to carry over 1 g of aniline. In practice the mixture is distilled until the distillate becomes almost clear, which shows the absence of minute droplets of the immiscible substance.

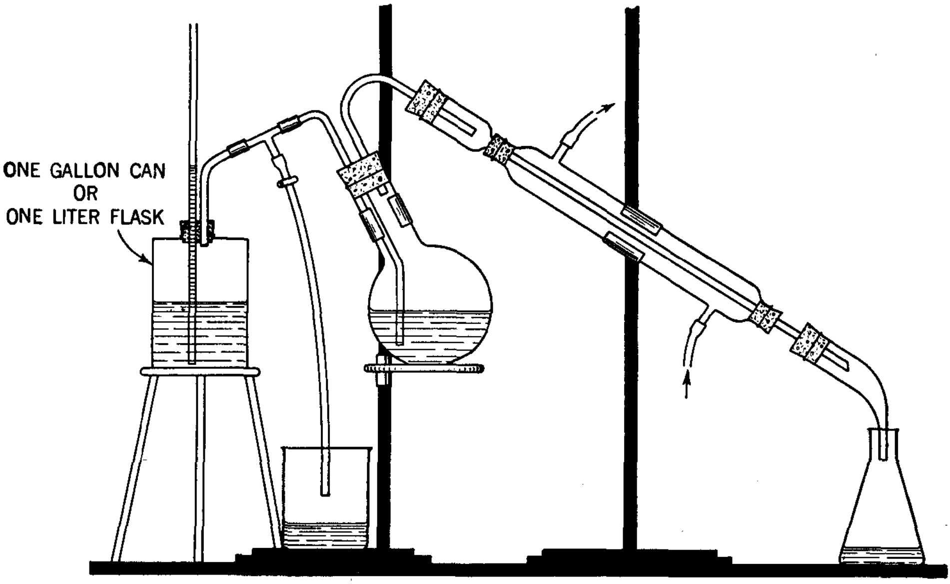

Fig. 48. Macro apparatus for steam distillation

Apparatus for macro steam distillation. Figure 48 shows the common setup for macro steam distillation. It is advisable to generate the steam in another vessel and pass it vigorously into the mixture to be steam distilled. For the steam generator, an ordinary one- or two-liter Florence flask may be used. If a number of steam distillations are to be performed it is more convenient to employ a one-gallon can (9 × 4 inches) such as is commonly used to ship solvents. The can or flask is fitted with a two-hole rubber stopper or cork. A tube 6–8 mm in bore and 60–80 cm in length is fitted through one of the holes so that it reaches almost to the bottom of the vessel and serves as a water pressure gauge. The steam-outlet tube fits through the other opening, and connects with a trap for the water which condenses before it reaches the boiling flask. By means of a pinch clamp the water is drained from time to time. The boiling flask is tilted to accommodate the rapid inlet of steam without spattering. In prolonged steam distillations it is advisable to preheat the mixture in the boiling flask and wrap the latter in a towel or other insulating material, so as to minimize the condensation of steam in the boiling flask. Steam admission should be as vigorous as possible, which involves the use of a very efficient condensing system. For ordinary steam distillations the flame of the steam generator is adjusted so that no uncondensed vapor passes out of the condenser tube. The use of a receiver cooled by circulating water is of help, and permits a more vigorous steam injection. In prolonged steam distillations it is advisable to use some type of special condensing system. One of the more common adaptations is to have the condenser tube connect through a two-neck addition tube. An upright (reflux) condenser fits through the other neck of the tube. The outlet of the addition tube passes through a stopper into the mouth of a two- or a five-liter round-bottom flask which is placed on an incline in a pail through which cold water circulates. Another type can be made with a little glass-blowing, by sealing an outlet tube at the bottom of a five-liter round-bottom short-neck flask. The flask is placed in a pail, which is converted to a water jacket by making three openings and soldering on collars into which corks or stoppers can be fitted. Two openings at the sides serve for water inlet and outlet. The flask is so placed in the pail that the bottom outlet passes through the opening into the receiver below. The mouth of the flask is fitted with a two-hole stopper, one for the vapor inlet and the other for an upright condenser. This apparatus for steam distillation is compact and it permits very rapid steam injection.

Semimicro steam distillation. Two different setups may be used, depending upon whether the student has available the heating bath described on pages 11–12. If this heating bath is not available and the amount of liquid to be distilled is about 5–7 ml, use the apparatus shown in Figure 49. Fit a No. 9 solid rubber stopper, or a No. 20 cork, on a wide-mouth 250-ml Erlenmeyer flask. The mouth of this flask has a diameter of about 40 mm. Drill very carefully on one side of the stopper an opening for a six-inch test tube. Then on the other side of the stopper drill two openings for 4 mm tubing. Insert the six-inch tube in the stopper so that only 20 mm projects outside. Place on the tube a two-hole stopper which holds two tubes of 4 mm bore. One tube is 160–170 mm in length and serves as the steam inlet; it reaches almost to the bottom of the tube and is curved at the other end so that it can connect with the steam outlet

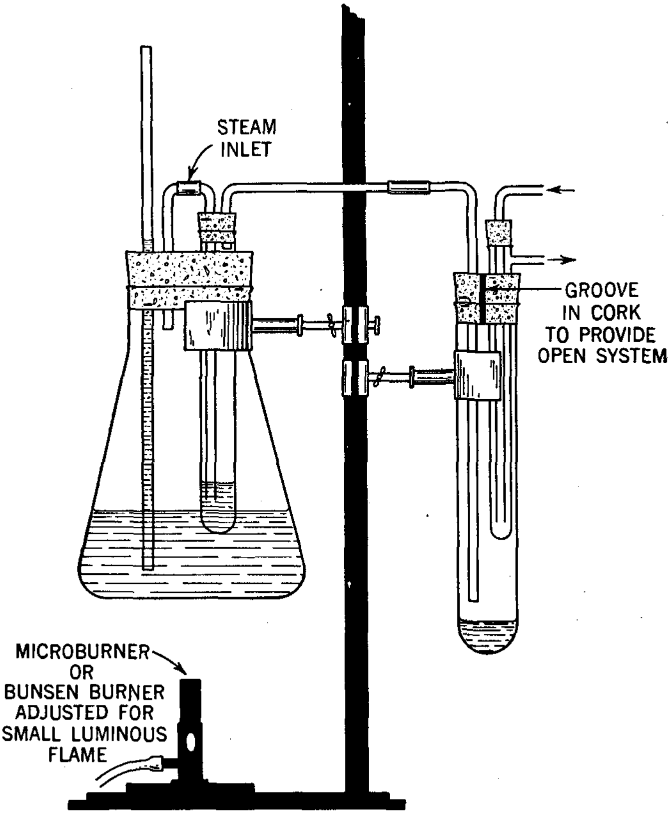

Fig. 49. Semimicro apparatus for steam distillation, using six-inch tube

from the flask. The other is a regular L-shaped short tube for a vapor outlet to the condenser.

Place 100–125 ml of water in the Erlenmeyer flask and 2–3 boiling stones. Fit the stopper carrying the test tube securely into the mouth of the flask. Insert a piece of glass tubing 300–350 mm in length through one of the small openings of the stopper, and push it until one end reaches almost to the bottom of the Erlenmeyer flask. Through the other opening fit a glass tube so bent that it is aligned with the steam injecting tube. The connection is made by

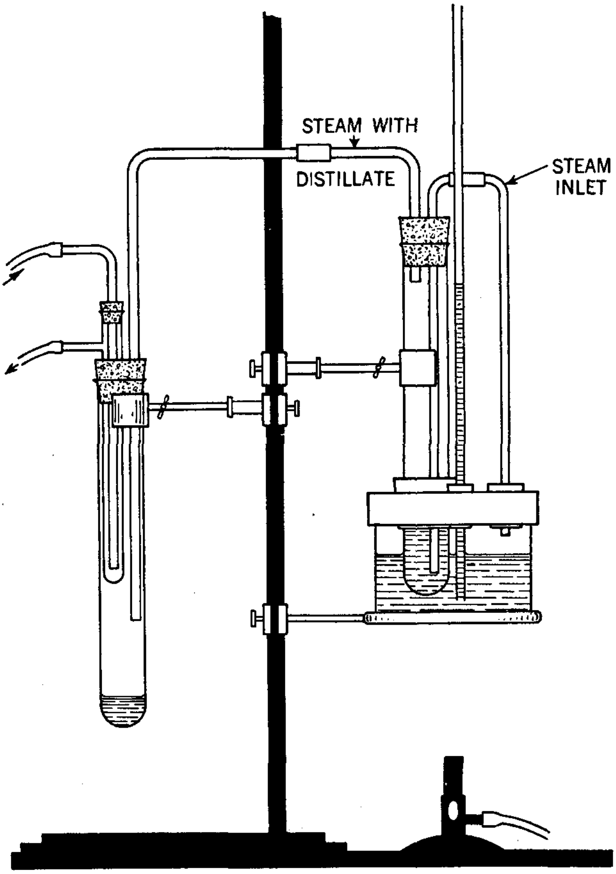

Fig. 50. Semimicro apparatus for steam distillation, using eight-inch tube

a short piece of rubber tubing. Perfect alignment of the steam outlet and steam injector is necessary to prevent kinking in the rubber connection. Finally, connect the vapor outlet from the six-inch boiling tube with a regular semimicro condensing system. The apparatus is now ready for charging.

The metal heating bath permits the steam distillation of 15–20 ml of a liquid mixture, and also affords great flexibility in operation, since the space to fit the various tubes is not limited. Since the time required for semimicro steam distillation is not long, volumes of 30–40 ml can be steam-distilled in two portions. To convert the heating bath into a steam distillation apparatus such as is shown in Figure 50, fit a No. 20 cork or a No. 9 rubber stopper into the largest opening of the bath. Carefully bore the stopper to hold an eight-inch tube snugly. Push the tube gently in far enough so that when the stopper is in place the tube reaches almost to the bottom of the bath. Fit a No. 14 cork or No. 6 one-hole rubber stopper through the other large opening of the bath. Fit a piece of glass tubing, 4–5 mm in diameter and curved slightly at one end, through this stopper to serve as the steam outlet. It connects through a small piece of rubber tubing with the steam injector, which is a glass tube of the same bore and 210–220 mm in length, and reaches almost to the bottom of the eight-inch tube. The vapor outlet projects 40 mm above the tube before it bends to connect with the condensing system. It is advisable to make the vapor outlet of tubing 5–6 mm in bore. This minimizes the danger of clogging and of carrying over in the distillate spattered material from the boiling tube. Fit a glass tube 4–5 mm in bore and 300–350 mm in length through a stopper and place it in one of the small openings of the bath. The long glass tube reaches almost to the bottom of the bath and serves as a water and pressure gauge. Close the remaining opening of the bath by a solid stopper.

Place the liquid to be steam-distilled in the tube (of either apparatus) and disconnect the rubber tubing which joins the steam inlet and steam injector. Place the flask or bath on a ring stand and clamp securely. Heat until the water rises in the gauge and steam issues from the steam-outlet tube. Remove the flame momentarily; after about 30 seconds connect the steam inlet with the injector, and resume heating. Adjust the flame so that the splashing does not reach the middle part of the vapor outlet tube. Use an eight-inch tube in the receiving system. If the micro condenser is not sufficient to cool the vapor, raise a beaker of cold water under the receiving tube.

(A) Preparation of Aniline (Sm.). (Use of iron as reducing agent.) Place in an 8-inch tube 0.5 g of Bentonite clay,[1] 3 ml of nitrobenzene, and 16 ml of 6 *N* hydrochloric acid. Place a micro condenser on the mouth of the tube arranged for reflux. Heat to boiling. Remove the flame, and add in small portions, with a micro spatula, over a period of 15 minutes, 4.5 g of iron powder. The heating is resumed after each addition, but the flame is adjusted so that the boiling is gentle. The iron should be powder and not filings, and all adhering grease and oil should be removed by washing with a little acetone or ether.[2] After the addition of the iron powder the reaction mixture is boiled for two hours, when practically all the odor of nitrobenzene will have disappeared.

Cool, and add in small portions solid sodium carbonate until the reaction mixture is distinctly alkaline after stirring with a glass rod. If a metal heating bath is available, construct the steam-distillation apparatus as directed, and proceed with the distillation, using the same eight-inch tube for a boiling tube. If the Erlenmeyer steam distillation setup is to be used, distill in two portions. Continue the steam distillation until 12–15 ml of distillate has been collected. Add 3 g of sodium chloride and shake until the salt is dissolved.

Extract with three 5-ml portions of ether, and unite the ethereal solutions. Add 2 g of sodium hydroxide (flake or crushed pellets), and shake. If an aqueous solution forms, pour the ether into a dry tube, and add 2 g of fresh sodium hydroxide. Allow to stand overnight. Pour the ether into a large distilling tube, add two small boiling stones, and distill the ether from a water bath. Remove the water bath, and empty the ether from the receiving tube into the bottle designated by instructor; wipe the distilling tube with a cloth and heat with a small smoky flame. When the temperature reaches 175°, change the receiving tube. The fraction which boils at 180–185° is collected in a tared tube. The yield is 1–1.5 g.

(B) Preparation of Aniline (Sm.). (Use of tin as a reducing agent.) Place 3 ml of nitrobenzene and 14 ml of concentrated hydrochloric acid in an eight-inch tube, and arrange for reflux with a micro condenser. Add in small portions 6.5 g of granulated tin. The reaction is controlled by the rate of addition of the metal. Shake the tube from time to time. When all the tin is added, boil gently for half an hour until the odor of nitrobenzene disappears.

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[1] A satisfactory colloidal clay (Volclay) can be obtained from the American Colloid Co., Chicago, Ill.

[2] It is more economical to wash enough iron powder for the needs of one class than to have each student perform the operation.

Cool, and add 7 g of solid sodium hydroxide[3] in small portions, cooling the tube by immersion in cold water. Stir with a rod. When all the alkali has dissolved, steam-distill as directed in section (A).

(C) **Preparation of Aniline (M.). (Use of iron as reducing agent.)** In a 500 ml round-bottom or Florence flask place 30 ml (35 g) of nitrobenzene, 5 g of Bentonite clay, 120 ml of water, and 20 ml of concentrated hydrochloric acid. Heat to boiling, remove the flame, and after a minute or so lift the cork which holds the condenser, and add all at once 36 g of iron powder.[4] Replace the cork at once and allow the vigorous reaction to proceed for 2–3 minutes, then resume heating. Boil briskly for 2 hours. Cool the reaction mixture, and add 50 ml of water and 8–10 g of sodium carbonate. The carbonate is added gradually to avoid frothing. Set up a steam distillation apparatus as directed (Figure 48), and steam-distill the reaction mixture until the distillate is perfectly clear. Saturate the distillate with 30 g of commercial sodium chloride, and extract with three 50-ml portions of ether. Dry the combined ethereal solutions with 6–8 g of sodium hydroxide pellets. If an aqueous solution forms on shaking, decant the ether solution into another dry flask and add a fresh amount of sodium hydroxide. Allow the ether to stand overnight. Pour one-half of the ether solution into a 125-ml distilling flask and distill off the ether from a water bath, observing the precautions given on pages 155–156. After most of the ether has distilled, add the remaining portion, and continue the distillation until all the ether has been removed. Remove the water bath, wipe off the outside of the flask, and heat the flask with a small free flame. When the temperature of the vapor reaches 120°, disconnect the water in the condenser and allow the jacket to drain, thus converting it to an air condenser. The fraction which boils at 180–185° is collected in a tared flask or bottle. The yield is 20–23 g.

(D) **Preparation of Aniline (M.). (Use of tin as reducing agent.)** Place 30 ml (35 g) of nitrobenzene and 65 g of tin in a flask. Provide with a reflux condenser, and add in 10-ml portions, over a period of half an hour, 140 ml of concentrated hydrochloric acid. The reaction should be vigorous; it can be controlled by the rate of addition of the acid and by immersing the flask momentarily in a pail of cold water. The rate of addition can be

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[3] Commercial grades of the solid, in the form of flakes, are more economical than the pure pellets.

[4] See note on page 171 for removal of oil and grease from iron powder used for reduction.

increased after about 15 minutes. Shake the mixture frequently. After the addition of acid is complete, warm the mixture on the water bath until the odor of nitrobenzene has disappeared. Cool, and add very slowly, with cooling, a solution of 110 g of sodium hydroxide (flake) in 200 ml of water.

Caution: Use care in making concentrated alkali. The solution is accompanied by heat. Hot concentrated alkali produces dangerous burns.

The oxides of tin which separate out at first dissolve towards the end. The solution should be distinctly alkaline. From this point on proceed with the steam distillation as directed in section (C). The yield of aniline is 23–25 g, slightly higher than the yield obtained in the reduction of nitrobenzene by iron.

Experiment 28

REACTIONS OF AMINES

NOTE: A number of the tests described in this experiment, such as the Hinsberg reaction, may be given as demonstrations by the instructor.

Introduction. The object of this experiment is to illustrate some of the most important reactions of amines. Like ammonia, amines are basic and form salts. The strength of the base in aqueous solution can be approximately estimated by determining the *p*H of the solution. The salts of weak amines undergo hydrolysis.

Primary and secondary amines possess replaceable amino hydrogen atoms. With acid chlorides (RCOCl) or anhydrides, $(RCO)_2O$, they yield crystalline derivatives which are very useful in their separation and identification. Benzoyl derivatives are often preferred to acetyl derivatives because the former are less soluble and have higher melting points; further, benzoyl chloride, unlike acetyl chloride, is not easily hydrolyzed in water, and hence the acylation can be carried out in aqueous solutions. Tertiary amines do not react and therefore can be obtained unchanged.

Benzenesulfonyl chloride is used for the systematic separation of the three classes of amines:

$$\mathrm{RNH_2,\ R_2NH,\ R_3N + C_6H_5SO_2Cl} \longrightarrow \left[\begin{array}{ll} \mathrm{RNHSO_2C_6H_5} & (1)\\ \mathrm{R_2NSO_2C_6H_5} & (2)\\ \mathrm{R_3N} & (3)\end{array}\right.$$

Derivative (1) is soluble in alkali, while derivative (2) is not. The tertiary amine (3) remains unchanged and can be extracted with ether.

Amino groups possessing replaceable hydrogen atoms react with nitrous acid. The tertiary amines are not affected, except for the formation of a salt (nitrite). Secondary amines with nitrous acid yield nitrosoamines. The nitrosoamine can be easily reduced back to the secondary amine by zinc and acid.

(A) **Solubility.** Methyl and ethyl amines are very soluble in water. Try the solubility of the three *butylamines*, of *aniline*, and of *methyl* and *dimethyl aniline*, by adding a drop to 2 ml of water. Save the solution for the next test.

(B) **Ionization.** Add 2 drops of Universal indicator to the amine solutions prepared in (A) and determine the approximate pH of each. Also determine the pH of 2 ml of $0.1\,N$ solutions of *methyl, dimethyl*, and *trimethyl amines*. Tabulate your observations.

(C) **Salt Formation.** To 2 ml of 33 per cent methyl amine solution add 3 ml of alcohol and 2 drops of 0.04 per cent bromophenol blue. Cautiously add concentrated hydrochloric acid, drop by drop, until the mixture is acid. If the salt does not separate on cooling, pour the solution on a watch glass and concentrate it on the steam bath. Filter the crystals. Repeat, using aniline. Aniline hydrochloride separates on cooling without evaporation.

(D) **Acetylation of Amines.** Place 1 ml of *aniline, dimethylaniline*, and n-*butylamine* in separate test tubes. Add to each of the tubes 2 ml of acetic acid (glacial) and 3 ml of acetic anhydride. Heat the tubes in boiling water for 3 minutes. Add slowly 10 ml of water. If no acetyl derivative forms, neutralize carefully with dilute ammonium hydroxide. Filter with suction, and wash the crystals with a small amount of water. Dry, place in small vials, label, and hand to the instructor.

(E) **Benzoylation of Amines (Schotten-Baumann Reaction).**[1] Place in an eight-inch tube 1 ml of aniline, 15 ml of 10 per cent aqueous sodium hydroxide solution, and 1.4 ml (1.7 g) of benzoyl chloride. Close with a No. 5 or No. 6 solid rubber stopper, and shake vigorously at intervals for 5–10 minutes, removing the stopper after each shaking. The mixture becomes warm and the benzoyl derivative separates out. Filter, and wash the crystalline product with water. The crude benzanilide may be recrystallized from water (m.p. 163°). The yield is 1.2–1.4 g.

(F) **Separation of Amines by the Use of Benzenesulfonyl Chloride (Hinsberg Reaction).** For this experiment the primary, secondary, and tertiary butylamines may be used, or aniline, methylaniline and dimethylaniline. To 1 ml of primary, secondary, and tertiary amine, in separate tubes, add 5 ml of $6\,N$ sodium hydroxide solution, 4 ml of water, and 2 ml of benzenesulfonyl chloride. The tubes are stoppered and shaken at intervals for 5 minutes while they are warmed in a water bath. The rate at which heat is

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[1] For a more extensive discussion of the acetylation and benzoylation of the amines the student is referred to p. 214.

developed when first shaken is a rough indication of the speed with which the amines react. The contents of the tubes are acidified cautiously with hydrochloric acid. If the derivative separates out as an oil, decant the aqueous layer, add some water and shake vigorously. Filter, and test the solubility of both derivatives in dilute sodium hydroxide solution.

(G) **Action of Nitrous Acid on Amines.** (1) **Primary Amines.** To 3 ml of methylamine solution in a test tube, add 3 ml of water and 2 g of solid sodium nitrite. Add slowly in small portions 2 ml of dilute sulfuric acid. After a few minutes, warm, and note the effect. What product remains behind? By what test may its presence be detected?

To 0.5 ml of aniline add 5 ml of dilute sulfuric acid, then slowly add 4.5 ml of 10 per cent solution of sodium nitrite. Allow to stand for a few minutes, then warm to 50°. After all the gas has been given off, it is possible, by heating, to detect the presence of phenol.

Repeat the above, but cool to 5° while adding sodium nitrite. Add 0.5 ml of β-naphthol dissolved in 1 ml of dilute sodium hydroxide and 3 ml of water. How does this reaction differ from the reaction obtained when the solution is warmed?

(2) **Secondary Amines.** Place 1 g of diphenylamine in a test tube, add 5 ml of alcohol, and warm in order to dissolve. Add 1 ml of concentrated hydrochloric acid, and cool to 5°. Add slowly 4 ml of sodium nitrite solution (10 per cent). Allow to stand for a few minutes, add 10 ml of water, and cool. Filter the crystals of diphenylnitrosoamine. The yield of crystals is 1.2 g, melting at 66°.

(3) **Tertiary Amines.** Repeat (G–1), using 3 ml of trimethylamine solution. Is it possible to determine whether nitrous acid has any effect upon tertiary amines?

Although nitrous acid has no effect on the tertiary amine group, except for the formation of a nitrite, it has a noticeable effect on the aryl amines in that the hydrogen atom para to the NH_2 group becomes reactive. Thus, with nitrous acid, the nitroso derivative is produced. To 1 g of dimethylaniline in 5 ml of water, add 3.5 ml of concentrated hydrochloric acid. Cool, and add 6 ml of 10 per cent solution of sodium nitrite in small portions. Allow to stand. The hydrochloride of the nitroso derivatives separates out.

(H) **Oxidation of Amines.** (1) To 1 ml of methylamine in a test tube, add 2 ml of alkaline permanganate, and to another portion add acid dichromate. How does the ease of oxidation compare with that of methyl alcohol?

(2) To a few milliliters of potassium permanganate, and also of

acid dichromate, add a few drops of aniline, and observe any evidence of oxidation.

(**3**) To 2 ml of trimethylamine (33 per cent solution) add 13 ml of 3 per cent hydrogen peroxide. Cork, and let stand until the next laboratory period. Note whether any odor of amine remains. Evaporate to dryness on a water bath, and add 2 ml of alcohol. The crystals which separate out are the hydrate of trimethylamine oxide, $(CH_3)_3NO \cdot 2\ H_2O$.

(I) Isocyanide Reaction of Primary Amines. Place 1 drop of aniline in one test tube, and 1 drop of *n*-butylamine in another. Add to each 3 or 4 drops of chloroform and 1 ml of alcoholic potash. (*Use the hood.*) Warm it for a few seconds. The isocyanides can be recognized by the odor. Clean the tube with concentrated hydrochloric acid, then with water. Write the equation for the reaction. What is the structure of isocyanide?

(J) Color Reactions of Arylamines. To 10 ml of water in a test tube add one drop of aniline, and shake. Add one or two drops of a suspension of bleaching powder or a drop of a solution of sodium hypochlorite. Note the color. Repeat with *o*-toluidine, and with dimethylaniline. The production of color is due first to oxidation, and second, to condensation to complex colored compounds.

Add a few small crystals of diphenylamine to 1 ml of concentrated sulfuric acid and shake gently. Prepare a very dilute solution of nitric acid (1 drop to 5 ml of water) and add a drop of this to the diphenylamine solution; note the color. This test may be used to detect nitrates.

Experiment 29

PREPARATION OF NITRO COMPOUNDS

NOTE: If the semimicro method is used, sections (A) and (B) may be run simultaneously. The macro method is given only for nitrobenzene; if that method is used for the other preparations the quantities given for the semimicro methods should be increased proportionately.

Introduction. The replacement of hydrogen atoms by nitro groups in organic compounds takes place easily by direct nitration in aromatic compounds. Although aliphatic nitro compounds are produced industrially by nitration in the vapor phase, the rates of nitration in aromatic compounds at temperatures below 100° are such as to be usually regarded as one of the chief differences from the aliphatic.

Aryl nitro compounds are easily prepared by the action of a mixture of nitric and sulfuric acids at 50–60°. If nitration is difficult, a mixture of potassium nitrate and sulfuric acid is employed; in other cases, as in the introduction of a second nitro group, a mixture of fuming nitric and fuming sulfuric acids is used. In nitration, water is one of the products of the reaction:

$$RH + HONO_2 \longrightarrow RNO_2 + H_2O$$

The function of sulfuric acid in nitrations is to absorb the water formed, thus preventing the dilution of nitric acid. Another useful purpose of sulfuric acid is its solvent property for many organic compounds. In some cases the first action of sulfuric acid is to sulfonate. The sulfonic acid groups are subsequently replaced by nitro groups. Due to their insolubility in water, nitro compounds are rather easily separated by dilution of the nitrated mixture.

Alkyl nitro compounds are not easily prepared by direct nitration. A few, however, can be prepared by direct nitration of the hydrocarbons in the vapor phase at 400°. Most alkyl nitro compounds can be prepared by the action of metallic nitrites on halogen compounds. This reaction also gives some isomeric alkyl nitrites. The object of the present experiment is to illustrate the preparation of an aryl nitro compound.

(A) **Preparation of Nitrobenzene** (Sm.). Place in an eight-inch test tube 5 ml of concentrated nitric acid. Immerse the tube in a beaker of cold water and add *cautiously* and *slowly* 5 ml of concentrated sulfuric acid. Place a thermometer in the tube, and allow to cool until the temperature is 25°. Add 5 g (6 ml) of benzene in small portions and at such a rate that the temperature does not rise above 50°. Shake the tube gently after each addition, so as to mix the two layers. Place the tube in a bath and heat for 20 minutes at about 50–60°, shaking the mixture every 2 minutes. Pour the mixture into 50 ml of cold water, stir for a few seconds, and then separate the nitrobenzene layer. Wash with 10 ml of water, and then with 5 ml of 5 per cent sodium bicarbonate solution. If the aqueous layer contains too many dispersed droplets of nitrobenzene, extract with 2 ml of benzene. Dry with 2 g of calcium chloride for about 20 minutes, shaking vigorously at frequent intervals, or let it stand overnight. Transfer the dry liquid into a distilling tube and distill, collecting the fraction which boils at 205–208°. Toward the end of the distillation, *avoid* superheating the residue in the tube, as it may explode violently. The yield is 3.5 g.

(B) **Preparation of Nitrobenzene** (M.). The same procedure is used as described in section (A). Use a 500-ml round-bottom or Florence flask. Place in it 35 g (25 ml) of concentrated nitric acid, immerse the flask in a pail of cold water, and add in small portions 50 g (28 ml) of concentrated sulfuric acid, shaking between additions. Cool and add in small portions 25 g (30 ml) of benzene at such rate that the temperature does not rise above 50°. Heat for about 45 minutes at 50–60° and follow the procedure in section (A). Use 10 g of calcium chloride to dehydrate the product, and warm in a water bath for a few minutes to aid the dehydration. The yield is about 35 g.

(C) **Preparation of α-Nitronaphthalene** (Sm.). To 6 ml of nitrating acid mixture (equal volumes of nitric and sulfuric acids prepared as in section [A]) add in small portions 3 g of naphthalene. Shake after each addition, and do not let the temperature rise above 50°. When all the naphthalene has been added, heat the mixture in a water bath at 60° for twenty minutes, with frequent shaking. Pour the mixture into 150 ml of water and cool. Remove the cake of nitronaphthalene to a 250 ml beaker containing 100 ml of water, and boil gently for five minutes in the hood. Allow to cool for several hours. The crystals which separate out are filtered, pressed between filter paper, and dried. The yield is about 2.5–2.8 g. The product melts at 58–59°. For larger amounts (10 times the quantities given) the same procedure is used. The time of nitration (at 60°) is increased to three hours.

(D) **Preparation of *m*-Dinitrobenzene** (**Sm.**). To 5 ml of fuming nitric acid (sp. gr. 1.5) in an eight-inch tube add gradually 5 ml of concentrated sulfuric acid. To this mixture add gradually 3 g of nitrobenzene. Heat in a water bath at about 90° for thirty minutes, shaking the tubes at intervals (**care**). The reaction mixture is poured slowly into 75 ml of water, and stirred vigorously. The crude *m*-dinitrobenzene is filtered, washed with water, pressed to drain, and then dissolved in 12–14 ml of hot methanol. The solution is filtered if necessary, cooled, and 2 ml of water added. The crystals which separate out are filtered, and dried in air. The product melts at 89–90°. If the melting point is lower, recrystallize a small amount from alcohol.

(E) **Preparation of Trinitro-*tert*-Butylxylene** (**Xylene Musk**) (**Sm.**). To 5 ml of fuming nitric acid (sp. gr. 1.5) add very cautiously and slowly 5 ml of fuming sulfuric acid. The tube is cooled to 25°, and then 3 g of *tert*-butylbenzene (Experiment 61) is added gradually. The mixture is heated for 5 hours at 90–95°, with frequent shaking. The reaction mixture is allowed to cool and then poured slowly and with great caution into 150 ml of cold water. Crystals of the trinitro compound having a strong musk-like odor separate out. Cool, filter the crystals, and dry in air.

Experiment 30

IMPORTANT REACTIONS OF NITRO COMPOUNDS

Introduction. Nitro compounds are insoluble in water. Primary nitro compounds, RCH_2NO_2, and secondary, R_2CHNO_2, are soluble in alkaline solutions, due to the formation of an *aci*-form by tautomerization, which reacts with bases to form salts. The most important reaction of nitro compounds is their reduction in acid media to amines. In neutral solutions the intermediate products, hydroxylamines, may be isolated. In alkaline media, azoxy, azo, and hydrazo compounds are formed. The object of this experiment is to illustrate some of these reactions.

(A) *Aci*-Form of Nitro Compounds. Place in three tubes five drops of 1-nitropropane, 2-nitropropane, and nitrobenzene, respectively. To each add 2 ml of dilute sodium hydroxide. Shake, and note whether the compound dissolves.

If it is desired to prepare the sodium salt of the *aci*-form, proceed thus: Prepare an alcoholic solution of sodium methoxide by adding 0.2 g of sodium to 5 ml of methanol, cooling the tube slightly. When all the sodium has dissolved, add 0.5 g of 1-nitropropane, shake, and cool. The salt may be filtered, washed with methanol, and dried.

(B) Reduction of Nitro Compounds to Amines. Place 0.5 ml of nitromethane or 1-nitropropane in a test tube immersed in cold water; add 2 ml of concentrated hydrochloric acid and then a piece of granulated tin. When the reduction is complete, add with cooling 5 ml of 6 *N* sodium hydroxide solution. Note the strong odor of alkylamine. Devise a test for confirmation.

(C) Reduction to Hydroxylamines. Place in an eight-inch tube 1 ml of nitrobenzene, 20 ml of water, and 0.6 g of ammonium chloride. Add in small portions 1.6 g of zinc dust, shaking the contents of the tube. The reduction of nitrobenzene to β-phenylhydroxylamine proceeds rapidly with evolution of heat, and the temperature rises to 50–60°. When all the zinc dust has been added, shake the tube for a few minutes longer, filter the zinc oxide and wash with 2–3 ml of hot water. Add to the filtrates 6 g of salt, shake, and cool. Long yellow needles of β-phenylhydroxylamine separate.

(D) **Reduction of Nitrobenzene to Azoxybenzene.** In alkaline media the reduction of nitro compounds may give azoxy ($RN{=}N(O)R$), azo ($RN{=}NR$), or hydrazo ($RNHNHR$), depending on the amount and type of reducing agent used.

Place in an eight-inch test tube arranged for reflux 1 g of nitrobenzene, 6 ml of methanol, and 1.4 g of solid sodium hydroxide. Heat for thirty minutes or until the odor of nitrobenzene is very faint. Add the reaction mixture to 30 ml of water, and cool. The oily azoxybenzene which separates out soon solidifies. Filter the crystals. It may be recrystallized from methanol.

(E) **Reduction of Nitrobenzene to Hydrazobenzene.** Place in an eight-inch tube arranged for reflux 2 g of nitrobenzene, 3 ml of 6 *N* sodium hydroxide and 12 ml of ethanol. Heat the mixture in a water bath to about 75°. Remove the burner, and add zinc dust in 0.2 g portions until about 3 g have been added and the solution becomes pale yellow. The zinc dust is added by slightly raising the cork for a moment. The reaction is allowed to subside before any further amount of zinc dust is added. If it becomes violent remove the hot bath and cool the tube. When the reduction is complete, the mixture is poured into 40 ml of water, cooled, and then 10–12 ml of concentrated hydrochloric acid is added slowly, with stirring, until the solution is definitely acid. The crystals of hydrazobenzene which separate are filtered, and washed with cold water.

Experiment 31

OXIDATION OF ALCOHOLS TO ALDEHYDES AND KETONES

Introduction. The controlled oxidation of primary and secondary alcohols yields compounds which have less hydrogen on the carbon atom to which the hydroxyl group is attached. The oxidation products of primary alcohols are represented by the general formula RCHO and are called *aldehydes*; the products from secondary alcohols have the general formula R_2CO and are called *ketones*. Both compounds have the carbonyl (CO) group as a functional group.

Oxidation on a large scale may be accomplished by dehydrogenation. For oxidation in the laboratory, an acid-dichromate mixture, or manganese dioxide and sulfuric acid are used. The use of these reagents is limited to the preparation of aldehydes and ketones that boil below 100°. If the products are not removed as they are formed, further oxidation to acids generally occurs. Under these conditions some of the alcohol unites with the acid, producing esters. Generally, the yield of aldehydes and ketones obtained by oxidation of alcohol in the aqueous phase is poor. The amount of oxidizing agent is calculated in the usual way:

$$3\ CH_3CH_2CH_2OH \longrightarrow 3\ CH_3CH_2CHO + 6\ e + 6\ H$$

$$Na_2Cr_2O_7 + 6\ e + 14\ H^+ \longrightarrow 2\ Cr^{+++} + 7\ HOH + 2\ Na^+$$

Thus it is easy to calculate that a third of a mole of dichromate is required for every mole of alcohol. Atmospheric oxygen may be used as the oxidizing agent. When a mixture of alcohol vapor and air is passed over hot copper, the following reactions occur:

$$2\ Cu + O_2 \longrightarrow 2\ CuO$$

$$CuO + CH_3OH \longrightarrow Cu + H_2CO + H_2O$$

In the laboratory (for tests), the process can be demonstrated by heating a copper spiral and plunging it into a dilute aqueous solution of methyl alcohol. The film of copper oxide acts as the oxidizing agent; the process is then repeated until all of the alcohol is oxidized.

(A) Semimicro Apparatus for Oxidation of Alcohols. The apparatus is shown diagrammatically in Figure 51. An Erlenmeyer flask of 250 ml capacity is provided with a three-hole rubber stopper. One opening is connected through a tube with the receiver. The other opening is provided with a glass tube connected through a short piece of rubber tubing with the outlet of an inverted eight-inch separatory tube. Through the third opening passes a thermometer adjusted to such a height (the bulb should be just below the opening of the outlet tube) that it records the temperature of the distillate.

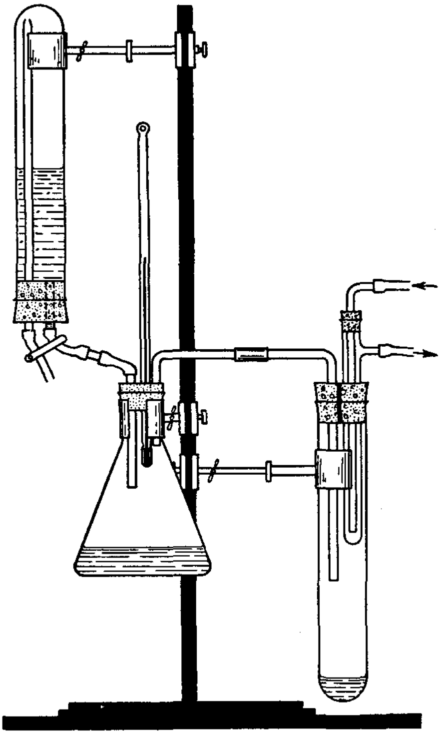


Fig. 51. Semimicro apparatus for oxidation of alcohols

Place in the flask 10 g of the alcohol to be oxidized and 20 ml of water. Prepare the oxidizing solution separately by dissolving 20 g of sodium dichromate in 28 ml of water and then adding slowly 16 ml of concentrated sulfuric acid. Cool the mixture to about 30°, then pour one half into an 8-inch test tube and fit the separatory stopper securely. To prevent the separatory stopper from slipping out, place two short pieces of wire or string under the lip of the tube and then tie across the stopper. Close the screw clamp, invert the tube and arrange in place as shown in Figure 51.

Place two boiling stones in the flask, and heat the mixture by means of a small flame until it just begins to boil. Remove the flame and allow to cool for one minute. Add the oxidizing mixture at the rate of one to two drops per second and rock the flask gently so as to mix its contents. After most of the oxidizing solution in the separatory tube has been added, charge the tube with the balance of the acid dichromate mixture. Heat the flask with a small flame before starting the addition of the oxidizing mixture. When all the solution has been added, close the screw clamp and heat the flask until the indicated temperature in each preparation is reached. The distillate contains water, unchanged alcohol and the aldehyde or ketone. The distillate is treated in accordance with directions given in each succeeding section.

(B) Preparation of Acetone (Sm.). Place 10 g of isopropyl alcohol and 20 ml of water in the "oxidation flask" described in the preceding paragraph. After heating nearly to boiling begin adding the acid dichromate mixture at such a rate that the temperature indicated by the thermometer does not go above 80°. Add about 1 ml each time, tighten the clamp and shake the flask a little by tilting and swaying the stand gently. After all the acid mixture has been added, the screw clamp is closed and the flask is heated slowly until the temperature of the distillate reaches above 96°. Remove the receiving tube (eight-inch), which contains about 8–10 ml of distillate, and fit on its mouth a fractionating column as described on pages 74–76. Add two small boiling stones and fractionate the liquid, heating very slowly. Collect fractions at 50–60°, 60–70°, and 70–80°. Reject the residue and make a second fractionation. With an efficient column the yield is 2.5–3.0 g of acetone boiling at 54–60°. About 1–1.5 g of liquid boiling at 60–70° is obtained. This fraction contains some acetone. Shake this portion with 10 ml of saturated bisulfite and let it stand. The bisulfite addition compound crystallizes out. If a refractometer is available determine the refractive index of the first fraction.

(B) Preparation of Butanone (Sm.). Place 10 g of *sec*-butyl alcohol and 20 ml of water in the flask and proceed as in the preparation of acetone. Add the oxidizing mixture, keeping the temperature of the outgoing vapors below 95°. When all the acid mixture has been added, distill for a few minutes longer after the temperature reaches 100°. Fractionate, collecting fractions at 75–85° and

85–95°. The final fraction which boils at 76–84° is collected as butanone. Pure butanone boils at 79.6°. The yield is 5–7 g.

(C) **Oxidation of Methanol.** Place 1 ml of methanol and 5 ml of water into a test tube. Prepare a spiral of copper wire by winding it around a glass tube. Heat the spiral until it is red hot and plunge it immediately into the dilute alcohol. Repeat the operation three times. Note the odor of the solution. Filter and test the solution with Tollen's reagent and Schiff's reagent according to sections (B) and (E), Experiment 34.

(D) **Preparation of Butanone (M.).** The same procedure is used as in the semimicro preparation of butanone section (B). Arrange a 500 ml round-bottom or Florence flask for fractional distillation as shown in Figure 27. The stopper which connects the fractionating column to the flask has an opening for a separatory funnel. The condenser fits through an adapter to a receiving flask immersed in cold water or ice-salt mixture.

Place 32 g (40 ml) of *sec*-butyl alcohol in the flask and add 80 ml of water and two boiling stones. Dissolve separately in a beaker 80 g of sodium dichromate in 100 ml of water and add very slowly, with stirring, 65 ml of concentrated sulfuric acid. Cool to 30° and then transfer it to a separatory funnel. Heat the flask on an asbestos-centered wire gauze until the alcohol mixture begins to boil. Remove the flame and add slowly the acid-dichromate mixture. The addition is regulated so that the temperature of the vapors entering the condenser does not rise above 95°. Do not add more than 1 ml of the oxidizing solution at one time, and occasionally shake the contents of the flask to prevent oxidation of a large amount of alcohol all at once. The heat of the reaction is sufficient to keep the mixture boiling. When all the acid-dichromate mixture has been added, raise the temperature slowly and keep it at nearly 100° for five minutes. Disconnect the flask, cool, and reject the residue. Clean the flask and transfer the distillate into it, add two boiling stones, and fractionate, using all the precautions given on page 73. Collect fractions boiling at 65–75°, 75–85°, and 85-90°. On the second fractionation collect the portion which boils at 76-82°. Pure butanone boils at 79.6°. The yield is 16–20 g.

Experiment 32

PREPARATION OF ACETALDEHYDE

Introduction. Acetaldehyde, CH_3CHO, polymerizes easily to paraldehyde, $(CH_3CHO)_3$. In the presence of a catalyst, such as sulfuric acid, the polymerization proceeds rapidly. The reaction is reversible and may be represented by the following equation:

$$3\ \underset{\text{B.p. }21^\circ}{CH_3CHO} \underset{H_2SO_4}{\overset{H_2SO_4}{\rightleftarrows}} \underset{\text{B.p. }124^\circ}{(CH_3CHO)_3} + \text{Heat}$$

For polymerization, acetaldehyde is cooled and a small amount of sulfuric acid is added. Since paraldehyde is not soluble in water and acetaldehyde dissolves readily, the polymerized mixture is washed with water to remove the catalyst and any unchanged monomer. In the pure form, paraldehyde keeps well. When acetaldehyde is needed, a few drops of sulfuric acid are added to paraldehyde, and the mixture heated in a flask to which is attached a fractionating column connected with a condenser and receiver. The receiver is cooled in a freezing mixture. The application of heat in the presence of a catalyst reverses the polymerization and aldehyde is formed.

(A) **Preparation of Acetaldehyde** (Sm.). Arrange apparatus as shown in Figure 33. Place 6 ml of paraldehyde in an eight-inch distilling tube. Add two boiling stones and 5 drops of concentrated sulfuric acid, and connect with the receiving tube. Immerse the latter in an ice-salt mixture. Heat by means of a very small smoky flame so that the temperature as indicated by the thermometer does not rise above 21°. Discontinue the distillation when the residue is about 0.5 ml. Place the aldehyde in an icebox and use it as needed.

(**B**) **Preparation of Acetaldehyde** (M.). Use a flask fitted with a fractionating column or a distilling flask having a Vigreau column. Place in the flask 100 ml of paraldehyde, 1 ml of concentrated sulfuric acid, and two boiling stones. Connect with a condenser fitted with an adapter which leads to a receiver surrounded by a freezing mixture. Place a small luminous flame under the flask and heat very slowly. The temperature in the fractionating column is not allowed to rise much above room temperature, and therefore any paraldehyde that boils off with the acetaldehyde condenses and falls back into the flask. When the distillation is complete, note whether any liquid is left in the flask. The acetaldehyde is kept at a temperature of 5–10°, and used as required.

Experiment 33

THE PREPARATION OF CYCLOPENTANONE

Introduction. The reduction of the carboxyl group (COOH) to the carbonyl group (CO) can be brought about by the simultaneous oxidation of another carboxyl group to carbon dioxide. This reaction takes place when the barium or calcium salt of acids is subjected to distillation:

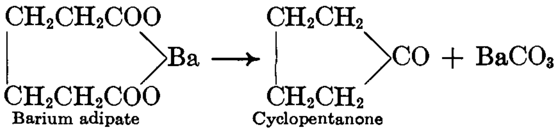
$$\underset{\text{Calcium acetate}}{CH_3\boxed{COOCaO}COCH_3} \longrightarrow \underset{\text{Ketone}}{CH_3COCH_3} + CaCO_3$$

A mixture of calcium acetate and formate gives an aldehyde:

$$CH_3\boxed{COOCaO}OCH \longrightarrow \underset{\text{Aldehyde}}{CH_3CHO} + CaCO_3$$

The yields in the laboratory are not very good, but it is possible to obtain good yields by passing the vapors of acids over catalysts at 250–300°.

The distillation of the calcium or barium salt of a dicarboxylic acid gives a cyclic ketone:



Adipic acid may be obtained from cyclohexanol by oxidation with hot nitric acid. Cyclohexanol is prepared from phenol by hydrogenation. Thus the entire series of reactions represents: (*a*) the change of an aromatic six-carbon compound to an alicyclic one; (*b*) the opening of a six-carbon ring to an open chain compound; (*c*) the cyclization of an open chain compound. The object of the present experiment is to illustrate this last step through the preparation of cyclopentanone from adipic acid.

(A) **Preparation of Cyclopentanone** (Sm.). Arrange apparatus for distillation as shown in Figure 25, using an eight-inch distilling tube. Pulverize 7.5 g of adipic acid and 0.8 g of barium hydroxide.

Mix and place in the distilling tube, arranging the thermometer so that it nearly touches the bottom of the tube. Heat with a free flame to 285–290°. Move the burner to and fro so that the heat is directed towards all sides of the tube. When the mixture has melted, adjust the flame so that the temperature remains about 290°. If the temperature is allowed to rise above 295°, adipic acid distills over and the side tube becomes clogged. Continue the distillation until only a small residue remains in the flask. Add 2 ml of saturated salt solution to the receiving tube, insert the separatory stopper, shake gently, and then withdraw the lower aqueous layer. Dry with 0.5 g of anhydrous calcium chloride and distill. The yield is 1.3–1.5 g. If a refractometer is available, determine the refractive index of your product.

(B) Preparation of Cyclopentanone (M.). Arrange a 250-ml distilling flask for downward distillation. The thermometer is so placed that it nearly touches the bottom of the distilling flask. Place in the flask 25 g of finely pulverized adipic acid and 3 g of finely ground barium hydroxide. Shake the flask so as to mix the contents, then insert the thermometer, and connect the flask with an air condenser. By means of a free flame heat the flask to 285–290°. The burner is moved to and fro so that the heat is directed at all sides of the flask. When the mixture has melted, adjust the flame so that the temperature remains at about 290°. If the temperature is allowed to rise above 295°, adipic acid distills over and the condenser becomes clogged. Continue the distillation until only a small residue remains in the flask. Transfer the distillate into a separatory funnel and add 10 ml of saturated salt solution and 10 ml of 5 per cent sodium bicarbonate solution. Shake cautiously and remove the ketone layer. Dry with 2–3 g of calcium chloride and distill. The yield is 14–18 g.

Experiment 34

REACTIONS OF ALDEHYDES AND KETONES

Introduction. The reactions of aldehydes and ketones can be conveniently divided into three groups: (1) reactions involving an addition to the carbonyl group, (2) reactions involving oxidation-reduction of the carbonyl group, and (3) condensation and polymerization reactions.

A number of addition derivatives may be used in the identification of the carbonyl compounds. Of these the crystalline derivatives formed with phenylhydrazine, $C_6H_5NHNH_2$, and hydroxylamine, NH_2OH, are the most important. The products formed with phenylhydrazine are called *phenylhydrazones*, and have the general formula, $RR_1C{=}NNHC_6H_5$. The products formed with hydroxylamine are called *oximes*, and have the general formula, $RR_1C{=}NOH$. Other crystalline addition compounds are formed with sodium bisulfite by aldehydes, and by those ketones which contain a methyl group. The addition compounds with ammonia, except in the case of acetaldehyde and a few other carbonyl compounds, are complex products.

In the oxidation of aldehydes the carbonyl group is oxidized to the carboxyl stage, producing an acid of the same carbon content as the aldehyde. In the oxidation of ketones, rupture of the carbon-to-carbon bond occurs, resulting in the formation of acids having less carbon atoms than the ketones. Therefore the rate of oxidation of aldehydes is much faster than that of ketones. Consequently aldehydes are more powerful reducing agents than ketones. For this reason mild oxidizing agents, such as Ag^+ and Cu^{++}, are easily reduced by aldehydes. The silver ion must be in the form of the silver ammonium complex, $Ag(NH_3)_2^+$. In this form the reduced silver deposits as a mirror on the walls of the test tube. The cupric ion is made by adding to a copper sulfate solution a mixture of sodium hydroxide and sodium potassium tartrate. The cupric hydroxide, $Cu(OH)_2$, which forms at first, redissolves owing to formation of a cupric tartrate complex. As the reduction proceeds the color of the solution changes from deep blue to the green color of cuprous hydroxide, $Cu_2(OH)_2$, which dehydrates slowly to form the red cuprous oxide, Cu_2O.

Condensation reactions involving the carbonyl group are illustrated by the aldol condensation. Under the influence of small amounts of hydroxyl ion two molecules of aldehyde unite to give a more complex molecule. The union occurs between the carbonyl group of one with the alpha carbon atom of another molecule:

$$2\ CH_3CHO \longrightarrow CH_3CH(OH)CH_2CHO$$

Aldehydes that do not have hydrogen atoms on the alpha carbon atom do not undergo the aldol condensation. Such aldehydes undergo the Cannizzaro reaction when treated with strong alkali. For example, formaldehyde with strong sodium hydroxide gives sodium formate and methyl alcohol:

$$2\ CH_2O + NaOH \longrightarrow HCOONa + CH_3OH$$

Since two molecules of the aldehyde form one molecule of alcohol and one molecule of acid, it is evident that the reaction is one of auto-oxidation-reduction. One molecule is oxidized and another is reduced.

NOTE: For a number of the following tests it is convenient to have the carbonyl compounds in 25 ml bottles provided with stoppers having a dropper at the end. Care must be exercised to replace the dropper in the proper bottle immediately after use. Pure acetaldehyde is kept in a bottle immersed in ice water. Of the number of tests listed the following are recommended for beginners: A, B, C, E, G, H. From the other tests selection is made depending on the time available.

(A) Solubility of Several Carbonyl Compounds. To 3 ml of water in a test tube, add 0.1 g or 0.1 ml (1–2 drops) of each carbonyl compound listed and observe its solubility. Tabulate your observations. Carbonyl compounds to be tested: *acetaldehyde, acetone, cyclopentanone, benzaldehyde, acetophenone, benzophenone.*

(B) Reduction of Silver Ion (Tollen's Reaction). First clean two test tubes thoroughly with cleaning solution and rinse well with water. Add 5 ml of a solution containing silver ammonium ion and 2 ml of water (Tollen's reagent, prepared according to directions given below), and a drop or two of the compounds to be tested. Mix well and allow to stand for 1–2 minutes. If a silver mirror does not form after 2 minutes, place in a tube of warm water for 2–3 minutes. Compare the action of silver ion on acetaldehyde and acetone or benzaldehyde and acetophenone. If black, finely divided silver is obtained instead of a mirror, the test tube is not thoroughly clean.

Tollen's reagent. To 3 ml of 1 per cent silver nitrate solution add 1 drop of $6N$ sodium hydroxide solution. Add, drop by drop, dilute ammonium hydroxide, with shaking, until the precipitate which forms at first just fails to redissolve. If excess of ammonia is added and the precipitate dissolves completely, add, drop by drop, silver nitrate solution until the precipitate just forms. Filter, and wash the filter paper in the sink. Place the filter paper in the waste jar. The precipitate is washed in the sink since it may contain silver fulminate, and detonate when dry. As the solution does not keep, it should be prepared just before use.

(C) **Reduction of Cupric Ion (Fehling's Reaction).** To 4 ml of Fehling's solution (made by mixing equal amounts of copper sulfate solution and a solution of sodium hydroxide containing sodium potassium tartrate[1]) add a drop of the compound to be tested, and warm. If no change occurs immediately, heat to boiling and set aside. Compare the action of acetaldehyde and acetone or benzaldehyde and acetophenone.

(D) **Comparison of Oxidation Rates of Aldehydes and Ketones.** Prepare 20 ml of 0.05 per cent neutral permanganate by diluting 1 ml of one per cent stock solution of permanganate with 20 ml of water. Distribute the solution equally in five clean test tubes. Add to each of four tubes 2 drops of the carbonyl compound to be tested, and shake. Note the color, by comparison with the solution in the fifth (control) tube, after one and five minutes. Use for the tests: *acetaldehyde*, *acetone*, *benzaldehyde* and *acetophenone*. Tabulate your observations. In making comparisons take into account the solubility of each compound.

(E) **Schiff's Fuchsin-Aldehyde Test.** Place in a small beaker 15 ml of water and 5 ml of fuchsin-aldehyde reagent.[2] Mix, and distribute solution equally into four clean test tubes. To the first tube add 2 drops of formaldehyde (40 per cent solution); to the second tube, add one drop of acetaldehyde; and to the third one drop of acetone. The last tube serves for control. Observe the rate at which the color develops.

(F) **Reaction of Lower Aldehydes with Ammonia.** (1) Cool thoroughly 15 ml of ether in a small Erlenmeyer flask and add 1 ml of acetaldehyde. Saturate with dry ammonia. The tube leading ammonia into the aldehyde solution should be wide. Filter off the crystals.

(2) Place 0.5 ml (7–8 drops) of a 40 per cent solution of formaldehyde and 4 ml of concentrated aqueous ammonia on a watch glass. Evaporate on a water bath (use hood). The crystals which

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[1] For the preparation of stock solutions for Fehling's reagent, see Appendix.

[2] For the preparation of the reagent, see Appendix.

remain consist of *hexamethylenetetramine*, $(CH_2)_6N_4$. In both aldehydes the reaction begins through the formation of the simple addition product R—CH(OH)(NH_2). In formaldehyde (and generally in most aldehydes) the reaction proceeds further with elimination of water.

(G) **Sodium Bisulfite Reaction.** Place 10 ml of saturated sodium bisulfite solution in an eight-inch test tube, and add 2 ml of the compound to be tested. Shake the mixture vigorously for 1 minute, and place the tube in a freezing mixture. After 5 minutes add 10 ml of alcohol, shake well, and allow to stand for 2–3 minutes. Filter with suction and, after washing with alcohol and finally with a small amount of ether, allow to dry. Place one-half of the crystals in a test tube, add 6 ml of ten per cent sodium carbonate solution, and warm, noting the odor. Use *acetone* and *benzaldehyde* for the tests.

(H) **Preparation of Phenylhydrazones.** Place 0.5 ml of benzaldehyde in a tube, and add 5 ml of phenylhydrazine reagent.[3] Stopper the tube securely, shake the contents vigorously for 1–2 minutes, and allow to stand for 10 minutes, with occasional shaking. Filter the crystals with suction, and wash first with one per cent acetic acid and then with water. The yield is about 1 g. If it is desired to determine the melting point, the product is recrystallized from methanol or ethanol.

The phenylhydrazones of cyclopentanone or cyclohexanone may be prepared in the same manner.

(I) **Preparation of Oximes.** (1) **Acetoxime.** Dissolve 1 g of hydroxylamine hydrochloride in 2 ml of water. Add 3 ml of 20 per cent sodium hydroxide solution (or 0.6 g of solid sodium hydroxide dissolved in 2 ml of water). Add 2 ml of acetone, cork securely, and shake vigorously for one minute. Allow to stand overnight. If crystals do not appear, seed with a minute amount of the oxime, and allow to stand for some time. Filter the crystals with suction and allow to dry. Place in a tube or bottle immediately.

(2) **Benzaldoxime.** Follow the same procedure as above. Use 1.5 g of hydroxylamine hydrochloride and 7 ml of sodium hydroxide solution. Add 2 ml of benzaldehyde. Shake vigorously and cool.

(J) **Polymerization of Acetaldehyde.** (1) Place 1 ml of pure acetaldehyde in a test tube which is immersed in a freezing mixture. Insert a thermometer in the tube and note the temperature. Place on the tip of the thermometer a trace of concentrated sulfuric acid, remove the tube from the mixture, and stir with the thermometer

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[3] For the preparation of the phenylhydrazine reagent, see Appendix.

thoroughly for a minute. Observe change in temperature. Add 2–3 ml of water and observe the solubility. The insoluble product is the polymer of the aldehyde.

(2) Place 2 ml of pure acetaldehyde in a test tube and add 5 ml of ether. Cool in an ice-salt mixture and pass through dry hydrogen chloride for one minute. Cork and allow to stand for ten minutes. Filter the crystals of metaldehyde with suction, wash with ether, and place in a bottle or tube. Pour the filtrate into a bottle designated by the instructor.

(K) **Resin Formation.** Place in a test tube 0.5 ml acetaldehyde and 3–4 ml of 6 *N* sodium hydroxide solution. Shake and warm cautiously, noting the color of the mixture. Allow to stand. Repeat this test by using a very dilute solution of alkali. To 5 ml of water add one drop of 6 *N* sodium hydroxide solution. This dilution gives roughly a solution of 0.1 per cent, while the concentrated solution is about 24 per cent. After shaking the mixture of alkali and aldehyde, warm and note the color. Finally boil the mixture and note cautiously the odor of the condensation product.

(L) **Cannizzaro Reaction.** Place in an eight-inch test tube or a small flask 2 ml benzaldehyde and 4–5 ml of 50 per cent sodium hydroxide solution. Cork well. Place a piece of cloth over the stopper and shake until a permanent emulsion results. Allow to stand overnight. Crystals of sodium benzoate separate out. Add 10 ml of water and note the layer of benzyl alcohol which separates on the top. Add 10 ml of ether, shake gently, and separate the ether layer by means of the separatory stopper. Withdraw the aqueous layer into a small beaker. The ether layer is placed in a bottle designated by the instructor. The benzyl alcohol may be separated by uniting the extracts of several reactions. The ether solution is shaken with saturated bisulfite solution, dried with 2–3 g anhydrous sodium carbonate and most of the ether distilled. The residue is transferred into a distilling tube and fractionated. The fraction which boils at 203–208° is collected.

To the aqueous layer add a drop of phenolphthalein and, carefully, sufficient concentrated hydrochloric acid to acidify the solution. Allow to stand for a few minutes, and filter the crystals of benzoic acid. The yield is about 1 g.

Experiment 35

THE POLYHALOGEN COMPOUNDS

Introduction. Polyhalogen compounds may be divided for the purpose of study into two groups. The first group includes compounds that have two or more halogen atoms on the same carbon atom, as for example, chloroform, $CHCl_3$, benzal chloride, $C_6H_5CHCl_2$, and 1,1-dichloroethane, CH_3CHCl_2. Such compounds on hydrolysis yield carbonyl and carboxyl compounds:

$$HCCl_3 + 3\ H_2O \longrightarrow HC(OH)_3 + 3\ HCl$$

$$HC(OH)_3 \longrightarrow HCOOH + H_2O$$

$$CH_3CHCl_2 + H_2O \longrightarrow CH_3CHO + 2\ HCl$$

The other group of polyhalogen compounds includes those which contain more than two halogen atoms in the molecule but not more than one halogen on any carbon atom, as, for example, ethylene chloride, CH_2ClCH_2Cl, and 1,2,3-tribromopropane, $CH_2BrCHBrCH_2Br$. Such compounds on hydrolysis yield polyhydroxy derivatives:

$$CH_2ClCH_2Cl + 2\ H_2O \longrightarrow CH_2OHCH_2OH + 2\ HCl.$$

The object of the present experiment is to illustrate the preparation and a few of the reactions of the first type of polyhalogens, since they have generic relations to the carbonyl and carboxyl compounds. Polyhalogen compounds may be prepared by prolonged halogenation of hydrocarbons and separation of the various isomeric products; also by the replacement of the carbonyl oxygen with chlorine in aldehydes (RCHO), ketones (R_2CO), and chlorides (RCOCl). The lower polyhalogen compounds, chloroform, $CHCl_3$, bromoform, $CHBr_3$, and iodoform, CHI_3, are conveniently prepared through a reaction which involves the activity of the alpha hydrogen atoms of certain carbonyl compounds. When ethyl alcohol is treated with an alkaline solution of a halogen, the alcohol is oxidized to aldehyde:

$$CH_3CH_2OH + NaOCl \longrightarrow CH_3CHO + H_2O + NaCl$$

Further action results in the chlorination of the alpha carbon atom, producing trichloroacetaldehyde, or chloral, $Cl_3C—CHO$. This compound, having two partially oxidized carbon atoms, on warming undergoes a rupture of the carbon-to-carbon bond:

$$Cl_3C—CHO + NaOH \longrightarrow Cl_3CH + HCOONa$$

Acetone undergoes similar halogenation of the alpha carbon atom which is followed by rupture, giving trihalogen compounds. Thus chloroform, bromoform, or iodoform can be prepared by treatment of acetone with the corresponding hypohalite. Many compounds which contain the $CH_3CO—R$ group and the $CH_3CHOH—R$ group yield iodoform when treated with a hypoiodite solution or in general give the *haloform* reaction.

(A) **Preparation of Iodoform from Acetone** (Sm.). Dissolve in an eight-inch test tube 2 g of potassium iodide in 15 ml of water. If a 10 per cent solution of the iodide is available, use 20 ml. Add 0.5 ml of acetone (about 8–10 drops) and then slowly, with shaking, add 20 ml of a 5–7 per cent solution of sodium hypochlorite.[1] The separation of iodoform crystals begins at once. Allow to stand for 5–10 minutes. Filter with suction, wash with cold water, and press the crystals as dry as possible. Place on a paper disc to dry. The yield is about 1–2 g.

(B) **Iodoform Test for Ethanol.** Place 6 drops of ethanol in a test tube. Add 5 ml of 10 per cent potassium iodide solution and then 4 ml of sodium hypochlorite solution.[1] Shake, and warm for 5 minutes at 60° by immersing in a beaker of warm water. Crystals of iodoform slowly separate. Repeat, using 5 drops of lactic acid.

(C) **Preparation of Chloroform** (Sm.). (1) Arrange an eight-inch test tube with a micro reflux condenser. Place in it 20 ml of sodium hypochlorite solution, and then 4 ml of acetone (3.2 g). Shake for a minute, and wait for five minutes for the reaction to start. Moderate the reaction, if it becomes too vigorous, by raising a beaker of cold water over the outside of the tube. If the reaction is too slow to start, warm cautiously until it begins. When the reaction has subsided warm the tube in a water bath at 60° for five minutes. Cool slightly and arrange for distillation. Distill carefully from a water bath. The yield of chloroform is 2.5–3 g.

(2) If it is desired only to demonstrate the formation of chloroform, the test may be performed by using one-fourth of the quantities and no condenser. The tube is warmed until the reaction

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[1] For preparation of hypochlorite, see Appendix.

begins, then cooled. The chloroform is detected by its odor or by the isocyanide test (page 177).

(D) **Reduction of Iodoform to Methylene Iodide.** To 1 g of iodoform add 5 ml of sodium arsenite solution[2] (made by dissolving 2.5 g of arsenic oxide and 5.5 ml of sodium hydroxide in 25 ml of water). The test tube is warmed for 5 minutes at 60–65° in a water bath and the mixture diluted with water. The oily drops which separate are methylene iodide. Look up the density and refractive index of the iodide.

(E) **Hydrolysis of Benzotrichloride.** Place in a large tube 2 ml of benzotrichloride. Add 6 ml of alcohol and 4 ml of 6 *N* sodium hydroxide solution, together with a small boiling stone. Provide the tube with a micro reflux condenser, and boil gently for 30 minutes. Cool, and acidify with 5 ml of dilute hydrochloric acid. Crystals of benzoic acid separate out. Filter, wash with water, and dry.

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[2] A stock solution of arsenite may be prepared according to directions given in Appendix.

Experiment 36

PREPARATION OF ACIDS BY OXIDATION OF ALCOHOLS

Introduction. Acids may be prepared by several general methods. The oxidation of alcohols and aldehydes, and the hydrolysis of nitriles and trihalogen derivatives give carboxylic acids. The present experiment illustrates the first general method.

In the oxidation of alcohols either alkaline permanganate or acid dichromate may be used. The use of permanganate with alcohols which contain tertiary hydrogen (branched chains), as for example, isobutyl alcohol, $(CH_3)_2CHCH_2OH$, involves the danger of oxidation in other parts of the molecules. In such cases the temperature during oxidation is not allowed to rise above 20°. In the oxidation by acid dichromate mixture, part of the organic acid which is formed reacts with the unchanged alcohol to form an ester. The ester may be separated and hydrolyzed to yield a further quantity of acid.

(A) **Preparation of Butanoic Acid** (Sm.). Arrange apparatus for oxidation of alcohols as shown in Figure 51. Instead of the thermometer insert a reflux condenser. This prevents the distillation of any aldehyde and insures a better yield. Place in the flask a solution of 20 g of sodium dichromate in 35 ml of water. Place in a small beaker 15 ml of water and add slowly 15 ml of concentrated sulfuric acid. Cool to 30° and add 10 ml of *n*-butyl alcohol. Mix, add one half to the separatory tube, and connect it according to directions given on page 185. Release the screw clamp cautiously, and add 2 ml portions of the alcohol-acid mixture to the dichromate solution. Shake the flask vigorously after each addition. Do not add further portions until on shaking the flask the reaction appears to be moderate. If the reaction is too vigorous, cool by raising a beaker of water underneath the flask. It will require 15–20 minutes for complete addition of the acid-alcohol mixture. After the addition is complete, heat by a smaller flame for 15 minutes. Cool slightly, remove the reflux condenser, add two boiling stones, and insert a short piece of glass rod in the opening formerly occupied by the reflux condenser. Distill until 30 ml of distillate has been collected in the receiver (eight-inch tube). Transfer to a 125-ml flask, add 4 g of solid sodium hydroxide to the distillate, and cool. Close securely with a solid rubber stopper, and shake the flask until the solid dissolves. Remove the stopper from time to time to release any pressure. A small layer of ester separates at the top. Add two small boiling stones and boil under reflux for 0.5–1 hour until the ester layer almost disappears. Cool, add 5–10 ml of ether to extract the butyl alcohol, and after shaking transfer to a separatory tube and withdraw the aqueous layer back into the same flask. Cool, and acidify cautiously by addition of a cold mixture of 2 ml of sulfuric acid and 2 ml of water. Extract the butyric acid with three 8 ml portions of ether. Dry the ethereal solution with 2 g of calcium chloride. Distill off the ether with a water bath; then fractionate, using a small direct flame. Collect the portion which boils at 158–165°. The yield is 2–2.3 g.

Experiment 37

PREPARATION OF ACIDS BY CARBOXYLATION OF THE GRIGNARD REAGENT

Introduction. A general method for the preparation of carboxylic acids is the addition of a Grignard reagent to carbon dioxide. The ethereal solution of the Grignard reagent is prepared according to methods already described (page 124). If carbon dioxide is passed into the ethereal solution, the MgX group of the Grignard RMgX adds to the oxygen atom of carbon dioxide and R adds to the carbon atom. The intermediate addition product on hydrolysis gives the carboxylic acid:

$$RCH_2MgBr + CO_2 \longrightarrow RCH_2CO(OMgBr)$$

$$RCH_2CO(OMgBr) + H_2O \longrightarrow RCH_2COOH + Mg(OH)Br$$

The Grignard reagent is usually carbonated by passing dry carbon dioxide gas into the ethereal solution. In the present experiment solid carbon dioxide is used to avoid the rather long time required for carbonation with the gas. Although the yield is lowered, the carbonation is completed within five minutes. For semimicro work the preparation of benzoic acid is recommended for beginners.

General directions. The Grignard reagent, using the semimicro method, is prepared in a large tube according to the detailed directions given in Experiment 16, page 124. About 0.03 moles of each reagent is used and the exact amount of each is given under the specific preparation. Be sure that the reagents and apparatus are free from moisture.

The carbonation of the Grignard reagent is effected by adding small pieces of dry ice. Since there is condensed moisture on the surface of solid dry ice, the following procedure is followed. Fifteen grams of dry ice are broken into small pieces the size of almonds. A small beaker with 20 ml of ether is placed near the reaction tube. By means of forceps a piece of dry ice is picked up firmly, dipped momentarily into the ether, and then dropped into the Grignard reagent after raising the cork. The reaction is vigorous, and care should be exercised in the beginning to add the dry ice slowly. For 0.03 moles of reagent 5–6 g of dry ice are required. Toward the end the mixture becomes very viscous and separates into a resinous mass. At this point the reaction is no longer vigorous. The resinous mass is allowed to stand for five minutes and is then decomposed with a mixture of 5 ml concentrated hydrochloric acid and 5 g of ice. This gives cold dilute hydrochloric acid. The reaction tube is immersed in cold water and the acid is dropped in slowly while the viscous mass is stirred with a rod. When the decomposition is complete and practically all the residual magnesium has dissolved, 5 ml of ether are added and the mixture is extracted. The extraction is repeated once or twice if the acid is appreciably soluble in water, as in the case of the lower open chain acids. The ether extracts are combined in a tube, and shaken with 10 ml of 5 per cent sodium hydroxide. The acid passes from the ether to the aqueous layer as it forms the sodium salt. The ether is washed with 1 ml of water, and the resulting aqueous layer is withdrawn and united with the alkaline solution. The solution containing the sodium salt is carefully acidified. If the acid is solid and sparingly soluble, it will separate out on cooling, in which case it is filtered after ten minutes. If the acid is liquid or somewhat soluble, the acidified solution is extracted twice with 6–8 ml of ether. The ether extracts are combined, and dried with 0.5 g of calcium chloride. After 15 minutes the ether is distilled and the acid is fractionated.

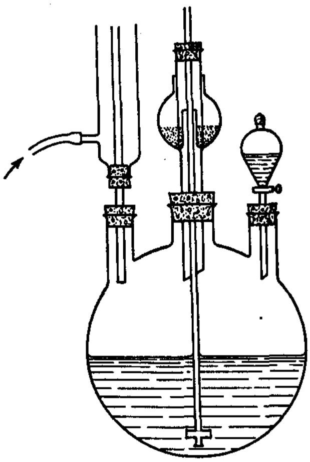


Fig. 52. Macro apparatus for preparation of Grignard reagent

(A) **Preparation of Benzoic Acid** (Sm.). Prepare the Grignard reagent according to directions given in the preceding paragraphs. Use 4.7 g of bromobenzene, 0.7 g of magnesium turnings, and 10 ml of dry ether. Carbonate, and decompose the addition product. The amount of acid obtained by acidifying the alkaline extract is 1.5–2.0 g, melting at 116–117°. Upon recrystallization from water the pure acid is obtained. The yield is 1.4–1.6 g.

(B) Preparation of Benzoic Acid (**M.**). For the preparation of one mole of the Grignard reagent use is made of the apparatus shown in Figure 52. It consists of a three-neck flask having a mercury-seal stirrer. An ordinary 500-ml round-bottom or Florence flask without a stirrer may be used for amounts less than 0.5 mole, although the time required for the preparation is longer.

Prepare the Grignard reagent according to the general directions given in the preceding paragraphs. Use 6 g of magnesium turnings, 50 ml of dry ether, and 23.5 g of bromobenzene in a 500-ml flask arranged as shown in Figure 40, page 104. After the reagent has been prepared, place a dry one-liter beaker in the hood. Weigh out rapidly 50–60 g of dry ice on a piece of strong paper. Wrap the paper around the dry ice and, by means of a pestle, break it into small lumps, but keep the paper tightly around it. Bring the flask with the Grignard reagent near the beaker. Empty the dry ice into the beaker and at once pour in the Grignard reagent in a steady stream. The unreacted magnesium adheres to the sides of the flask. A vigorous reaction takes place. Stir the mass well, and allow to stand until all the dry ice has evaporated. Add slowly a mixture of 40 ml of hydrochloric acid and 100 g of ice. Stir until the gelatinous addition compound has decomposed. Transfer the mixture to a separatory funnel. Wash the beaker with two 40-ml portions of ordinary ether and add the ether to the mixture in the separatory funnel. Shake gently and then withdraw the aqueous layer. Wash the ether layer twice with 25–50 ml of water. Extract the ether with two 75-ml portions of a 5 per cent solution of sodium hydroxide, and withdraw the aqueous extract in a clean beaker. Place the ether in a bottle designated by the instructor. Add to the aqueous extract 1 g of charcoal and 0.5 g of Super-cel. Stir, and then filter. Acidify the filtrate with dilute hydrochloric acid. Cool, filter, and dry the crystals. The yield is about 10 g. If the melting point is low purify by crystallization.

(C) **Preparation of *n*-Caproic Acid** (Sm.). Use 4.5 g of *n*-amyl bromide, 0.7 g of magnesium and 10 ml of ether. After carbonation and decomposition of the addition product, the alkaline layer from the ether extraction is cooled and carefully acidified, and then extracted with three 6-ml portions of ether. The ethereal solution is dried with 0.5 g of calcium chloride, and the ether is distilled directly from the large tube until 5 ml of liquid remains. This is transferred to a distilling tube and fractionated. The tube is heated with a very small flame. The portion which boils at 200–206° is collected. The yield is 1 g.

(D) **Preparation of Phenylacetic Acid** (Sm.). Use 3.8 g of benzyl chloride, 0.7 g of magnesium acid, and 10 ml of ether. The same procedure is followed as in the preparation of benzoic acid. The solubility of phenylacetic acid in water is much greater than that of benzoic acid, hence care should be taken not to use excessive amounts of water. Save all filtrates, and if the yield is poor, evaporate the filtrates. The acid has a strong odor resembling roses.

Experiment 38

REACTIONS OF CARBOXYLIC ACIDS

NOTE: Sections (F) and (G) are recommended only in case students do not perform Experiments 39 and 40. Section (E) may be given as a demonstration.

Introduction. The object of this experiment is to illustrate a number of general reactions of carboxylic acids. Salt formation is a characteristic property of the carboxyl group. The salts of the alkali metals as a rule are soluble. The higher, sparingly soluble, fatty acids form salts which give colloidal dispersions. The soluble salts are prepared by neutralization of the acid with alkali, or by boiling with an excess of the metallic carbonate and evaporating the solution.

The hydrogen-ion activity of the carboxylic acids is not very great. The introduction of groups such as the halogens into the radical increases the acidity. The acid is estimated by titration with standard alkali, using phenolphthalein as an indicator.

The carboxyl group undergoes a number of reactions in which the hydroxyl group is replaced by (OR) to form esters, by (NH_2) to form amides, and by (Cl) to form acyl chlorides. The carboxyl group as a whole is resistant to oxidation. Substituents in the α-carbon atom reduce the stability. Thus a hydroxyl or a nitro group in the α-carbon atom produces an instability which is manifested when the acid is heated in the presence of reagents. Similarly, the reduction of the carboxyl group is difficult.

Dicarboxylic acids exhibit reactions similar to those of the monocarboxylic. The presence of two carboxyls naturally gives rise to two types of salts, esters, and other derivatives, the normal and the acid. The stability of the dicarboxylic acids where the two groups are adjacent, as in oxalic acid, or separated by a CH_2 group, as in malonic acid, is not very great. They decarboxylate easily. In the case of malonic acid, this reaction is made use of in the synthesis of other compounds. The aliphatic acids, upon treatment with halogens in the presence of the usual halogenating catalysts, undergo substitution of the α-hydrogen and give α-halogen acids.

(A) **Solubility.** Test the solubility of the following acids: *acetic, butyric,* n-*caproic, stearic,* and *benzoic acids.*

(B) **Ionization Constants.** Determine the *p*H of 0.1 *N* solutions of *acetic, chloroacetic,* and *trichloroacetic acids.* Convert the *p*H to hydrogen-ion concentration as moles per liter; then calculate the ionization constants for acetic and monochloroacetic acid.

(C) **Oxidation of Carboxyl Group.** Place in each of five test tubes 5 ml of 0.05 per cent alkaline permanganate solution, then add five drops respectively of the acid to be tested, and note any change in color. If there is no immediate change, heat nearly to boiling. Use for the test: *formic, acetic, propionic, lactic, benzoic* and *oxalic acids.* Tabulate the results and draw some general conclusion as to the stability of the carboxyl group.

(D) **Oxidation of Formic Acid.** To 3 ml of Tollen's reagent, prepared according to directions given on pages 192–193, add 1 to 2 drops of formic acid and warm gently.

(E) **Decarboxylation of Nitroacetic Acid.** The stability of the carboxyl group (which, if attached to a $—CH_2$ group, is quite stable) depends on the other groups which are adjacent to it. The effect of the nitro group is illustrated as follows:

Dissolve 1 g of chloroacetic acid in 3 ml of water, and add slowly, cooling in tap water, 0.6 g of solid sodium carbonate. Add 4 ml of a 20 per cent solution of sodium nitrite and a small boiling stone. Heat the tube slowly until a vigorous evolution of carbon dioxide begins, and then remove from the flame and allow the decarboxylation to proceed. The solution becomes yellowish brown and develops a strong odor of nitromethane. If desired, the nitromethane can be distilled from the reaction mixture. The yield is about 0.5 g.

(F) **Ester Formation.** To 1 ml of ethanol in a test tube, add 8–10 drops of acetic acid and 5 drops of 6 *N* sulfuric acid. Warm, and note the odor of ethyl acetate.

(G) **Identification of an Acid.** Obtain an unknown acid from the instructor. Determine roughly the solubility and *p*H. Heat about 0.1 g with alkaline permanganate (see section [C]). Test for presence of an aromatic nucleus by nitrating 0.2 g as directed on page 122.

Place 0.5 g of the sample in a test tube. Add 1 ml of thionyl chloride (using the hood) and warm in a beaker of water at 60° for 30 minutes. Obtain information from your instructor whether the acyl halide formed boils above 100°. In such case raise the temperature of the water bath to 95° for about 15 minutes, to drive off the excess of thionyl chloride. If hood space is not available, place a cork with one hole on the mouth of the tube, and fit in a glass tube bent at right angles in such a manner that it acts as a delivery tube; this leads into another test tube cooled in a beaker of cold water which acts as a condenser and collects the excess of thionyl chloride driven off. Dispose of the thionyl chloride immediately in accordance with the directions given by the instructor. If the acyl halide boils below 100°, obtain special directions from your instructor as to the procedure. One procedure is to use 1 ml of phosphorus trichloride instead of thionyl chloride. After heating, pour off the chloride, from the viscous phosphorous acid and react it directly with ammonia.

Add to the crude acyl chloride 3 ml of concentrated aqueous ammonia and shake the tube for a few minutes. If the chloride does not react immediately shake and warm cautiously for a minute. Cool the clear solution and filter the crystals which may separate. Evaporate the filtrate on a watch glass to obtain a second crop of crystals. If no crystals separate after the acyl halide has reacted with ammonia, the amide is quite soluble in water. Evaporate the filtrate to dryness on a watch glass. Recrystallize one-half of the crystals, after consulting with the instructor as to the appropriate solvent. Determine the melting point of the amide. Consult the literature and obtain a list of amides which melt within 5° of the melting point obtained. By means of mixed melting points (see page 53) identify definitely the amide which you prepared. You may use the original acid for the identification by mixed-melting-points determination. Report the name and formula of the unknown acid.

Experiment 39

PREPARATION AND PROPERTIES OF ESTERS

Introduction. The reaction between an acid and an alcohol yields an ester and water:

$$ROH + R_1COOH \rightleftharpoons R_1COOR + H_2O$$

The reaction indicated by this equation is the most widely used method for the preparation of esters. The reaction, however, as indicated, is reversible, and both heating and catalysts are used to accelerate the rate at which equilibrium is reached. The student is referred to the text for a thorough discussion of esterification. In practice sulfuric acid and hydrogen chloride in amounts of 2–4 per cent are used as catalysts. Removal of the water by distillation and an excess of alcohol are the means used to convert all the acid to the ester. This, of course, is not good practice, if the alcohol is more expensive than the acid. Generally, primary alcohols esterify faster and more extensively than secondary or tertiary. Tertiary alcohols (and phenols) do not esterify easily by this method. For the esterification of tertiary alcohols or phenols a number of indirect methods can be used. Alcoholysis of anhydrides or acid chlorides gives esters. The object of the following experiment is to illustrate the various methods of preparation of esters, and a few of their properties. Sections (A), (B), (C), and (D) illustrate esterification by heating an alcohol and an acid in the presence of sulfuric acid. Section (E) illustrates the use of anhydrides, and section (F) the use of acyl chlorides, in the preparation of esters.

(A) **Preparation of Ethyl Acetate** (Sm.). Place in an eight-inch tube 5 ml of ethanol, 5 ml of glacial acetic acid, and 0.5 ml (7–8 drops) of sulfuric acid. Insert a micro condenser in the tube arranged for reflux, and heat for 0.5 hours. Remove the reflux condenser and distill from a water bath until no more distillate passes over. The distillate consists of ethyl acetate and small amounts of acetic acid, ethanol, water, and sulfur dioxide. The latter was formed by the oxidizing action of the sulfuric acid. Add 2 ml of a saturated solution of sodium carbonate to the mixture in the receiving tube, and shake cautiously. Add a drop of indicator and, if the upper layer is acid, repeat the addition of carbonate until it is neutralized. Insert the separatory stopper and remove the aqueous layer. Wash the ester with 3 ml of water, and after separation dry with 0.5 g of anhydrous magnesium sulfate. Pour the dry ester in a distilling tube and add two small boiling stones. Fractionate, collecting the portion which boils at 73–80°. The yield is about 4–4.5 g.

(**B**) **Preparation of Ethyl Acetate** (**M.**). Place in an 125-ml distilling flask a mixture of 25 ml of alcohol and 25 ml of concentrated sulfuric acid. Attach the flask to a condenser which leads into a receiver. Through a cork fit a separatory funnel and a thermometer which reaches to the bottom of the flask. Place in the dropping funnel a mixture of 50 ml of alcohol and 50 ml of glacial acetic acid. Heat the mixture in the flask over an asbestos-centered wire gauze until the temperature rises to 140°. Adjust the flame so that the temperature remains at this point, and allow the acid-alcohol mixture to drop into the distilling flask at the same rate as it distills. When all the mixture is added, discontinue.

The distillate contains ethyl acetate, and small amounts of alcohol, acetic acid, ether, water, and sulfur dioxide. Transfer the distillate into a separatory funnel, and add small amounts of a saturated solution of sodium carbonate until the upper layer is no longer acid (test with litmus). Remove the lower aqueous layer. The remaining layer contains the ester and a small amount of ethanol. Shake with 10 ml of concentrated calcium chloride solution to remove traces of alcohol. Dry the ester with 6 g of anhydrous magnesium sulfate, then transfer to a distilling flask and fractionate. The portion which boils below 73° is rejected. The fraction boiling at 73–80° is collected. The yield is about 40–50 g.

(**C**) **Preparation of Methyl Benzoate** (**Sm.**). Place in an eight-inch tube provided with a micro condenser 5 ml of methanol, 5 g of benzoic acid, and 0.5 ml of concentrated sulfuric acid. Reflux for half an hour in a water bath. Dilute with 6–8 ml of water, and separate the ester. Dry with 0.5 g anhydrous potassium carbonate, and distill from a small distilling tube. The fraction which boils at 195–205° is collected.

(**D**) **Preparation of Benzyl Acetate** (**Sm.**). Place in an eight-inch tube 4 g of benzyl alcohol, 7.5 ml of glacial acetic acid, and 1 ml of concentrated sulfuric acid. Reflux by heating in a water bath for half an hour, and proceed as in section (C). Collect the fraction which boils at 210–217°.

(**E**) **Preparation of β-Naphthyl Acetate** (**Sm.**). Dissolve 2 g of β-naphthol in 4 ml of 6 N sodium hydroxide solution and 6 ml of water (or in 10 ml of 10 per cent solution). Add a few pieces of ice and 2.5 ml of acetic anhydride. Cork the tube and shake vigorously for 5–10 minutes, cooling under tap water from time to time. The ester separates as colorless crystals. It is filtered, washed with water, pressed with a cork and then placed on a piece of paper to dry. The yield is about 1–1.5 g. For a discussion of this method see section on acylation in Experiment 41.

The usual method of acetylation by means of acetic anhydride or a mixture of acetic acid and anhydride is to reflux the hydroxy compound and the anhydride for 10–15 minutes. In the present instance, the temperature is kept low by the presence of ice and the hydrolysis of the anhydride is inhibited, permitting it to react with the hydroxy compound. Phenol and other aromatic hydroxy compounds can be acetylated by this method.

(F) **Preparation of Phenyl Benzoate (Sm.).** The use of acyl chlorides in the formation of esters is illustrated in the following preparation. Place in an eight-inch tube 1 g of phenol, 15 ml of 10 per cent sodium hydroxide solution, and 1.5 ml of benzoyl chloride. Place a solid rubber stopper firmly in the mouth of the tube and shake vigorously at intervals for 10 minutes. Remove the stopper, warm the mixture slightly, and shake again for one minute. The ester which separates is filtered, washed with cold water, and dried. The yield is about 2 g.

REACTIONS OF ESTERS

Esters, under appropriate conditions, undergo hydrolysis. This reaction is the reverse of esterification as shown in the equation on page 207. Esters react with aqueous or alcoholic ammonia to form amides. A number of reactions of esters are due to activity of the carbonyl group and the adjacent α-hydrogen atoms. The reaction of esters with Grignard reagents to form ketones or tertiary alcohols, and the various condensations, are examples of this type of reaction.

(G) **Hydrolysis of Esters.** Place 2 ml of ethyl or methyl benzoate and 10 ml of 10 per cent sodium hydroxide solution in a test tube provided with a micro condenser. Heat in a water bath for 20–30 minutes until the ester layer disappears. The solution contains the alcohol and the sodium salt of the acid. If it is desired to separate the alcohol, the liquid is distilled until 5 ml of distillate is collected; otherwise, the solution is cooled, and acidified with hydrochloric acid. Benzoic acid separates from the solution. The crystals are filtered and dried.

(H) **Rate of Hydrolysis of Esters.** Place 5 ml of water and 5 drops of universal indicator in each of five test tubes. To separate tubes add 10 drops of the ester to be tested, shake and note any change in the *p*H of the solution. Test *ethyl formate, ethyl acetate, ethyl benzoate, ethyl lactate.* Immerse in water and heat to 50°. Note the change after ten minutes. Add one drop of 1 *N* sodium hydroxide, note the *p*H, and again heat for 10 minutes. Tabulate the results.

(I) **Ammonolysis of Esters.** (1) To 5 ml of saturated solution of ammonia in methanol add 2 ml of ethyl acetate. Cork, and allow to stand until the next laboratory period. Place the contents of the tube in an evaporating dish and evaporate the alcohol over a water bath. Determine the weight of the amide.

(2) To 0.5 ml of ethyl oxalate add 3–4 drops of concentrated aqueous ammonia. The amide separates within a few minutes.

Experiment 40

PREPARATION AND PROPERTIES OF ACYL CHLORIDES

(Acylation of Hydroxy and Amino Compounds)

Introduction. Of all acyl halides, the chlorides are the most commonly used. They are usually prepared by the action of phosphorus trichloride, phosphorus pentachloride, or thionyl chloride on the acids:

$$3\ RCOOH + PCl_3 \longrightarrow 3\ RCOCl + P(OH)_3 \qquad (1)$$

$$RCOONa + PCl_5 \longrightarrow RCOCl + POCl_3 + NaCl \qquad (2)$$

$$RCOOH + SOCl_2 \longrightarrow RCOCl + HCl + SO_2 \qquad (3)$$

The method to be used is determined by the practicability of the separation of the chloride from the by-products of the reaction, and the excess of the reagent used. Thus, in the laboratory, phosphorus trichloride is used for the lower fatty acids because their chlorides are more volatile than phosphorous acid. The acid, together with 1.5 times the amount of phosphorus trichloride, as indicated in equation (1), is refluxed, and then the acid chloride is distilled from the viscous phosphorous acid and fractionated. Phosphorus pentachloride is used with aromatic acids as shown in equation (2). The dry, finely pulverized potassium or sodium salt of the acid is mixed with a little more than the calculated amount of the pentachloride and heated until the reaction is finished. The resulting oxychloride ($POCl_3$) is removed by distillation. If the boiling points are too close, then the mixture of aryl acid chloride and phosphorus oxychloride is added to finely chopped ice. The oxychloride decomposes instantly, while the aryl acid chloride does not react appreciably at this temperature. The chloride is either separated or extracted with ether, dried, and then fractionated.

The use of thionyl chloride has the great advantage of forming gaseous products, sulfur dioxide and hydrogen chloride, as shown in equation (3), thus rendering the purification simpler. In addition to this, it permits the preparation of small amounts for the purpose of identification. For most cases, a little more than the theoretical amount of thionyl chloride is added to the acid and warmed at 60–70° for an hour. If the acyl chloride boils above 100° C., it is only necessary to heat to this temperature and remove the excess of thionyl chloride.

The object of this experiment is to illustrate the preparation of an acyl halide and its application to the acylation of amines.

Caution: All apparatus used for the preparation of acyl halides must be *perfectly dry*, since the reagents as well as the products are decomposed by water. *Goggles* should be worn throughout the experiment. Benzoyl chloride is a *lachrymator*, and should be handled with care. Residues should not be thrown into the sink, but washed with ammonia and then poured into a bottle placed in the hood. *Care* should also be exercised in handling phosphorus and sulfur halides. Do not allow any halide to come in contact with the skin, as they produce severe burns.

(A) **Preparation of Acetyl Chloride** (Sm.). Arrange an eight-inch distilling tube for regular distillation (Figure 53). The micro condenser is fitted into the mouth of the distilling tube in place of the thermometer, and is pushed past the side arm so that the reaction mixture can be heated under reflux. The side arm of the distilling tube is connected with the receiving tube, which is partially filled with water. The delivery tube is just above the water level but does not dip into it. When the apparatus is connected, remove the stopper bearing the micro condenser, and add in the tube 5 g (5 ml) of glacial acetic acid, and then, all at once, 4.5 g (3 ml) of phosphorus trichloride, replacing the cork immediately. Warm the tube by means of a water bath at 50° for 15–20 minutes. Two layers separate; the upper is the halide, while the lower consists of phosphorous acid. Cool slightly, remove the condenser and insert in its place a thermometer. Change the receiving tube, replacing it with a dry one, and arrange the micro condenser as in regular distillation. Distill through the water bath, and collect the fraction which boils at 50–56°. It is well to cool the receiver by immersion in a small beaker of ice water. The yield is 3.5–4 g.

(B) **Preparation of Benzoyl Chloride** (Sm.). Use the same apparatus and method described in section (A). Place 5 g of benzoic acid and 5 ml of thionyl chloride in the tube. Heat at 60° for 30 minutes. Then change the condenser, and insert the thermometer and a new receiving tube. Heat the water bath to boiling. The liquid that distills over is unchanged thionyl chloride, which boils at 78–80°. Remove the water bath and dry the outside of the tube. Be sure you are wearing goggles. Add two boiling stones, then heat the tube slowly. The temperature rises rapidly to 190°. Change the receiving

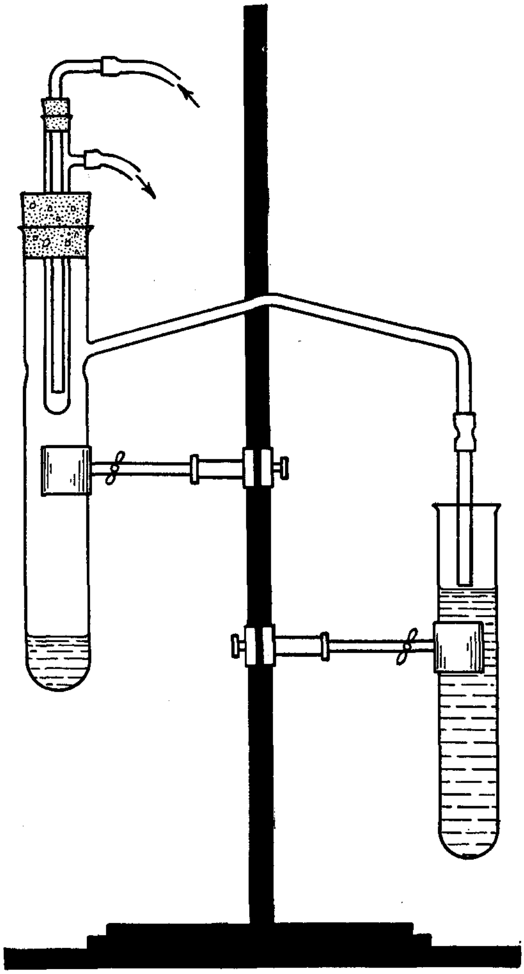


Fig. 53. Semimicro apparatus for preparation of acetyl chloride

tube, replacing it with a new tube which has been tared. Collect the fraction which boils at 193–199°. The yield is about 4 g.

(C) **Preparation of Acetyl Chloride** (M.). Arrange a dry 125-ml distilling flask in a water bath for regular downward distillation.

In place of the thermometer insert a cork holding a dropping funnel. For receiver use either a filter flask or another 125 ml distilling flask. The side tube of the flask is attached to a calcium chloride tube. This in turn is connected by means of a short piece of glass tubing to a funnel inverted over a beaker of water which serves to absorb the gases that are given off. Use either rubber stoppers or corks which have been coated with a quick-drying lacquer. All apparatus used must be perfectly dry.

Place 32 g (31 ml) of glacial acetic acid in the distilling flask and close it with the stopper that holds the dropping funnel. Add slowly through the funnel 28 g (19 ml) of phosphorus trichloride. As soon as the addition is complete close the stopcock, and rock the flask gently so as to mix the contents. Heat the mixture in a water bath at 40–50° for 25–30 minutes. When the contents have separated into two layers, cool the receiver in an ice mixture, raise the temperature of the bath to 95–100° and distill the acetyl chloride. Heat until no more liquid passes over. Disconnect the distilling flask, and discard the residue. Wash the flask first with water, then with acetone, and dry. Pour the acetyl chloride back into the flask, and replace the dropping funnel by a thermometer. Redistill the acetyl chloride and collect the portion which boils at 50–56°. Place the acetyl chloride in a tared glass-stoppered bottle and ascertain its weight. The yield is 27–32 g.

ACYLATION

The hydrolysis of acyl chlorides to a carboxylic acid and hydrogen chloride is rapid and violent in the lower aliphatic acyl chlorides. With increase in the complexity of the radical there is a corresponding increase in stability. Aryl acyl chlorides are only slowly hydrolyzed at low temperatures. In general, however, the halogen attached to the acyl group is very much more reactive than a halogen attached to other organic radicals.

The reaction of acyl chlorides with hydroxy compounds and amines has already been met in previous experiments. Generally, hydroxy compounds, ROH, primary amines, RNH_2, and secondary amines, R_2NH, react with acyl chlorides, the reactive hydrogen being replaced by the acyl group:

$$ROH + R_1COCl \longrightarrow ROCOR_1 + HCl$$

$$RNH_2 + R_1COCl \longrightarrow RNHCOR_1 + HCl$$

$$R_2NH + R_1COCl \longrightarrow R_2NCOR_1 + HCl$$

It will be noted that the hydroxy compounds yield esters and the amines yield substituted amides. Acid anhydrides may be used as the acylating agent (see page 175). For acetylation of amines, heating with glacial acetic acid may be used advantageously.

For the introduction of the benzoyl group (benzoylation) the procedure generally adopted is to use benzoyl chloride in dilute (10 per cent) alkaline solutions. Since benzoyl chloride reacts slowly with water at room temperature, the amino compound reacts fairly rapidly when shaken with it. The hydrogen chloride produced in the acylation is removed by the alkali. This method is known as the *Schotten-Baumann* reaction. The benzoyl derivatives nearly always crystallize well. The product is recrystallized to remove adsorbed and occluded impurities. If the derivative does not crystallize well, then a substituted benzoyl chloride is used, for example, *p*-nitrobenzoyl chloride. It will be recalled that for the characterization of the alcohols use was made of 3, 5-dinitrobenzoyl chloride.

(D) **Hydrolysis of Acyl Chlorides.** To a test tube containing 5 ml of water add a few drops of acetyl chloride. Observe the result immediately, and then again after shaking the tube. Repeat, using benzoyl chloride. If no reaction takes place, warm the tube. How can the products be identified?

(E) **Alcoholysis of Acyl Chlorides.** Add 5 drops of acetyl chloride to 1 ml of ethanol. What is the product resulting from this reaction? Can this test be used for detection of the hydroxyl group? If so, try it with a less reactive hydroxy compound.

(F) **Benzoylation of an Amine.** (See also page 175.) Place 10 ml of 10 per cent sodium hydroxide solution in an eight-inch test tube, and add 2 ml of *o*-toluidine. Close tube with a No. 5 or No. 6 solid rubber stopper and shake for a few seconds. Remove the stopper and add 2 ml of benzoyl chloride. Shake vigorously for 1 to 2 minutes, then at intervals for 8 to 10 minutes. Pour the mixture into water. The benzoyl-*o*-toluidide separates out. Filter, and wash the crystals with water. Recrystallize from alcohol. The yield is 3–4 g. The melting point may be determined in the usual way.

Experiment 41

PREPARATION AND PROPERTIES OF AMIDES

Introduction. The general methods for the preparation of amides are (1) ammonolysis of esters, acyl halides, and anhydrides; (2) the dehydration of the ammonium salts of carboxylic acids:

$$CH_3COOC_2H_5 + NH_3 \longrightarrow CH_3CONH_2 + C_2H_5OH$$

$$CH_3COCl + 2\ NH_3 \longrightarrow CH_3CONH_2 + NH_4Cl$$

$$(CH_3CO)_2O + NH_3 \longrightarrow CH_3CONH_2 + CH_3COOH$$

$$CH_3COONH_4 \xrightarrow{-H_2O} CH_3CONH_2$$

The ammonolysis of acyl chlorides is commonly employed whenever the preparation of an amide is desired for the identification of a carboxylic acid. The acyl chloride is prepared and treated with aqueous ammonia, or, if the amide is very soluble in water, with ammonia in benzene. In the latter case the ammonium chloride is filtered off, and the amide obtained by evaporation of the benzene with powdered ammonium carbonate. The preparation of amides from carboxylic acids is based upon the formation of an equilibrium mixture when the ammonium salts of the acid are heated:

$$CH_3COONH_4 \rightleftarrows CH_3CONH_2 + H_2O$$

Removal of water by distillation shifts the equilibrium point to favor formation of the amide. For preparation of the amide by this method the ammonium salt of the carboxylic acid is prepared and dehydrated, melted, allowed to cool, and then pulverized. The powdered material is placed in a distilling flask and heated. Another method is to add solid ammonium carbonate to the carboxylic acid, and distill directly.

(A) **Preparation of Acetamide** (**Sm.**). Place in an eight-inch distilling tube 10 ml of glacial acetic acid, and add slowly 4 g of ammonium carbonate, a little at a time. When the evolution of carbon dioxide has subsided, attach to the mouth of the tube a micro condenser arranged for reflux. The end of the condenser should be just below the side arm opening. Add two boiling stones and heat with a small luminous flame for 20 minutes. After the dehydration of the ammonium salt the apparatus is arranged for distillation. The micro condenser is removed and a thermometer inserted in its place. The side arm of the distilling flask is connected with the receiving tube. Distill the mixture very slowly until the thermometer reaches 170°. Change the receiving tube and insert the delivery tube much below the micro condenser by pulling the latter upward until only a small portion protrudes into the receiver. Distill the acetamide at a regular rate, and collect the fraction which boils at 215–225°. The yield is 2–3 g. It can be purified by recrystallization from acetone. Pure acetamide boils at 223° and melts at 82°.

(B) **Preparation of Acetamide** (M.). Place 40 g of ammonium carbonate in a 200–300 ml round-bottom flask. Add slowly 100 ml of glacial acetic acid and 2–3 boiling stones. Fit a short fractionating column on the mouth of the flask and connect it with a condenser for downward distillation. Heat the flask so that the mixture boils very gently and the vapors do not rise in the fractionating column. After the mixture has boiled for one hour, increase the heat so that water and some acetic acid distill off slowly. The temperature of the vapors passing into the condenser should not be above 125°. When 50–55 ml of distillate has passed over, discontinue the heat, allow to cool for a few minutes, and then transfer to a distilling flask attached to an air-cooled condenser arranged for downward distillation. Add two boiling stones and continue the fractionation. The portion which boils from 190–230° is collected. Cool the distillate until it solidifies, and press the crystals as dry as possible between sheets of filter paper. The yield is 25–30 g. Place in a dry bottle at once.

The crude acetamide may be recrystallized from a mixture of three parts of benzene to one part of ethyl acetate, or from an alcohol-ether mixture. Dissolve 0.5 g of acetamide in 1 ml of methanol by warming; cool, and add 6–7 ml of ether. Cork tube, and cool. If crystals do not separate within a few minutes, even on stirring, add a minute crystal of pure acetamide and allow to stand. Filter the crystals with suction and wash with ether. Place on a paper disc or watch glass and dry in a dessicator. Determine the melting point.

(C) **Preparation of Benzamide** (Sm.). Perform the experiment in the hood. Place 5 g of ammonium carbonate in a mortar and pulverize well. Add 2 ml of benzoyl chloride and mix with the pestle for a few minutes. Add 2 ml of concentrated aqueous ammonia, and allow to stand for 10 minutes. Transfer the reaction mixture by means of water to a beaker and stir well. Ammonium carbonate dissolves, leaving the crystals of benzamide. Filter by suction, and wash with water. The yield is about 2 g. If desired, the crystals may be recrystallized from water.

PROPERTIES OF AMIDES

The most important properties of amides are the reactions which they undergo with water, nitrous acids and hypohalites. In aqueous solutions amides are weak proton acceptors and donors. The proton-repelling properties are increased in the imides, $R(CO)_2NH$, and sulfonamides, $R—SO_2NH—R$; these substances have definite acidic properties. Amides undergo hydrolysis when heated with water. The rate is increased by both acids and bases. Nitrous acid reacts with amides as with other amino, RNH_2, compounds. The action of alkaline hypobromite on amides gives first a bromoamide, RCONHBr. The bromine atom in such a position is active, and on warming a complex rearrangement takes place, with decarboxylation and formation of an amine.

(**D**) **Acid and Basic Properties of Amides.** (1) Determine the *p*H of a sample of pure acetamide in water. Which amide is most likely to show definite acidic properties? Devise a test to show that acetamide forms salts with metallic ions.

(2) To 0.5 g of soluble saccharin add 5 ml of water and warm until it dissolves. Add 2 drops of dilute hydrochloric acid. Write the equation for this reaction.

(**E**) **Hydrolysis of Amides.** Place in a test tube 0.5 g of acetamide and add 3 ml of sodium hydroxide solution. Boil and note the odor. Repeat, using 5 ml of dilute sulfuric acid and 0.5 g of benzamide. Boil for a few minutes and notice any change.

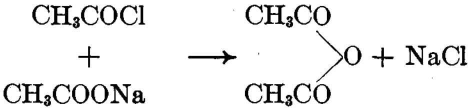
(**F**) **Action of Nitrous Acid.** To 0.5 g of acetamide add 2 ml of 10 per cent sodium nitrite solution and 0.1 ml of acetic acid. Note the change.

(**G**) **Decomposition of Bromamide.** To 2.5 ml of bromine (**care**) in a test tube which is immersed in a freezing mixture add 3 g of acetamide, and then a cold solution of 2 g of sodium hydroxide in 5 ml of water. By rubbing the sides of the tube with a glass rod, crystals of the bromoacetamide may be separated out. Add 10 ml of 40 per cent solution of sodium hydroxide. Provide a delivery tube which passes into a receiving tube immersed in an ice bath and containing 5 ml of water. Warm the alkaline solution of bromamide, and stop when the reaction begins (**care**). The methylamine vapor dissolves in the water. Devise two tests to prove that the solution in the receiving tube contains methylamine.

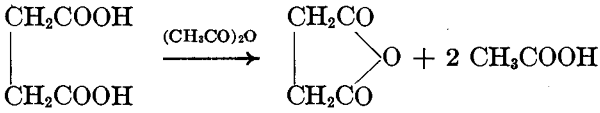
Experiment 42

PREPARATION OF ACID ANHYDRIDES

Introduction. The object of this experiment is to illustrate two general methods for the preparation of acid anhydrides. Two carboxyl groups may under certain conditions be dehydrated to give an anhydride. The two carboxyl groups may be derived from the same molecule, as in succinic and phthalic anhydrides, or from different molecules, as in acetic anhydride. The simple anhydrides are usually prepared in the laboratory by the action of an acyl chloride on the salt of the acid:



If the acyl chlorides are not available, use may be made of excess of acetic anhydride or acetyl chloride to dehydrate the acid. For example, succinic acid when refluxed with excess of acetic anhydride or acetyl chloride is converted completely to succinic anhydride:



In many cases, particularly for aryl acid anhydrides, the sodium, ammonium, or potassium salt of the acid is heated with sufficient phosphorus oxychloride or thionyl chloride to convert half of the salt into the acid chloride. The latter reacts with the other half of the salt to give the anhydride. This method is used for the preparation of the anhydride of *o*-sulfobenzoic acid (see page 339). Finally, a few dicarboxylic acids, such as phthalic acid, which contain two carboxyl groups attached to adjacent carbon atoms, when heated above their melting point lose water and form the anhydride.

The most important use of anhydrides is for the acylation of hydroxy and amino compounds. Acetic anhydride is the most important anhydride and industrially is prepared by the addition of acetic acid to ketene.

(A) **Preparation of Succinic Anhydride** (Sm.). Use the same apparatus as described for the preparation of acetyl chloride (Experiment 40 A). Place in the distilling tube 5 g of succinic acid and 9 ml of acetic anhydride. Adjust the micro condenser for reflux, and heat in the water bath at 90–100° for 30–45 minutes until a clear solution is obtained. Remove the distilling tube from the water bath and attach to the side arm (through a short rubber tubing) a calcium chloride tube. When the tube has acquired room temperature cool in an ice-salt mixture. Filter the crystals with suction and wash twice with 4 ml portion of ether. Place the product in a bottle. The yield is 3–4 g.

(B) **Preparation of Acetic Anhydride** (M.). Use the same apparatus as for the preparation of acetyl chloride, except that the distilling flask has a capacity of 125 ml. Place in the flask 30 g of finely pulverized anhydrous sodium acetate.[1] Place 25 g of acetyl chloride in the separatory funnel. Add the acetyl chloride slowly; when the addition is completed remove the funnel and close the flask by a solid cork. Shake the flask well in order to mix the salt with the chloride thoroughly. Heat by means of a direct smoky flame, moving it to and fro over the bottom of the flask to avoid superheating and cracking. Continue heating until the distillation stops. Allow the flask to cool, and replace it by a small dry distilling flask. Add to the distillate in the dry flask 2–3 g of anhydrous sodium acetate, and redistill. Collect the portion which boils at 130–140°. The yield is about 20 g.

(C) **Action of Heat on Phthalic Acid.** Place 1 g of phthalic acid in a dry evaporating dish which rests on an asbestos-centered wire gauze. Invert over the dish a funnel which has a plug of cotton in the stem. Heat the dish over a very small flame. Phthalic acid sublimes to the anhydride, which deposits in the form of long needles inside the funnel.

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[1] Anhydrous sodium acetate is dehydrated by heating in an iron dish, as directed on page 354 of the Appendix.

PART III

PREPARATION AND PROPERTIES OF COMPOUNDS OF GREATER COMPLEXITY

Experiment 43

PREPARATION OF CHLOROACETIC ACID

(Chlorination of Organic Compounds)

Introduction. The object of this experiment is to illustrate the method used for the chlorination of organic compounds in the liquid phase. The use of the macro method is restricted to advanced students, since it involves the use of compressed chlorine. Although it is possible to generate chlorine in the laboratory for the preparation of 25–30 g of material, the time required for the completion of the experiment is rather long. The semimicro method permits chlorination of 5–10 g of a substance within one or two hours.

For chlorination in the liquid phase, chlorine gas is led into the liquid and is dispersed in the form of fine bubbles. In most chlorinations heat and a catalyst are employed. Phosphorus and its halides, sulfur and its halides, iron, aluminum chloride, antimony chloride, and iodine are among the common catalysts used for chlorinations. For laboratory use red phosphorus, iron, and thionyl chloride give good results. Aluminum chloride (or aluminum-mercury couple), although a very efficient catalyst, clogs the disperser. The use of actinic light is sometimes used to promote chlorination in the liquid phase, and is extensively used in the vapor phase. The action of the catalysts is assumed to activate a few chlorine molecules which initiate chain reactions. For example, in the chlorination of benzene the reaction begins with the dissociation of a few molecules of chlorine to atoms:

$$Cl_2 + \Delta \longrightarrow 2\,Cl$$

$$Cl + C_6H_6 \longrightarrow C_6H_5Cl + H$$

$$H + Cl_2 \longrightarrow HCl + Cl \text{ etc.}$$

In the preparation of α-halogen fatty acids phosphorus is used as a catalyst. It is assumed that the phosphorus forms the halide which acts on the acid to form the acyl halide:

$$2\,P + 3\,Cl_2 \longrightarrow 2\,PCl_3$$

$$PCl_3 + 3\,CH_3COOH \longrightarrow 3\,CH_3COCl + P(OH)_3$$

The presence of a small amount of acetyl chloride is sufficient for the chlorination of a large amount of acid. The acyl halide chlorinates easily to form chloroacetyl chloride, which then acts on unchanged acetic acid to form the α-halogen acid and regenerate acetyl chloride.

$$\mathrm{CH_3COCl + Cl_2 \longrightarrow CH_2ClCOCl + HCl}$$

$$\mathrm{CH_3ClCOCl + CH_3COOH \longrightarrow CH_2ClCOOH + CH_3COCl}$$

The regenerated acetyl chloride is again chlorinated, and thus only a small amount is needed for the cycle. The progress of chlorination is followed by weighing the flask which contains the material to be chlorinated, the catalyst and the disperser at the beginning of the experiment; from time to time the passage of the gas is stopped and the flask is weighed again. When the reaction mixture has gained 80–85 per cent of the calculated amount the chlorination is stopped. In the chlorination of carboxylic acids, polyhalogen compounds tend to form towards the end. The dispersing of chlorine into fine bubbles is of importance in liquid phase chlorinations. Although in some chlorinations it is possible to bubble chlorine through the liquid by means of a tube, in most cases it is necessary to disperse the gas into minute bubbles in order to obtain efficient absorption. Dispersers made of fritted glass, commercially available, are used for macro work. A more efficient disperser made of an alundum crucible is described later in this experiment. For semimicro work a small disperser is described in the next paragraph.

Apparatus for semimicro chlorination. Figure 54 represents the apparatus used for semimicro chlorinations. The chlorine generator is a Florence flask of 500 ml or 1000 ml capacity. The charge consists of technical manganese dioxide, with commercial concentrated hydrochloric acid added through a separatory funnel. A thistle tube may be used in place of the separatory funnel. In this case the thistle tube should be pushed down until the outlet is 5 mm from the bottom of the flask. After the required amount of hydrochloric acid has been added the flask is heated by a small smoky flame until a constant stream of chlorine is obtained. The generation of chlorine is controlled by reheating the flask from time to time. The flow of chlorine is regulated to such a rate that the bubbles can be counted in the drying bottle.

The chlorine generator is connected through a piece of rubber tubing with a wide-mouth bottle of about one liter capacity containing 400 ml concentrated sulfuric acid. The inlet tube from the generator reaches almost to the bottom of the bottle, while the outlet reaches 10 mm below the rubber stopper of the bottle. Through a third hole in the rubber stopper a glass tube 900 mm in length and 6 mm in diameter is inserted to serve as safety valve. This tube reaches almost to the bottom of the bottle, and the rise of sulfuric acid above its level in the bottle is a measure of the pressure within the apparatus. The height of the sulfuric acid during chlorination is about 350 mm. If it goes above 400 mm this is indication that the disperser is clogged. In such case the rubber tube which connects the disperser with the generating train is disconnected and the generator is cooled. The disperser becomes clogged when gelatinous material is formed in the course of the reaction, as when aluminum chloride is used as catalyst. The chlorine "washing bottle" is connected to a 250-ml bottle containing some glass wool, which serves as a trap to prevent any fine spray of sulfuric acid reaching the chlorination apparatus.

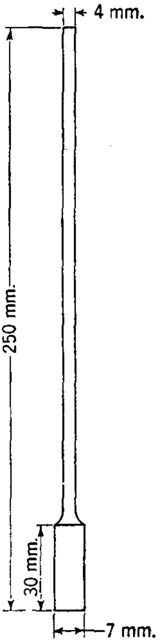

Fig. 54(*a*). Micro disperser for chlorine

The chlorinator consists of a regular eight-inch Pyrex tube. It is closed by a three-hole rubber stopper through which are attached (*a*) the disperser, (*b*) a micro condenser, (*c*) an outlet for gases. The disperser is shown diagrammatically in Figure 54(*a*). It consists of a piece of refractory tubing 30 mm in length and 7 mm in diameter, in which is inserted a glass tube 4 mm in diameter and 250 mm in length. The glass tube is pushed gently into the refractory tube about 3 mm, and is sealed by cement. The open end of the tube is also sealed with cement pushed in about 1 mm. The complete disperser and also the pieces of refractory tubing are commercially available.[1] A satisfactory cement is made from litharge, glycerine and sodium silicate. After the seals have been made, the cement is allowed to harden for a few hours; then the disperser is heated in an oven at about 100° for 3–4 hours. The efficiency of the disperser is tested by dipping it in an eight-inch tube containing 10 ml of water and blowing gently through it. A fine stream of bubbles should emerge from the refractory part of the tube. If the bubbles are large then the seals are defective. The tube is dried by

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[1] Wilkens-Anderson Co., Chicago, Illinois. The price of the complete disperser is about 50 cents, and the price of refractory tubing, unattached, is about 20 cents.

placing first in cleaning solution, then washing with water thoroughly, then with alcohol and finally with ether.

The micro condenser is inserted about 80–90 mm in the tube.

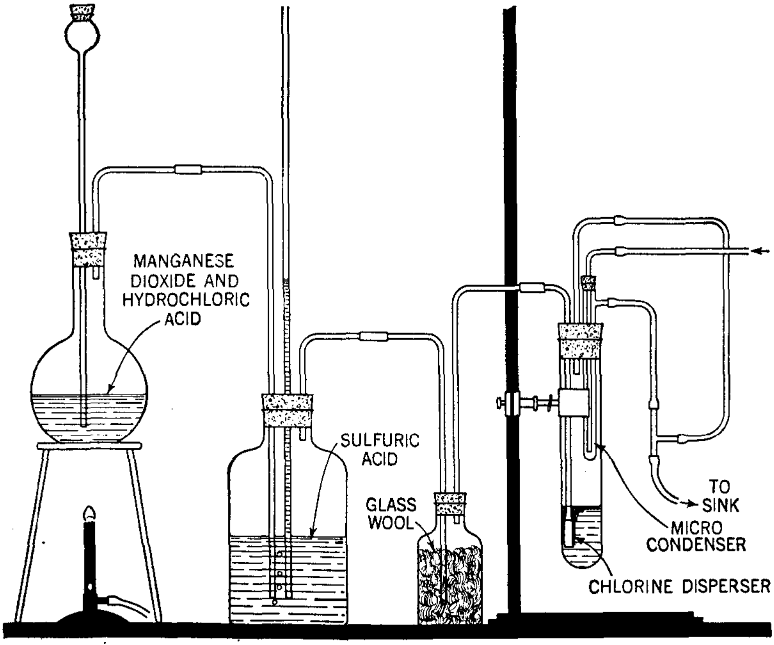

Fig. 54(*b*). Semimicro apparatus for chlorination

The outlet tube is connected by a piece of short rubber tubing with a piece of glass tubing 4–5 mm in diameter which is bent at right angles downwards, and is connected to one end of a T tube. One end of the T tube is connected with the outlet of the micro condenser and the other with a piece of rubber tubing leading to the trough or sink; as the water runs downwards from the condenser it washes out the gases coming from the chlorination apparatus. There is a danger, however, of the water sucking back in the chlorinating tube if there is a sudden change in pressure. This danger can be avoided by placing a small bottle between the chlorinator and the T tube.

(A) Preparation of Chloroacetic Acid (Sm.). Place in an eight-inch tube 10 g of glacial acetic acid and 0.5 g of red phosphorus; then arrange the apparatus as directed in the preceding paragraph.

Blow through the disperser to make sure that it is not clogged. Charge the chlorine generator with 25–30 g of manganese dioxide (granular) and add 40 ml of commercial concentrated hydrochloric acid. Add another portion of 35–40 ml of acid after 1 hour. Heat the flask gently until chlorine begins to bubble through the sulfuric acid, and observe whether a fine stream of gas issues from the disperser. If the disperser operates well, heat the mixture of acetic acid and phosphorus until the acid just begins to boil. The reaction from this point on generates sufficient heat to keep the mixture refluxing gently. As soon as the chlorine begins to be absorbed increase the rate at which chlorine is passed in the tube. Continue for about 2 hours. The phosphorus by this time has almost gone into reaction. If a closer check on the progress of the reaction is desired, the chlorinator (tube, with stopper, condenser, disperser, and mixture of acid and phosphorus) is weighed in the beginning before chlorination is started, and again after two hours. There should be a gain in weight of about 3 g. The actual amount of chlorine is about 5 g. But one or more grams are lost, owing to the fact that the gases leaving the reaction carry along some of the vapors of acetyl chloride, acetic acid and chloroacetyl chloride.

The chlorination is discontinued by breaking the connection of the disperser at the trap bottle, and also at the gas outlet. The generator is cooled slightly so that chlorine does not continue to bubble through the sulfuric acid. The connection between the generator and the sulfuric acid should also be removed, for as the generator cools there is a tendency for the acid to be drawn up towards the generator.

Remove the chlorinator to the hood, raise the disperser above the liquid, and blow gently through it to remove the liquid which is in the lower end. Pour the contents of the tube into a small beaker and cover it with a watch glass. Use **caution** in handling chloroacetic acid, as it produces severe burns in contact with the skin. On cooling, the contents of the beaker will solidify. Immerse in an ice-salt mixture for about 15 minutes and then filter with suction. The crystals are pressed down, then removed on filter paper and pressed between several thicknesses of paper, using great care not to allow any liquid or solid to touch the skin. The crude crystals are placed in a tared bottle or tube. The filtrates, which consist of acetic acid, acetyl chloride, and chloroacetyl chloride, may be used for another chlorination of acetic acid. In such case the amount of phosphorus is reduced to 0.2–0.3 g. The yield is 10–11 g. The crude analyses 90–95 per cent of chloroacetic acid, and is sufficiently pure to be used directly in the preparation of glycine (Experiment 50). If the pure acid is desired, the crystals are placed in an eight-inch distilling tube and distilled. The portion which boils at 184–192° is collected. The yield of pure acid is 7–8 g. The same method is used for the chlorination of propionic, butyric and caproic acids.

(**B**) **Preparation of Chloroacetic Acid** (**M.**). Set up an apparatus as shown in Figure 55. The three-neck flask has a capacity of two liters. The first two bottles in the absorption train contain water and the third dilute sodium hydroxide. In order that chlorination may be effective, the chlorine must be dispersed. A glass dispersion tube with a fritted disc is used. A very efficient gas-dispersion thimble can be made in the laboratory as follows: Use a No. 2 Alundum crucible 30 mm in diameter and 30 mm in depth. Pack glass wool within the thimble and insert a glass tube 5–6 mm in diameter and 300 mm in length so that it reaches almost to the

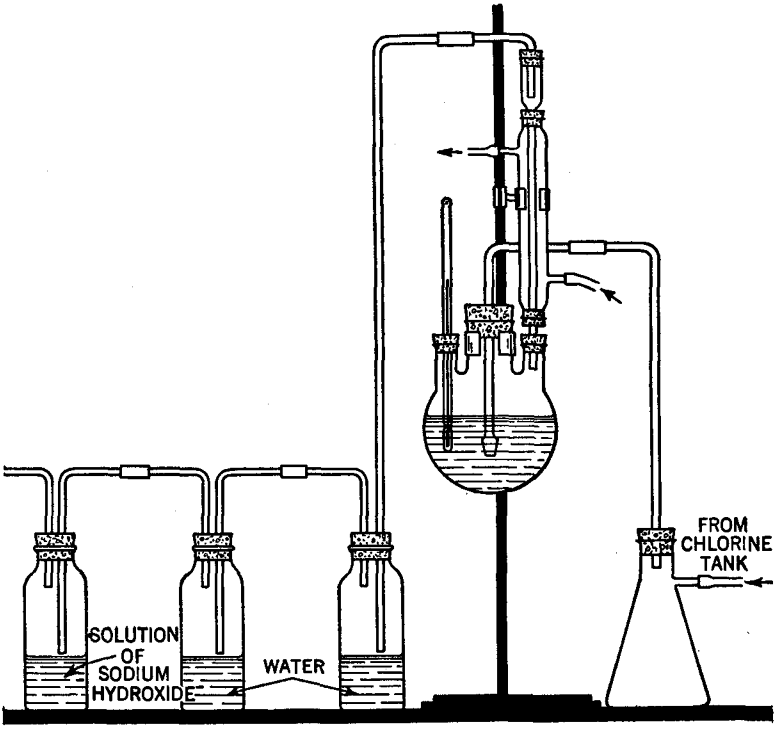

Fig. 55. Macro apparatus for chlorination

bottom of the crucible. Prepare a cement by making a paste of 5 g of sodium silicate, 5 g of glycerine, 5 g of litharge, and 3 g of common fibre asbestos, mixing in the order given. Seal the top of the thimble by pressing the cement against the delivery tube. The cement sets within a few minutes. Paint the cement with a thin paste of litharge and glycerine and allow to stand in an oven at 100° overnight. The thimble can be cleaned after use by washing it with acetone and then with water, and drying it at 100° after it has drained.

Place in the flask 12 g of red phosphorus and 300 g of glacial acetic acid. Insert a thermometer and the delivery tube, and heat to about 100°. Chlorine is obtained from a cylinder which is connected first to a filter flask, which acts as a trap, and then to the disperser. Rubber tubing (red) of 5 mm in diameter is used to make the connections between the filter flask and the disperser. Open the main valve of the cylinder first, making about one quarter turn, and then, very slowly, open the needle valve. Adjust the latter so a fine stream of bubbles issues through the disperser. Pass chlorine into the mixture slowly at first and increase the flow gradually. The flame is adjusted so that the heat from the reaction is sufficient to keep the temperature at 105–110°. Chlorine is passed into the mixture until the contents of the flask have gained about 150 g (85 per cent of theory) in weight. The time required is about nine hours. After six hours it is necessary to reduce the flow of chlorine.

Pour the contents of the flask with care into a liter Claisen distilling flask and distill at ordinary pressure until the temperature rises to 175°. Arrange the flask for vacuum distilling according to directions given on pages 238–239. Distill the acid until only about 30 ml of liquid remains in the flask. The yield is about 420 g. The acid is about 96–98 per cent pure.

The same method of preparation may be used for α-chloropropionic acid, α-chlorobutyric acid, and α-chlorocaproic acid.

(C) **Chlorination of Organic Compounds** (Sm.). The semimicro method for the chlorination of acetic acid may be used for the chlorination of many organic compounds in the laboratory. Iron or pyridine may be used as a catalyst. Aluminum chloride, or aluminum amalgam should be avoided, as they clog the disperser. The chlorination of benzene will serve as an example. Place 10 g (13 ml) of benzene and 0.15 g of iron powder in the chlorinating tube. Heat to 75–80° and pass chlorine for about 1–1.5 hours. Transfer the mixture to an eight-inch distilling tube, and fractionate. Collect the portion which boils at 129–135°. The yield is 5–7 g.

Experiment 44

PREPARATION OF α-BROMOPROPIONIC ACID

PROPERTIES OF α-HALOGEN ACIDS

Introduction. The bromination of fatty carboxylic acids is analogous to the chlorination of acetic acid discussed in the preceding experiment. The acid is heated with a little more (1.1 moles) than the calculated amount of bromine and a small amount of phosphorus trichloride which acts as a catalyst. The halogen acid is purified by distillation. The most important properties of α-halogen acids are metathetical reactions in which the halogen group is replaced by the amino, cyano, and other groups. The tendency to drop off hydrogen and halogen at the same time and thus form an unsaturated compound is less in the α-halogen acids than in the β-isomers, unless a radical is attached to the α-carbon atom. The object of this experiment is to illustrate the general method for the preparation of bromo acids, and a few of their properties.

(A) **Preparation of α-Bromopropionic Acid** (Sm.). Read on page 269 the precautions for handling bromine. Arrange an eight-inch tube as shown in Figure 53. The micro condenser fits in the mouth of the tube through a rubber stopper which has been coated with sodium silicate and allowed to dry. This prevents the rapid attack of bromine on rubber. Place in the tube 7.4 g of propionic acid and 17 g (5.5 ml) of bromine; add 5 drops of phosphorus trichloride, and warm in the water bath at 40–50° for 30 minutes or until no fumes of bromine are visible in the tube. Remove the micro condenser, and insert a thermometer through a rubber stopper coated with sodium silicate. Add two boiling stones, and fractionate. Use a small luminous flame to heat the tube, and move the flame to and fro so that the acid does not become superheated. Collect the first fraction until the temperature rises to 160°. Change the receiving tube and distill, under reduced pressure as directed in the next experiment (Experiment 45). Collect the fraction which boils at 95–100°/10 mm. This fraction may be used directly for the preparation of *dl*-alanine in Experiment 50. The same method may be used for the preparation of α-bromobutyric, α-bromocaproic, and other bromo acids.

(B) Preparation of α-Bromopropionic Acid (M.). Arrange a 500-ml Florence flask as shown in Figure 46, without the dropping funnel; the absorption train is the same as used in the preparation of chloroacetic acid (page 225). The rubber stopper which connects the reflux condenser to the flask is painted with sodium silicate twice, and allowed to dry each time.

Place 37 g of pure propionic acid in the flask, add 84 g of bromine, and connect with the reflux condenser. Raise the stopper connecting the top of the condenser with the absorption line, add rapidly 1–2 ml of phosphorus trichloride, and replace the stopper securely. Warm the water bath under the flask slowly until the reaction begins (40–50°). Adjust the flame so that the evolution of hydrogen bromide is not so vigorous as to carry any considerable vapor of bromine into the absorption bottles. The reaction proceeds smoothly without a great deal of watching. When bromine vapor no longer appears in the condenser tube, the reaction is completed.

The crude acid is transferred to a 125 or 250 ml Claisen flask and distilled at ordinary pressure until the temperature of the vapor rises to 160°. The apparatus is arranged for vacuum distillation (pages 238–239). The fraction which boils at 95–100°/10 mm is collected. The yield is 60–65 g.

(C) Reactivity of the Halogen. For this test use α-bromobutyric, β-bromobutyric, and α-bromoisobutyric acids. Place 0.1 g or 0.1 ml in separate tubes with 10 ml of water. To each add 1 ml of 0.1 *N* silver nitrate and observe the extent of reaction after one and after five minutes.

(D) Formation of Unsaturated Acid. Place in separate tubes 1 g of each acid used in section (D). Add to each 5 ml of 6*N* sodium hydroxide solution; cork, and allow to stand overnight. Place tubes in an ice bath, and acidify cautiously by the addition of 5–6 ml of dilute (6*N*) sulfuric acid. Cool to 20°, add 2 ml of 0.5 per cent solution of bromine in carbon tetrachloride, and shake. The presence of unsaturated acid is shown by rapid decolorization of the bromine solution.

Experiment 45

DISTILLATION UNDER REDUCED PRESSURE

GENERAL CONSIDERATIONS

Introduction. The distillation of liquids and low melting solids under reduced pressure was briefly mentioned in Experiment 5 (page 57). In the present experiment a more extensive discussion will be given, together with directions for the procedures commonly used in the laboratory in distilling under reduced pressure.

The reasons for using distillation under reduced pressure (often called vacuum distillation) are connected with the instability of organic compounds. Many pure carbon compounds, when distilled at atmospheric pressure by heating in a glass flask, undergo changes, such as pyrolytic reactions, oxidation by atmospheric oxygen present in the air above the liquid, and rearrangement reactions. For example, assume that butyric acid was brominated in presence of red phosphorus. The reaction mixture contains α-bromobutyric acid, and small amounts of dibromo acids, unchanged butyric acid, butyryl bromide, bromobutyryl bromide, phosphorus bromide and hydrogen bromide. If this mixture is distilled at atmospheric pressure the last four products will come over first, then unchanged butyric acid at 160–170°. After all the butyric acid has distilled, the temperature will rise to about 212° and α-bromobutyric acid will distill with decomposition, which increases toward the end of the distillation. The distillate will contain α-bromobutyric acid with small amount of hydrogen bromide, crotonic acid and even β-bromobutyric acid. Under the effect of heat hydrogen bromide is eliminated by the halogen acid, to form the unsaturated crotonic acid, which may add hydrogen bromide to form β-bromo acid. Thus it becomes evident that even for ordinary work distillation at atmospheric pressure is inadvisable even if the impurities will do no harm for the purpose desired. While it is not uncommon in industrial work to use a crude intermediate and purify the final product, this procedure in the present case is not economical. This can be readily proved by dividing the crude into two equal portions and distilling one by ordinary distillation and the other under

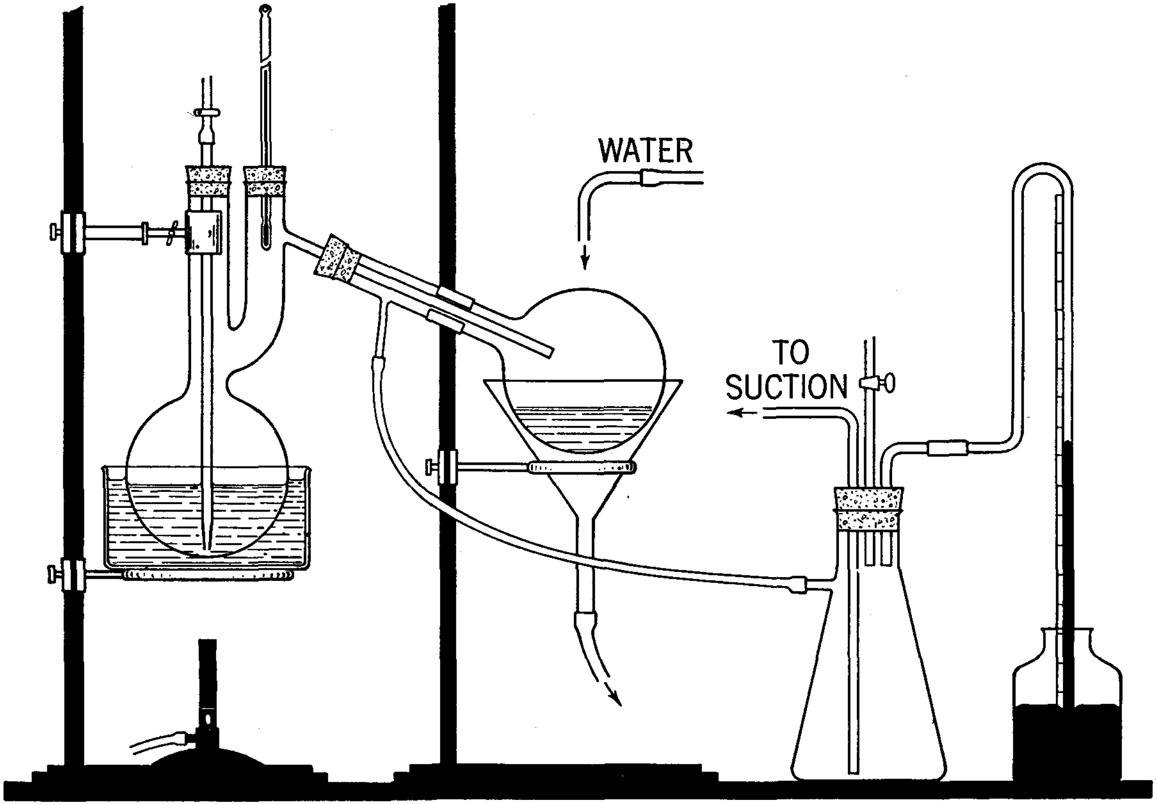

Fig. 56. Macro apparatus for distillation under reduced pressure

(The amount of mercury in the bottle need be sufficient only to fill the U tube and leave a depth of 10 mm in the bottle.)

reduced pressure. Comparison of the yields shows that there is a considerable loss due to decomposition.

Apparatus for distillation under reduced pressure. Figure 56 shows the apparatus generally used by students for distillation under reduced pressure. For advanced work a great many modifications and refinements are introduced. The use of the Claisen distilling flask with two necks is dictated by the difficulties encountered when liquids are boiled under reduced pressure. Bumping, splashing, and frothing occurs more often and with more violence than in ordinary distillations. If an ordinary flask is used the distillate will most likely become contaminated with a spray of liquid which is thrown violently upward in the flask. The splashing and frothing is inherent to distillations under reduced pressure. In an ordinary distillation, when a minute amount of liquid passes into the vapor state its volume increases tremendously. Care must be taken not to allow a great amount of liquid to pass at once into the vapor state in the form of a large bubble, which will cause violent bumping. Boiling stones are added, and as the gases adsorbed in their surfaces rise upwards as small bubbles, they "pick up," so to speak, the vapor which is continuously being formed at the hot inner surfaces of the flask. If the pressure is reduced to 20–25 mm it follows, according to Boyle's law, that there will be an increase in volume and the minute amount of liquid will change into a volume of vapor more than 25 times that which it would have occupied at one atmosphere pressure. Addition of boiling stones is of no great value, since as the pressure is diminished the adsorbed gases are rapidly driven out and the stones lose their ability to give off small bubbles before distillation begins.

To offset these inherent difficulties a flask with two necks is used, in which the side arm from which the vapor passes to the condenser is so placed that it is not easily reached by the spray which forms within the flask. The flask should not be more than half full. To assist the formation of small bubbles of vapor, and hence minimize bumping and splashing, a fine stream of bubbles is sucked into the boiling liquid through a glass capillary. For this purpose a glass tube is drawn out into a fine capillary, and inserted through a rubber stopper which fits one of the necks of the flask. The capillary reaches almost to the bottom of the flask. A small screw pinchcock is fitted at the top of the capillary tube by means of a small piece of rubber tubing. The pinchcock is regulated, after the pressure has been diminished, so that there is a steady stream of fine bubbles. The exact adjustment of the pinchcock is a matter of experience, since with some liquids the inlet of air causes serious frothing.

Generally it is best to allow the minimum amount of air so that the liquid will boil without excessive bumping. The thermometer is fitted through the neck of the flask which has the side arm. Some of the hot vapors condense into liquid on the rubber stopper or cork which holds the thermometer. The liquid may become discolored and run down into the side-arm tube and contaminate the distillate. In such cases the side arm should protrude a few millimeters within the neck of the flask; such a side-arm tube is known as an "inner seal."

Heating is done by means of a water bath if the liquid can be boiled below 100°, and an oil bath if the liquid can be boiled at 100–250°. A metal bath is used for temperatures above 250°, at which oils fume badly. The use of baths avoids superheating, promotes even boiling, and reduces the danger of injury if the flask suddenly collapses. The points of weakness in the flask which develop with use, such as scratches and points of glass crystallization, become sources of real danger when heated by direct flame. The bath is usually heated 15–20° higher than the temperature of the distilling vapor. The apparatus is evacuated before heating is started and the flame is *always* removed *first*, before the pressure is released.

An ordinary distilling flask serves as both condenser and receiver. A stream of water directed on the bulb of the flask is satisfactory for all distillations under reduced pressure which take place above 50°. The bulb of the flask must be thoroughly cleaned so that water spreads uniformly and bathes the bulb completely. If uneven distribution occurs even after cleaning the bulb, a small clean piece of cloth wrapped around the bulb and tied below by means of a string answers the purpose. Two different iron stands are used to support the Claisen and receiving flasks. A wide funnel, with a piece of rubber tubing at the end, fitted in a long iron ring, serves to carry the water to the drain. The receiving flask is connected by means of thick pressure rubber tubing with the outlet arm of a 500-ml or 1000-ml filter flask, which serves as a trap. The three-hole rubber stopper fitted at the mouth of this flask is provided with a glass tubing connecting to the manometer, which measures the pressure within the apparatus. Another glass tube connects with the suction pump. In the third opening is fitted a glass tube having a stopcock, so as to release the vacuum by allowing air in the apparatus. The trap also serves to catch any liquid which may be drawn back as a result of a sudden change in pressure.

In some distillations it is desired to collect several fractions. One way to accomplish this is to stop heating, release the pressure, change the receiver, re-evacuate, and heat until distillation begins again. This is not cumbersome if two fractions must be collected. In ordinary work the first fraction contains residual solvent and the impurities. The second or main fraction is collected, discarding the residue. It is possible to take successive fractions without interruption of the distillation or breaking the vacuum, by using a special adapter. A great many varieties are used. One special receiver is shown in Figure 57. When it is desired to change the receiver, the adapter is slightly turned until the distillate drops into the proper flask.

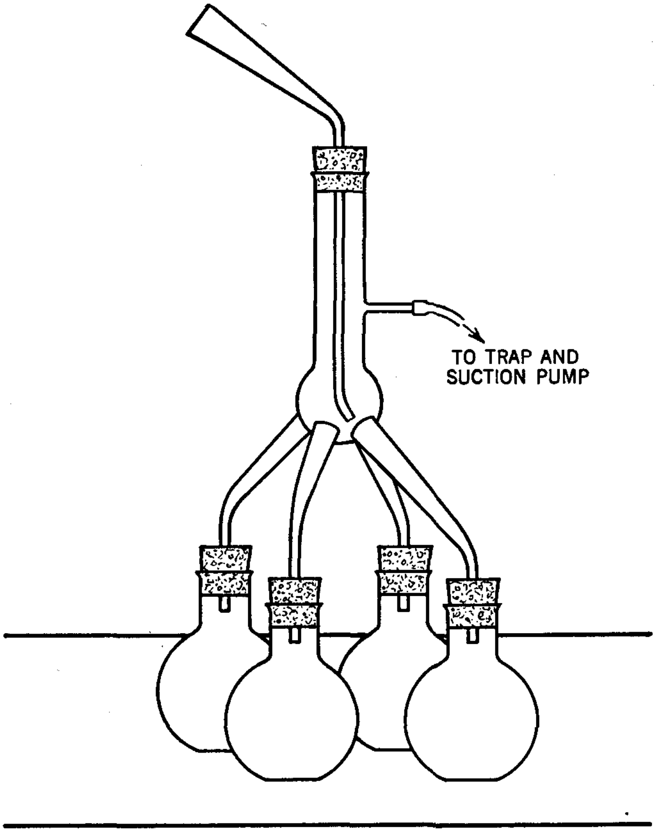

Fig. 57. Apparatus for changing receiver during distillation under reduced pressure

The stoppers used in the apparatus are usually rubber. Red rubber stoppers have greater resistance to softening, which takes place at temperatures above 150°. The use of corks is admissible when a high vacuum is not essential. It is difficult to obtain tight joints with corks. Good quality corks should be selected, rolled and pressed, fitted into the apparatus, and then painted with a clear lacquer or collodion. Suction is applied for a few minutes and the process repeated.

After some time the system is evacuated and tested with a manometer. The connections of rubber tubing to the glass tubing of the apparatus are always a source of leaks. When a pressure below 20 mm is desired, the joints should be painted with a molten mixture of equal parts of yellow beeswax and rosin, or any other suitable non-cracking cement.

Several types of suction pumps may be used to evacuate the system. The common metal aspirator used as a filter pump can be used if the water pressure in the line is not reduced by having several outlets open, as is the usual case in a student's laboratory. It is best to arrange to conduct a vacuum distillation at hours when a good water pressure is obtainable. Special glass aspirators are available which have greater efficiency. In any case, the pressure obtained by water aspirators is limited by the vapor pressure of the water, which depends on the temperature. If the temperature of the water is 10°, then the best pressure obtainable is about 15 mm, or at any rate not less than 10 mm. Usually in summer the best obtainable pressure is about 25 mm and in winter about 12–15 mm. Motor-driven oil pumps are employed when the pressure required is below 10 or 15 mm. Pressures as low as 0.1 mm can be obtained by using a good oil pump. The disadvantage of oil pumps is that they are made of metal and will corrode, particularly when no great care is exercised to trap the vapors of organic compounds which inevitably come from the receiver, no matter how efficiently the bulb is cooled. A pump giving a vacuum of 0.1 mm in a distillation setup such as is described above may after six months give at best 5 mm, if no provision is made to use a "drying train" between the trap and the pump. The "train" consists of 2–3 wide-mouthed bottles which contain soda lime, calcium chloride, and solid sodium hydroxide. It is also advisable to remove residual solvent (alcohol, ether, etc.), using a water pump, before connecting with the oil pump. The vapors of these liquids are hard to condense or absorb, and as a result they exert vapor pressure and reduce the vacuum. The oil should be changed from time to time. A good grade of medium-viscosity paraffin-base lubricating oil is usually marketed under the trade designation of "oil for pumps."

Several types of manometers are available for measuring reduced pressures. One that can be constructed by any student is shown in Figure 56. It consists of a vertical tube about 78° mm in length dipping into a mercury well that is tied against a meter stick. The trap is connected to the upper end of the tube, so that when the system is evacuated the difference between the level of the mercury in the manometer tube and that in a standard barometer (in the place where the distillation is performed) gives the pressure of the distillation. The commercial manometers are shorter and have a closed end; the difference in the mercury level of the two columns gives the pressure of the apparatus. A stopcock between the manometer and the apparatus minimizes the condensation of liquids in the manometer tube. The stopcock is opened momentarily to read the pressure, then closed. Apparatus for regulating the pressure under which distillation takes place, so as to reduce the variation, is commercially available.

The boiling point of a substance at a particular reduced pressure cannot be calculated from knowledge of its boiling point at atmospheric pressure or other related data. Generally liquids which boil at a range of 150–250° at one atmosphere pressure, will boil 100–120° lower if the pressure is diminished to 20 mm. Nitrobenzene, which boils at 208° at 760 mm, distills at 99° at 20 mm; the boiling point is lowered by 107°. As the pressure is lowered below 20 mm, the rate at which the boiling point is lowered is greater than at pressures above 20 mm. The boiling point of nitrobenzene at 30 mm is 108°; at 20 mm, 99°; at 10 mm, 85°; and at 1 mm, 53°. This shows the importance of high vacuum.

GENERAL DIRECTIONS

Macro distillation under reduced pressure. Arrange apparatus as shown in Figure 56. Use a 250 ml Claisen flask, and a liter filter flask as a trap. Make a capillary by one of the following two methods. (1) Take a glass tube 5–6 mm in diameter and 125 mm in length, and seal on to its end a small piece of scrap tubing to serve as a handle. This is more economical than using a piece of glass tubing 200 mm in length. Heat the glass tube over a flame, using a wing top burner, remove from flame, and pull out slowly into a capillary. Cut the capillary to a length so that the end reaches almost to the bottom of the flask. Fit the capillary through the stopper, fasten a short piece of pressure tubing in the upper end of the tube, and attach a screw clamp to the rubber tubing. (2) A capillary with a fine hole, which does not require rubber tubing with a screw clamp for the regulation of air, is made according to the following procedure. Take a glass tube 100–125 mm in length and 5–6 mm in diameter, and seal on a handle as above. Heat in a sharp flame, holding the tube at an angle of 75°. Allow the glass walls to collapse until the inner diameter is very small while the outside diameter remains unchanged. In this manner a thick wall is built with a fine opening. Apply strong heat at the thick wall section, remove from the flame when soft, and pull out into a capillary.

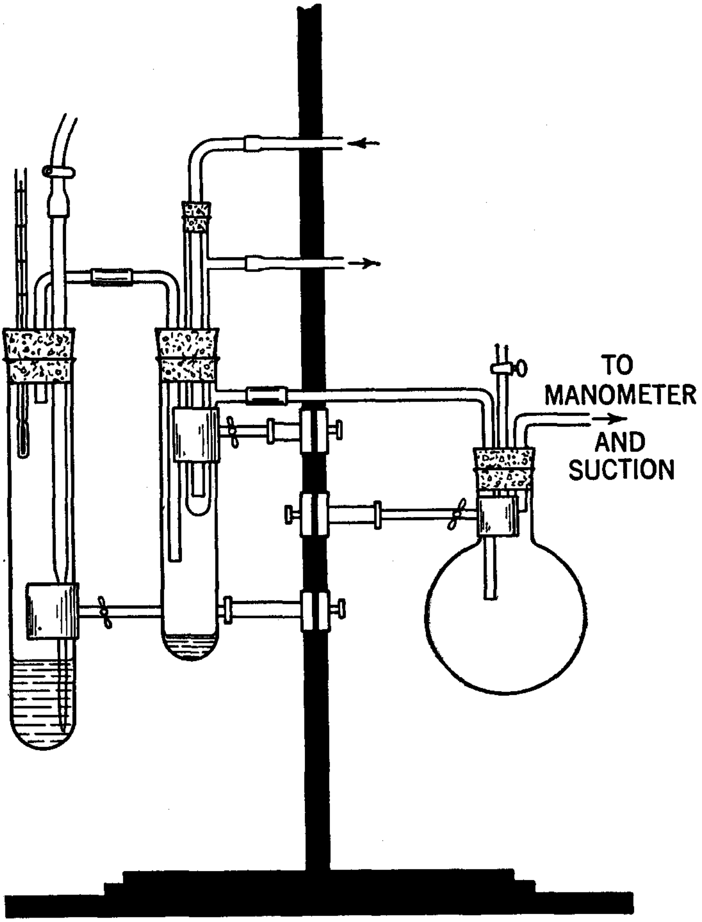

Fig. 58. Semimicro apparatus for distillation under reduced pressure, using eight-inch tube

Select as receivers 2 or 3 distilling flasks having about the same diameter at the opening, so that they fit tightly on the stopper of the side arm of the Claisen flask. The stopper should protrude about one-quarter to one-half of its length into the flask. The same is true of the other stoppers. Connect the side tube of the receiver with the trap. *Wear goggles from this point on,* and do not take them off at any time while the system is under diminished pressure. Shut off the pinchcock of the capillary, and begin the evacuation of the system by turning on the pump. Check all connections for leaks and note the lowest pressure that can be obtained. Release the vacuum slowly by means of the stopcock on the trap, and when the system is at atmospheric pressure shut off the pump. The apparatus is now ready for use.

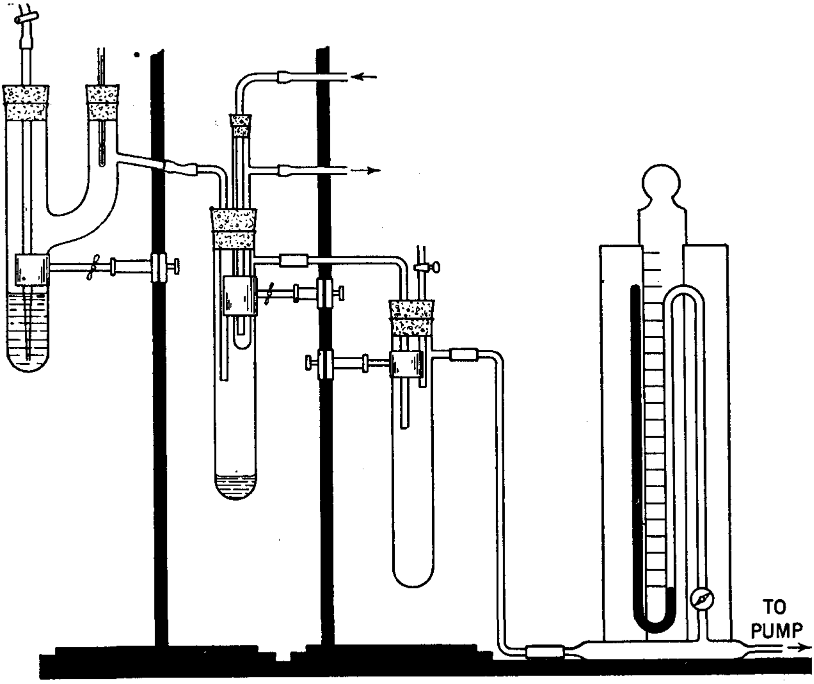

Fig. 59. Semimicro apparatus for distillation under reduced pressure, using Claisen tube

Semimicro distillation under reduced pressure. Two arrangements of apparatus are shown for semimicro distillation under reduced pressure. Figure 58 uses two eight-inch tubes. The first tube has a three-hole stopper for the thermometer, glass tube for outlet of vapor, and capillary tube. The capillary tube is made of 3–4 mm glass tubing in accordance with directions given in the preceding section. The glass tube for the vapor outlet is 4–5 mm in diameter, and is bent as shown in the diagram. It can be cut midway between the two tubes and the connection made through thick-wall pressure tubing. The receiver is an eight-inch Pyrex tube with a side arm. It has a two-hole stopper. One connects with the distilling tube and the other holds the micro condenser. The small flask has a capacity of 125 mm, and can be replaced by an eight-inch tube. It serves as a trap and connects with the manometer and suction pump, and also holds the tube with a stopcock for release of pressure. There are some drawbacks to this type of apparatus. One is the danger of splashing and bumping, which, however, can be controlled if the volume of liquid to be distilled is not more than 5–8 ml. Another difficulty is encountered in fitting the thermometer, the outlet tube, and the capillary tube through a No. 5 rubber stopper. This also can be accomplished with a little care and patience. Both of the above difficulties are removed if the eight-inch tube with the Claisen side neck is used. The apparatus as shown in Figure 59 uses two eight-inch tubes, with a side arm for receiver and trap. The amount of liquid that can be distilled in such apparatus is 20 ml. The apparatus is assembled, using the same precautions as given under the section on macro distillation, and is tested by evacuation. *Goggles are used at all times*, whether one works with the semimicro or macro method. For a heating bath a small amount of oil is placed in a 150-ml beaker or a small tin can. The beaker offers the advantage of visibility, while it suffers from the possibility of breakage.

SPECIFIC DIRECTIONS

(A) **Macro.** Obtain a sample of 50–60 ml of an impure compound to be distilled under reduced pressure. Obtain any special directions or information which the instructor may have. The boiling point of the compound may not be furnished. *Put on your goggles.* Remove carefully the stopper holding the capillary tube and place it on the desk in such a manner that it does not roll and break. Place the sample in the flask, using a funnel. Replace the stopper with the capillary.

Close the screw clamp on the capillary and start evacuation. If a water aspirator is used, keep the valve completely turned on and avoid opening another faucet on the same line. Adjust the flow of air so that a steady flow of small bubbles rises through the liquid. Heat the oil bath gradually, and when the temperature of the oil bath is about 100° reduce the flame and allow the temperature to rise slowly until the distillation begins. Note the temperature and pressure at which the first sign of the distillate appears in the receiver. Distill at about 1–2 drops per second and observe both temperature and pressure. When the temperature remains constant with distillation proceeding at the usual rate, and the pressure does not vary more than 1 or 2 mm between two temperature readings taken a minute apart, the boiling point of the substance at that pressure has been reached. *Remove the flame.* Close the inlet of air in the capillary. Begin releasing the pressure gradually until atmospheric pressure has been reached. Leave the stopcock of the trap open, turn off the pump, and lower the oil bath slightly (*with care*). Remove the receiver, transfer the distillate into a small bottle. and mark it Fraction 1, noting temperature and pressure range. Clean the flask by washing it 2–3 times with a little acetone or another solvent; set aside to dry. Put another receiving flask in place; raise the oil bath. Do not heat until the system has been evacuated again. Open and adjust the capillary. Begin heating, and observe the temperature and pressure when distillation begins and every 2–3 minutes thereafter. When the temperature rises 5° without an appreciable rise in pressure or faster rate of distillation, discontinue heating. Release the pressure and lower the oil bath as before. Transfer the distillate into a tared bottle and mark it Fraction 2, noting the temperature and pressure range. Determine the weight of the distillate.

If there is a considerable amount of residue in the Claisen flask a third fraction is distilled, using the same precautions as before. Finally, when the distillation is completed, the capillary is removed at once and cleaned by placing it carefully in a test tube containing 5 ml of acetone. Insert a piece of clean glass tubing in the rubber tube and draw the acetone a few times upwards to about the middle of the tube. Clean the Claisen flask according to the usual procedure. Hand the distillate to the instructor with the note book and report.

Semimicro distillation. Obtain 8 ml of a liquid to be distilled. Remove stopper holding the capillary and pour the liquid into the tube as completely as possible. Replace stopper. *Put on your goggles.* Raise a small oil bath under the tube. Close the air inlet and evacuate the apparatus. Adjust the air inlet so that the fine bubbles can be counted. Begin heating the oil bath. When the temperature reaches 100° reduce the flame. When the first sign of distillate appears, remove the flame entirely from under the bath. Note the temperature and pressure. Do not let the distillation proceed fast. When about 1–1.5 ml of distillate has been collected (10–20 per cent of the total) the temperature should be constant, with little variation in the pressure. Close the inlet of air and release the pressure very slowly. Change the receiver by loosening the stopper, withdrawing the tube, and replacing it with a dry clean tube immediately. If this precaution is not observed moisture will condense on the micro condenser. If the receiver is not replaced at once, the condenser should be wiped off with a clean dry cloth just before the tube is fitted on the stopper. Begin evacuation, raise the oil bath, and finally adjust the inlet of air. Heat slowly until distillation is resumed. Note the temperature and pressure. Remove the flame, and heat intermittently until 6 ml of distillate has been collected. At this point the distillation is discontinued. Pour the two fractions into tared tubes or bottles, and place a label on each, noting the weight of the distillate, and the temperature and pressure range at which it distilled. Clean the capillary and distilling tube in accordance with the directions given under the section on the macro method. Hand the bottles containing the distillate to the instructor together with note book and report.

Experiment 46

DETERMINATION OF OPTICAL ROTATION

Introduction. Visible light is a form of energy transmitted by wave motion. The vibration of the waves of light is transverse: they vibrate in a direction at right angles to that in which the waves are moving. Sound waves are longitudinal and vibrate in the same direction in which the waves are moving. If a beam of ordinary light which has its vibration distributed in all directions is allowed to pass through certain materials such as (*a*) a tourmaline crystal, (*b*) a polaroid plate, (*c*) a specially constructed crystal of calcite, the light which passes through consists of waves vibrating in or parallel to a *single plane*. Such light is called *polarized*. The human eye has no mechanism for detecting this difference and therefore it is necessary to construct an instrument to demonstrate it. Assume

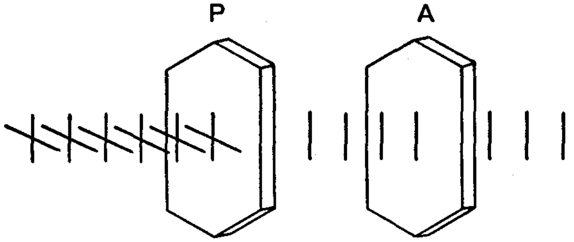

Fig. 60. Polarizer *P* and analyzer *A* in parallel position. Light passing through *P* becomes polarized and passes through *A* with reduced intensity.

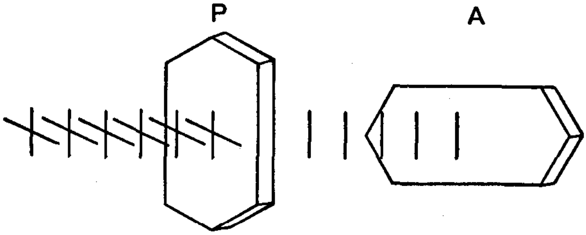

Fig. 61. Polarizer *P* and analyzer *A* at right angles. No light is transmitted through *A*.

that two polaroid plates or two tourmaline crystals are designated by the letters *P* for polarizer and *A* for analyzer, as shown in Figure 60. The axes of the polarizer *P* and analyzer *A* are parallel. Light which passes through *P* becomes polarized and, since only a part of the original beam is transmitted, the intensity is reduced. Since the axis of the beam emerging from *P* is parallel to the axis of *A*, light will be transmitted. If *A* is turned at right angles to *P*, so that the axis of *A* is perpendicular to the axis of the beam, as shown in Figure 61, no light is transmitted through *A*.

If a glass tube with flat ends is inserted between *P* and *A*, in Figure 61, and water is placed in the tube, no light passes through *A*, and if one looks through it he will see a dark field. If tartaric acid, lactic acid, glucose or sucrose is dissolved in the water, it is found that the field becomes luminous. The analyzer *A* can now be rotated until the field becomes entirely dark as before. Obviously the dissolved substance caused the rotation of polarized light. This property is known as *optical activity*. The degree to which the analyzer is rotated until the field becomes dark as before is known as the *optical rotation*. The instrument by which optical rotation is measured is known as the *polarimeter*.

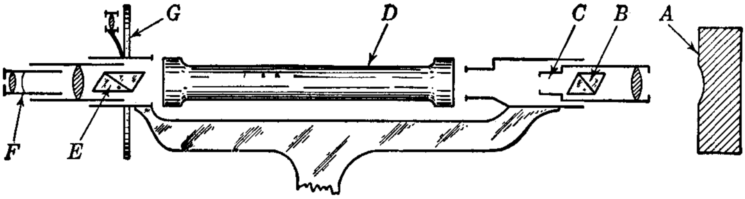

Fig. 62(*a*). Polarimeter

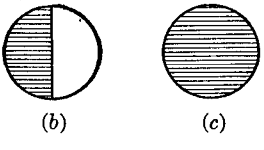
(*b*) (*c*)

Fig. 62. (*b*) Two halves of the field with different intensities of illumination. (*c*) Two halves of the field with uniform illumination (zero point of the instrument).

The polarimeter. Figure 62 shows a diagram of a polarimeter. The light employed in making the measurement of optical rotation is the monochromatic light of a sodium flame, and is obtained by placing a piece of fused sodium chloride in the flame. The light from flame A passes through the polarizing Nicol prism B. A plate of quartz, cut parallel to the optic axis, covers half the opening C, and is of such thickness that it produces a difference of a half wave length between the two rays which it gives by double refraction. The light then passes through the substance which is placed in the tube D and strikes the analyzing, movable Nicol prism E. The telescope F is focused on the edge of the quartz plate at C. If the prism E is turned, a pointer moves over the graduated circle G, indicating the angle through which the prism was moved. When the tube is filled with a non-rotating liquid—pure water, for instance—and placed between the two prisms, the light passing through, because of the construction of the instrument, will produce different intensities of illumination in the two halves of the field, as shown in Figure 62(*b*) above. The movable prism is turned until uniform illumination is obtained. This is the zero point of the instrument (Figure 62[*c*]). When the tube is filled with an optically active liquid, or the solution of an optically active substance, and placed between the two prisms, the light rotates through a certain angle. It is necessary to move the prism C through an angle equal to the angle of rotation in order to establish uniform illumination again. The angle of rotation varies with the length of the column of liquid in the tube. For comparison, the specific rotation is defined as the angle of rotation produced by one gram of an active substance in one cubic centimeter by a layer one decimeter in length.

For sodium light (*D* line, 5890 Angstroms wave length) the specific rotation $[\alpha]$ is calculated by the use of the following formula, applicable to solutions of pure liquids and compounds:

$$[\alpha]_D = \frac{\alpha \times 100}{L \times c}$$

where α is the observed rotation of the sample in degrees, L is the length of the tube in decimeters, and c is the concentration of the dissolved active substance per 100 ml of solution. If three factors in the equation are known, the fourth can be determined. For example, if the specific rotation is not known, a definite weight of the pure substance is dissolved in a volumetric flask and diluted to known volume. The tube, usually 200 mm in length, is filled and the rotation of the sample is measured. Dilutions from this solution are made, and again the rotation is measured. From the observed rotation of various concentrations the specific rotation is calculated. The variation between the figures obtained by using various concentrations should be small. More often, in the laboratory, the specific rotation is known (from tables in the literature), and the concentration of the active substance is sought. Assume for example that a sample of freshly expressed cane-sugar juice is filtered and its optical rotation determined. It is possible, by a few minutes' calculation, to determine accurately the amount of sucrose in the juice. The object of this experiment is to illustrate the simple applications of the polarimeter.

(A) **Rotation of an Unknown Substance.** Obtain from the instructor a sample of an optically active substance, and from the stock room three bottles of 100-ml capacity, one 100-ml volumetric flask and a 25-ml graduated pipette. Weigh accurately 15–20 g of the powder on a piece of glazed paper. Transfer carefully to the volumetric flask, and add 75 ml of water. Stopper the flask and shake until solution is complete. Make up the solution exactly to 100 ml. Fill the 200-mm tube with distilled water and place it in the instrument. Determine the zero of the instrument by turning the movable prism until the two halves of the field have uniform illumination. This is the true zero of the instrument and may not coincide with the zero of the graduated circle. Make at least five readings and take the average. The variation should not exceed 5 minutes. Note the temperature at the time of the reading. The tube is then emptied, dried, and filled with the solution. The tube is placed in the instrument and the movable prism is turned until equality of illumination of the field is obtained. Note the reading of the circle, and then repeat the observation 4–5 times. Enter data, including the temperature, in your note book.

Put the contents of the volumetric flask into one of the clean and dry bottles. Wash the volumetric flask three times with distilled water. By means of the graduated pipette transfer 50 ml of the stock solution into the volumetric flask and dilute to 100 ml. Determine the rotation of this solution at the same temperature as used in the first solution. Dilute 50 ml of the second solution to the same degree, and determine its rotation. Using the formula, calculate the specific rotation for each concentration. Tabulate your observed data and calculations.

(B) **Determination of the Concentration of an Unknown Substance.** Obtain from the instructor about 100 ml of a solution and the specific rotation of the dissolved substance. Determine the rotation of the sample, using the directions given in section (A) and making similar dilutions. From the observed rotation calculate the concentration of the unknown solution. Express the results in grams of dissolved substance per 100 ml of solution.

Experiment 47

ESTERS OF POLYHYDROXY COMPOUNDS

FATS AND OILS

Introduction. The polyhydroxy compounds contain more than one hydroxyl group. The dihydric alcohols having the general formula $C_nH_{2n}(OH)_2$ are known as glycols. Of the other polyhydric alcohols, glycerol, $CH_2OHCHOHCH_2OH$, is the most important, due to the widespread occurrence in nature of its fatty acid esters. The polyhydroxy compounds form alkoxides, esters, ethers, and halogen derivatives, and in general exhibit all the characteristic reactions of the hydroxyl group. The ethers of glycol are of industrial importance as solvents, particularly for cellulose derivatives. The esters which glycol and glycerol form with nitric acid are important explosives. The fats and fixed oils derived from plants and animals are composed to a large extent of glycerol esters.

When fats and oils are heated with strong solutions of sodium or potassium hydroxide, they undergo hydrolysis with the formation of glycerol and the alkali salts of fatty acids, which are called *soaps*. In making soap the fats and oils are heated to 80°, a part of the required amount of alkali is added, and the mixture is stirred; when the oil has been dispersed, the remainder of the calculated alkali is added and the mixture is heated to 100° until the reaction is complete. Salt is added, which helps the soap to separate on top, while the liquor containing glycerol settles to the bottom and is withdrawn to be used in the production of glycerol. A number of oils, called *drying oils*, are extensively used in the manufacture of paints. When such oils are exposed to air in thin films they absorb oxygen and polymerize to form tough rubbery films. Drying oils contain a large proportion of glycerides of linolic, linolenic and other unsaturated acids. The object of this experiment is to illustrate the saponification of fats and oils and some of the properties of glycerol, glycol, and their derivatives.

(A) Reactions of Hydroxyl Group. Recall the reaction of ethanol with metallic sodium, phosphorus trichloride and acetyl chloride.

(1) To 10 drops of glycerol in a test tube add a small piece of

sodium metal and note the immediate reaction. Repeat, using ethylene glycol. Explain the reactions by means of equations.

(2) To 10 drops each of glycerol and glycol, in separate tubes, add 10 drops of acetyl chloride (**use hood**). Shake the tube, warm for a minute, and observe for signs of any reaction. Explain by means of equations.

(B) **Ethers of Glycol.** Determine the solubility of the monomethyl ether (cellosolve) and dioxane in water, alcohol, and ether. Determine the solubility of cellulose acetate in these two ethers. Use 0.1 g in 2 ml of the ether.

(C) **Acrolein Test for Glycerol and Its Esters.** To 2 drops of glycerol add 0.5 g of potassium hydrogen sulfate, and heat in the hood. Note the odor *cautiously*. The strong, pungent odor is due to allyl aldehyde, or acrolein. Write the equation for the reaction. Repeat the test, using cottonseed oil, or any animal fat or vegetable oil.

(D) **Preparation of Soap.** Place 10 g of any fat or oil in a 250-ml beaker. Prepare a solution of 3 g of solid sodium hydroxide dissolved in 8 ml of water, and dilute it until the volume is 12 ml. Add 5 ml of this solution to the oil, and heat it in a water bath at 60–70° for 20 minutes, with frequent stirring. Add one half of the remaining solution of the alkali and 5 ml of denatured alcohol. Cover the beaker with a watch glass. Heat for 15 minutes, with frequent stirring, then add the balance of the alkali, stirring the mass well. Raise the temperature of the bath to 90–95° and stir frequently for about 20 minutes. The saponification is complete when a droplet of the mixture placed in a few milliliters of water shows no traces of oil. If the saponification is not complete, remove the beaker from the bath, add 5 ml each of water and alcohol, and boil gently on a wire gauze. Use a very small flame and stir so as to avoid spattering. Add 50 ml of hot water, stir until the mass is homogeneous, and then pour the hot solution, with vigorous stirring, into about 250 ml of cold water in which 20 g of commercial sodium chloride has been dissolved. Filter the soap with suction and wash with 10 ml of cold water. Use the soap in the following tests.

(E) **Preparation of Free Fatty Acids.** Place 5 g of the crude soap in a 50-ml beaker, add 30 ml of water, and heat nearly to boiling until it dissolves. Add 7–8 ml of 6 *N* sulfuric acid, and stir until the oily layer of fatty acids separates as a distinct layer on the top. Cool the mixture in an ice-salt mixture for about 15–20 minutes. Lift the solidified cake of fatty acids, press between filter paper, and place in a small evaporating dish.

(F) **Neutralization Equivalent of Fatty Acids.** The neutralization equivalent of the fatty acid mixture may be determined in the following manner. Lift the cake and place in another beaker with 20 ml of distilled water, melt by heating, and stir well to wash out any adhering salt impurities. Cool again, lift the cake, and press between filter paper. Place the fat in an evaporating dish and heat gently at 110° for 15–20 minutes. If minute droplets of water are observed in the oil the heating period should be longer. Chill the oily material, and weigh out accurately about 0.5 of the fat into a small Erlenmeyer flask. Add 25 ml of alcohol which has been previously neutralized with $0.1\,N$ solution of sodium hydroxide, using phenolphthalein as indicator. Titrate the sample with $0.1\,N$ alkali until a faint pink color appears. From the amount of standard alkali used, calculate the neutralization equivalent of the mixture of fatty acids.

(G) **Test for Unsaturation.** Dissolve 0.4 g (or 7–8 drops) of the fatty acid mixture in 3–4 ml of carbon tetrachloride. Add from a burette, drop by drop, one per cent solution of bromine in carbon tetrachloride until the color of bromine persists even with shaking. Repeat, using about the same amount of stearic and oleic acid.

(H) **Cleaning Properties of Soap.** Dissolve 1 g of the soap in 100 ml of hot water.

(1) To 5 ml of the clear soap solution add 2 drops of kerosene and shake well. To another tube containing 5 ml of water add the same amount of kerosene. Shake both tubes well and note any differences in the appearance of the liquid, and of the walls of the tubes.

(2) To 5 ml of the soap solution in separate tubes add 5 drops each of calcium chloride, magnesium chloride and ferric chloride solutions. Note the formation of metallic soaps. Repeat, using instead of soap one per cent solution of the salt of a sulfated fatty alcohol (Dreft or similar product).

(3) Place 5 ml of distilled water in a test tube and add drop by drop soap solution until, on shaking, a permanent lather results. Shake after the addition of each drop and count the number of drops required to produce a permanent lather. Repeat, using tap water; also with 5 ml of tap water containing one drop of calcium hydroxide solution.

(4) Add to each of two test tubes 5 ml of soap solution. Add to one tube 2–3 drops of one per cent solution of gum karaya (or gum tragacanth or gum arabic). Place thumb over each tube, shake well for 10 seconds, and observe the length of time required for the lather to disappear in each tube.

(I) Drying Test for Oils. Use the back of a watch glass. With a fountain pen draw two double lines to divide the surface in three sections leaving a small margin between each section. Place 2–3 drops of linseed oil on the first section and with a small piece of paper spread the oil as a thin film, being careful not to spread it over on to the adjoining section. Place the glass in a vertical position. Place on the second section 2–3 drops of linseed oil and a pinch (2–3 mg) of litharge. Mix with a spatula and then cover the surface of the second section. Cover the third section in the same manner with linseed oil to which·a pinch (2–3 mg) of manganese or cobalt japan drier has been added. Tung oil, if available, may be used on this section instead of linseed oil. Place the watch glass in a vertical position inside the drawer and test with the finger at intervals for "tackiness." Note how long it requires for the film to become dry.

Experiment 48

PROPERTIES OF CARBOHYDRATES

Introduction. The monosaccharides, as well as the disaccharides, are colorless crystalline solids or syrupy liquids, highly soluble in water, and sparingly soluble in the common organic solvents. They possess a sweet taste and are known as *sugars*. The polysaccharides are mostly amorphous powders which form colloidal dispersions in water. The monosaccharides are polyhydroxy aldehydes or ketones, and reduce Tollen's reagent and Fehling's solution with varying speeds. In glucose the initial oxidation results in the conversion of the carbonyl to carboxyl, but the presence of the hydroxyl groups renders further oxidation possible, so that five cupric ions are reduced by one molecule of glucose. The exact mechanism of the oxidation is not known. A number of disaccharides, such as sucrose and trehalose, do not reduce Fehling's solution, since the two monosaccharides which form their molecules are linked through the carbonyl groups. Another class of disaccharides, such as maltose, exhibits reducing action because the two monosaccharides within its molecule are joined through the carbonyl of one and a hydroxyl of the other and hence the disaccharide contains a free carbonyl group. Polysaccharides do not reduce Fehling's solution. When polysaccharides are hydrolyzed, by the action of either acid or enzymes, they yield disaccharides (maltose) and monosaccharides which have reducing properties. The hydrolysis of di- or polysaccharides is accelerated by acids or specific enzymes. Starch gives glucose as the final product of hydrolysis, and therefore it is assumed to be composed of glucose units. Cellulose, like starch, has the composition $(C_6H_{10}O_5)_n$, but hydrolyzes with great difficulty and is insoluble in water. When completely hydrolyzed, it gives glucose.

The reaction of phenylhydrazine, and particularly substituted phenylhydrazines, with the carbonyl group of sugars is extensively utilized in their identification. The derivatives are called *osazones* if two molecules of phenylhydrazine add to one molecule of sugar, as in the case of glucose, and *phenylhydrazones* when one molecule of phenylhydrazine adds to one of sugar, as in maltose. These derivatives are sparingly soluble in cold water. The rates of formation, the crystalline structure, and the rotation of these derivatives are used for the characterization of sugars. Disaccharides with no free carbonyl groups, as, for example, sucrose, do not form osazones. Sugars which differ only in the first two carbon atoms of the molecule (e.g. glucose and fructose) give the same osazone.

Sugars react through the hydroxyl groups to form acyl derivatives (esters) and alkyl derivatives (ethers). Glucose treated with dimethyl sulfate gives pentamethyl glucose, and with acetic anhydride it forms pentaacetyl glucose. Cellulose can be made soluble in organic solvents by esterification. Treatment with nitric acid gives the dinitrate and trinitrate, and with acetic anhydride, the acetate. Esters of cellulose are soluble in acetone, glycol ethers, and other organic solvents.

There are a number of color reactions utilized in the detection of carbohydrates. A general test is the purple color developed with α-naphthol under specified conditions. Starch gives a blue color with iodine, while its first hydrolysis products (dextrins) give a red color. Pentoses, which are widely found in plants in the form of polysaccharides called *pentosans*, when warmed with phloroglucinol (*sym*-trihydroxybenzene) and hydrochloric acid, give a deep violet coloration. This coloration is due to the condensation between phloroglucinol and furfural which is produced by the dehydration of pentoses. This test is used for the quantitative estimation of pentoses and also for the detection of ground wood in paper. The woody parts of plants contain pentosans. Therefore when ground wood is added to bleached chemical wood fiber or other fibers used in paper, it can be detected qualitatively by the addition of a drop of hydrochloric acid which contains a small amount of phloroglucinol in solution.

(A) Molisch Test for Carbohydrates. Apply the test to small amounts of the following: *sucrose, starch,* and *paper fibers.* Place in a test tube 2 ml of one per cent carbohydrate solution or dispersion. Add 2 drops of a 10 per cent solution of α-naphthol in alcohol, and mix. Add this carefully down the side of a tube containing 2 ml of concentrated sulfuric acid so that it will form a separate layer. Carbohydrates give a purple color at the junction of the two liquids.

(B) Reducing Action of Sugars. Use the same method as in the study of aldehydes and ketones. To 5 ml of Fehling's or Benedict's solution[1] which has just been boiled add a few drops of five per cent solution or suspension of each of the following: *glucose, fructose, sucrose, maltose, lactose, starch,* and *cellulose.* Boil for one minute; allow to stand, and note if there is any evidence of a reaction. Observe also the time required for each sugar to give a reaction.

Prepare 5 ml of Tollen's reagent in accordance with directions given on pages 192–193, and test the reducing action of glucose. Record your observations.

(C) **Acid Hydrolysis of Disaccharides and Polysaccharides.** Place in separate tubes 5 ml of solutions or suspension of *sucrose, starch* and *cellulose.* Add 1 ml of dilute hydrochloric acid and heat in a water bath for one-half hour. Add a drop of phenolphthalein, and neutralize carefully with sodium hydroxide. Repeat the Fehling's solution test, using a few drops of the hydrolyzed solution. Write the equations for the hydrolysis which took place as determined by the tests.

(D) **Enzymatic Hydrolysis.** Place in a test tube 2 ml of starch suspension, and in another tube 2 ml of sucrose solution. Add about the same volume of saliva to each (obtained by chewing a small piece of paraffin to promote secretion). Place the tubes in a water bath at 37–40° and allow to stand for 15 minutes. Test with Fehling's solution.

(E) **Reaction of Starch and Dextrine with Iodine.** To 5 ml of distilled water, add two drops of starch suspension and a drop of dilute iodine solution.[2] Repeat the procedure, using dextrin suspension.

(F) **Furfural Formation from Aldopentoses.** To a drop of furfural in 1 ml of water add 2 drops of phloroglucinol reagent. On small pieces of various samples of paper (mimeograph, bond, wrapping paper, etc.) place a drop of phloroglucinol with hydrochloric acid.[2] Note the color produced, and explain differences.

(G) **Preparation of Osazones.** Place in four separate eight-inch tubes 10 ml of each of the following solutions: *glucose, fructose, maltose,* and *lactose.* Add 5 ml of phenylhydrazine reagent,[2] shake gently to mix, and heat in a boiling water bath for thirty minutes, with occasional shaking. Turn out the flame and remove tubes except the one with maltose, which is allowed to cool very slowly. The other three are allowed to cool in air. Filter the crystals through a funnel, wash with water, and place on paper discs to dry. Examine a small amount of each product under the microscope and draw the characteristic shape of each.

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[1] For the preparation of Benedict's and Fehling's solutions, see Appendix.

[2] For preparation of reagent, see Appendix.

(H) **Preparation of α-*d*-Glucose Pentaacetate.** Place into an eight-inch test tube 10 lm of acetic anhydride and 0.4 g of fused zinc chloride (see pages 131–134). Attach a reflux condenser, and heat on a boiling water bath for 5 minutes. Add very slowly 2 g of glucose powder, shaking gently so as to mix the contents of the tube. Heat the tube for one hour in a boiling water bath. Pour the contents of the tube, with stirring, into 100 ml of cold water. Stir, and cool the mixture for 30 minutes. The oil which separates at first will soon solidify on scratching the sides of the vessel with the rod. The crystals are filtered and washed with water. If desired, the crystals are purified by recrystallization from methanol. The product melts at 110–111°. The yield is about 3 g.

(I) **Preparation of β-*d*-Glucose Pentaacetate.** When glucose is acetylated in presence of sodium acetate the β-isomeric pentaacetate forms. The procedure is similar to the preparation of the α-isomer. Add 1 g of anhydrous sodium acetate to 10 ml of acetic anhydride, and heat in the water bath for five minutes. Add 1 g of powdered glucose. Heat for one hour, pour into cold water, and proceed as in section (H). The yield is about 3–4 g. If desired, the crystals are purified by recrystallization from methanol. Pure β-*d*-glucose pentaacetate melts at 132°.

(J) **Acetylation and Nitration of Cellulose.** Soak for a few minutes one gram of absorbent cotton in water. Press between fingers to remove the excess water, and finally between filter papers. Loosen the fibers and divide into two parts.

(1) Place in a tube 10 ml of acetic anhydride, 15 ml of acetic acid, and 2 drops of concentrated sulfuric acid. Add 0.5 g of the cotton prepared above and push it with a rod to the bottom of the tube. Cool the tube at first and allow to stand for 15 minutes. Heat in a water bath at 60–70° for 30 minutes. A homogeneous viscous, liquid results. Add the clear solution slowly, with vigorous stirring, to 400 ml of water. Filter through a filter paper with suction or through a piece of cloth. Squeeze out as much water as possible, and dry by pressing between sheets of filter paper. Allow the material to dry in air.

(2) Place in a 250-ml beaker 20 ml of concentrated nitric acid and then add slowly, with stirring, 20 ml of concentrated sulfuric acid. Add the other portion of cotton (0.5 g) to the hot acid mixture, and with a glass rod press it toward the bottom of the beaker. After three minutes remove the nitrated cotton into 20 ml of water. Wash with running water, then squeeze out most of the water until free from acid, press between layers of filter paper and allow to dry.

Caution: Cellulose nitrate is very inflammable. Handle it with care. Do not leave any nitrocellulose in your drawer. It should be used as soon as it is prepared, and if any remains it should be disposed of according to directions of the instructor.

(**3**) Hold small amounts of the acetylated and nitrated cotton near the flame with tongs, and note difference in inflammability. Test the solubility in the following solvents: *chloroform*, *glycol methyl ether*, and a mixture of 40 per cent *alcohol* and 60 per cent *ether*.

Place a solution of nitrate and another of acetate on watch glasses and allow each to stand until all the solvent has evaporated. Pour water on the film, and after a few minutes remove it from the watch glass and allow it to dry.

Experiment 49

PREPARATION AND PROPERTIES OF UREA

Introduction. In the normal processes of the animal organism, proteins (which contain nitrogen) undergo oxidation to give carbon dioxide, water and ammonia. Carbon dioxide is eliminated through the respiratory system. Most of the ammonia is eliminated by reacting with carbon dioxide to form urea, which passes through the kidneys as urine. There is abundant evidence to indicate that the synthesis of urea takes place in the liver, where also amino acids undergo deamination. Urine may be regarded as a solution containing approximately one per cent of urea and smaller amounts of inorganic ions (sulfate, phosphate, ammonium), uric acid, and other compounds, resulting from the metabolism of amino acids.

Urea is prepared industrially by heating ammonium carbamate under pressure at 130°.

$$CO_2 + 2\ NH_3 \underset{60^\circ}{\rightleftarrows} H_2NCOONH_4 \overset{130^\circ}{\rightleftarrows} NH_2CONH_2 + H_2O$$

The historical synthesis of urea by heating potassium cyanate and ammonium sulfate is analogous to the synthesis of substituted ureas from amines and the cyanate:

$$(NH_4)_2SO_4 + 2\ KCNO \longrightarrow K_2SO_4 + 2NH_4CNO \qquad (1)$$

$$NH_4CNO \rightleftarrows NH_2CONH_2 \qquad (2)$$

$$2\ \underset{\text{Methylamine sulfate}}{CH_3NH_2HSO_4} + 2\ KCNO \longrightarrow K_2SO_4 + 2\ \underset{\text{Methyl urea}}{CH_3NHCONH_2} \qquad (3)$$

Substituted urea may also be formed by heating urea with an amine salt. Urea in aqueous solutions is in equilibrium with a small amount of ammonium cyanate as shown in equation (2), which reacts with the amine salt in the same manner as potassium cyanate is shown to react in equation (3).

Urea is a diamide, and as such it exhibits the general properties of its functional groups. Its acyl derivatives are called *ureides*. A number of synthetic drugs are cyclic ureides. Uric acid is a complex cyclic ureide. On oxidation with nitric acid it forms a molecule of urea and alloxan. The latter may be regarded as derived from urea and malonic acid. The object of the present experiment is to illustrate a few of the properties of urea.

(A) **Preparation of Urea from Urine.** Place 4–5 drops of chloroform in a pint bottle provided with a cork, and collect about 200–300 ml of urine in the morning before coming to the laboratory. The chloroform prevents decomposition of the urine. Place 1 g of charcoal and 0.5 g of Filter-cel in the bottle, shake well, and filter the urine into a beaker. Place a 250-ml beaker over an asbestos-centered gauze, add 2–3 boiling stones and one half (125 ml) of the filtered urine. Boil vigorously at first, adding in small portions, as the evaporation proceeds, the remaining 125 ml of urine. When the volume is reduced to about 100 ml reduce the flame, place a stirring rod in the beaker, add two boiling stones, and continue the evaporation until the volume is about 40 ml. Stir the syrupy liquid to aid evaporation and prevent superheating. Cool the syrupy residue in an ice-salt mixture, and add dropwise 12 ml of cold concentrated nitric acid. Stir well after addition of each 0.5 ml. Allow to stand for ten minutes and filter the crystals of urea nitrate with suction, using a hardened filter paper. Wash with 2 ml of dilute nitric acid, and press to drain the mother liquor.

Transfer the salt to a 150 ml beaker and add 5 g of barium carbonate and 5 ml of 95 per cent ethanol. Stir the mass into a paste so long as carbon dioxide is evolved. When the evolution of gas is complete add 10 ml of alcohol, and heat in a water bath to boiling, with constant stirring. Remove beaker from the water bath. Allow the solids to settle, and pour off the supernatant liquid through a folded filter paper into an evaporating dish. Repeat the extraction of the residue with 15 ml of alcohol. Evaporate the filtrates on a water bath until crystals of urea separate on the surface of the liquid. Remove the dish to a cool place, cover with a watch glass and allow to cool. Filter the crystals of urea with suction. If the product is colored, recrystallize from a small volume of alcohol. The yield is 2–3 g.

(B) **Properties of Urea.** Dissolve 2 g of urea in 4 ml of water, and use for the following tests.

(1) Place 5 drops of the urea solution in each of two test tubes. Add to the first tube 5 drops of concentrated nitric acid and to the second 5 drops of a saturated solution of oxalic acid. Note the precipitate which forms in each tube, and enter the equations for these changes.

(2) Place 2 ml of bromine water in a test tube and add drop by drop dilute sodium hydroxide until the color of bromine just dis-

appears. Add to this solution of sodium hypobromite 10 drops of the urea solution, shake, and note the result. Write the equation for the reaction.

(**3**) To 1 ml of sodium hydroxide solution add 5 drops of urea solution, heat to boiling, and note carefully the odor of the vapors.

(**4**) Add 5–6 drops of urea solution to 2 ml of dilute acetic acid, and 2–3 drops of sodium nitrite solution, and note the evolution of any gas.

(**5**) Place in a dry test tube 0.2 g of urea, heat very gently above the melting point. Ammonia is first evolved, and after one or two minutes the liquid solidifies to biuret.

$$2\ NH_2CONH_2 \longrightarrow NH_2CONHCONH_2 + NH_3$$

Cool and dissolve the biuret in 5 ml of water. Add one drop of dilute sodium hydroxide solution, and two drops of very dilute solution (0.1 per cent) of copper sulfate. What other substances give this coloration?

(**C**) **Preparation of Substituted Ureas.** Place in an eight-inch tube arranged for reflux 2 g of aniline hydrochloride, 1 g of urea, 10 ml of water and 3 boiling stones. Boil the solution gently for about one hour. Diphenylurea crystallizes as the boiling proceeds. Remove the flame and filter the hot mixture rapidly with suction through a micro Buchner funnel, which has been previously heated by filtering 20 ml of boiling hot water. Remove the filtrate in a small beaker, wash the crystals of diphenylurea in the funnel with 5 ml of water and place on a filter disc to dry. Cool the filtrate to 5°. Filter the crystals of monophenylurea which separate, wash with water and dry.

Experiment 50

PREPARATION AND PROPERTIES OF α-AMINO ACIDS

Introduction. The most convenient method for the preparation of amino acids is the ammonolysis of α-halogen acids:

$$RCHBrCOOH + 2\ NH_3 \longrightarrow RCHNH_2COOH + NH_4Br$$

The amino acid produced reacts further with the halogen acid to give secondary and tertiary amino derivatives. To avoid such formation the molar ratio of the halogen acid to ammonia is increased from *1*:*2*, as required by theory, to *1*:*10* or more. The great excess of ammonia increases the rate of reaction and inhibits the reaction of the amino compound with unreacted halogen acid. The formation of secondary and tertiary amino compounds can be inhibited by the same method used in the preparation of amines (page 174). Addition of ammonium chloride or ammonium carbonate blocks the amino group and prevents to a large extent the side reactions. After the ammonolysis of the halogen acid is completed, the excess ammonia is distilled off and the solution is evaporated to a small volume. Addition of methanol precipitates the amino acid which is contaminated with ammonium halide. By dissolving the precipitate in hot water and reprecipitating with methanol, the pure amino acid is obtained. The α-amino acids are *non-volatile*, crystalline solids. The presence of a carboxyl and an amino group leads to the formation of a dipolar ion and almost neutral reactions. Those with two carboxyl groups have definite acidic properties, while those with two amino groups have definite basic properties. They easily form complex ions, and exhibit all the characteristic reactions of the two functional groups, e.g., they form esters, salts, and react with acyl halides and nitrous acid. The amino group reacts with nitrous acid to form nitrogen; this reaction is utilized in their quantitative estimation.

(A) **Preparation of Glycine** (Sm.). Place 17 g of ammonium carbonate and 15 ml of water in a 125- or 250-ml Florence flask. Warm to 40–50° for 15 minutes and then cool to room temperature. Add 20 ml of concentrated aqueous ammonia, and 5 g of commercial chloroacetic acid or the crude acid from Experiment 43. Insert a solid rubber stopper securely, and adjust a piece of wire or string to hold the stopper in place. Allow the flask to remain until the next period. Place the flask in a water bath and connect with a series of three absorption bottles containing water. Heat until most of the ammonia has been distilled. Remove the flask, place on a wire gauze, and disconnect it from the absorption train. Place two boiling stones and a thermometer in the solution and heat to gentle boiling until the temperature rises to 112°. Add 0.2 g of charcoal, boil for a minute longer, and filter rapidly. The funnel should be warmed by pouring hot water through it before filtering the solution. Transfer the filtrate (10 ml) into a beaker, add 30 ml of pure methanol, and stir. Cover with a watch glass and allow to stand overnight. Filter the precipitated glycine, wash with 5 ml of methanol, and suspend for one hour in 10 ml of 95 per cent methanol. Filter, wash with 3 ml of methanol, and dry. The yield is about 2 g.

(**B**) **Preparation of Glycine** (**M.**). Use the same method as in section (A). Use a 500-ml Erlenmeyer flask and 10 times the quantities given for the semimicro preparation. After distillation of ammonia and further evaporation, the solution is treated with 0.5 g of charcoal and filtered. The residue is washed with 5 ml of hot water. The filtrate (about 100 ml) is placed in a beaker and 300 ml of methanol are added. After 24 hours the crude glycine is filtered, dried by suction, then pulverized while wet, suspended in 100 ml of methanol, and allowed to stand for an hour, with occasional stirring. The crystals are filtered, washed twice with 10 ml portions of methanol, and dried. The yield is about 25 g. The product prepared in this manner contains traces of ammonium chloride as impurities. If a very pure product is desired, the crystals are dissolved in 50 ml of boiling hot water, and the solution is treated with 1 g of charcoal and 0.5 g of Super-cel. It is then filtered with suction while hot and the solution diluted with 150 ml of methanol. The precipitated glycine is allowed to cool for an hour, filtered with suction, washed with 10 ml of methanol, and dried. The loss on recrystallization is 10–12 per cent.

(**C**) **Preparation of *dl*-Alanine** (**Sm.**). Place in an eight-inch test tube 11 ml of concentrated aqueous ammonia and 5.5 g of powdered ammonium carbonate. Place the tube in a water bath and warm at 40° for 15 to 20 minutes. Cool to 25° and then add 3 g (0.2 moles) of α-bromopropionic acid (obtained in Experiment 44). Stopper, and place the tube aside for 24 hours at room temperature. Remove the stopper, place in a water bath, and heat gradually to expel the ammonia and carbon dioxide (use hood). Continue heating until the liquid in the tube has been reduced to a volume of 4–5 ml. Add 15 ml of methanol, and cool the tube for one hour. Filter the alanine crystals and wash twice with 2 ml portions of methanol. Transfer the crystals to a small beaker, add 20 ml methanol, and let stand for 30 minutes with occasional stirring. Filter, wash once with methanol, and remove crystals on to a paper disc to dry. The yield is about 1.2 g. The product should give only a faint opalescence when its solution is tested with acidified (HNO_3) silver nitrate.

(D) Tests for Properties of Amino Acids. (1) Taste a small amount of glycine, *dl*-alanine, and glutamic acid.

(2) Determine the *p*H of 0.1 *N* solutions of glycine, alanine, and glutamic acid.

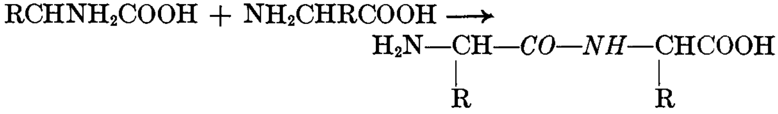
(3) Prepare a small amount of cupric hydroxide by adding 1 ml of copper sulfate to a drop or two of sodium hydroxide solution. Add 2 ml of glycine and shake. Explain.

(4) Place 2 ml of glycine solution and 2 ml of 10 per cent sodium nitrite solution in a test tube. In another tube place 2 ml of the nitrite solution and 2 ml of water. Hold both together in the left hand, and to each tube add 5 drops of dilute acetic acid, shake, and observe any reaction. What is the name of the product formed? Write the equation for the reaction.

Experiment 51

PROPERTIES OF PROTEINS

Introduction. Proteins are substances produced by living matter which on enzymatic or acid hydrolysis yield amino acids. They are non-volatile and of high molecular weight, and form colloidal dispersions from which they may be precipitated by heat, alcohol, various salts, and acids (tannic, picric, and phosphotungstic). Each protein has a minimum solubility at a characteristic *p*H which is called the iso-electric point. At this point the protein molecules exist as aggregates and the solution has the maximum turbidity. The nature of the union of various amino acids in the protein molecule is not known. One theory assumes that the carboxyl of one amino acid unites with the amino group of another, thus:



$$\mathrm{RCHNH_2COOH + NH_2CHRCOOH} \longrightarrow \mathrm{H_2N{-}\underset{\underset{\textstyle R}{|}}{CH}{-}}\mathit{CO}{-}\mathit{NH}{-}\mathrm{\underset{\underset{\textstyle R}{|}}{C}HCOOH}$$

This mode of union is called *peptide linkage*. The presence of the peptide linkage is thought to account for the development of a violet color when a protein comes in contact with an alkaline solution of cupric ion. The color is given by biuret, formed by urea on heating: $NH_2CONHCONH_2$. The reaction is known as the *biuret reaction*. It is not given by any amino acid.

The protein molecule has free carboxyl and amino groups. Therefore it exhibits amphoteric properties. A number of color reactions have been developed for proteins to determine the presence of specific amino acids. The following are among the most important:

Millon's reaction. This reaction consists in the development of a red coloration when a substance containing a monohydroxybenzene group is heated with a mixture of mercuric nitrate and nitrite (Millon's reagent). Proteins giving this reaction contain *tyrosine*.

Xanthroproteic reaction. This reaction is given by all proteins containing amino acids with phenyl radicals (tyrosine, tryptophane, phenylalanine). It consists in the development of a yellow color on heating with strong nitric acid.

Tryptophane reactions. There are several tryptophane reactions; one of these consists in the development of a violet color when a solution of protein which contains tryptophane is treated with glacial acetic acid and concentrated sulfuric acid. It is explained by the fact that the ordinary acetic acid contains glyoxylic acid, HOC—COOH, in small amounts, and this aldehyde-acid reacts with the indol group of tryptophane. The same color is given by glyoxylic acid. Proteins which do not yield tryptophane do not give this color.

(A) **Solubility and Precipitation of Proteins.** (1) Use 5 ml of the protein solution. Test the effect of solutions of copper sulfate, lead acetate, mercuric chloride, and tungstic acid on solutions of *egg albumen* and *gelatin*. Tabulate the results.

(2) Test the effect of heating on 5 ml of one per cent solutions of *egg albumen* and *gelatin*. Repeat the procedure, adding a few drops of acetic acid. Filter the coagulated protein and wash it with water. Place it back in the tube, add water, and note whether it redissolves.

(3) Test the solubility of *egg albumen*, *casein*, and *gelatin* in water, in dilute sodium hydroxide solution, and in dilute hydrochloric acid.

(B) **Elements Present in Proteins.** Place at the end of a wire a small piece of protein and heat for a short time in the flame. Use *hair*, *egg albumen*, and *gelatin*; also *casein*.

Boil 0.2 g of hair with 3 ml of sodium hydroxide solution for one minute. Dilute with 5 ml of water, cool, and filter. Acidify the filtrate carefully with acetic acid, and add a few drops of lead acetate.

Recall the test for nitrogen in casein, and repeat it if necessary. Use 0.5 g of casein; mix it with 1 g of soda lime, and heat strongly. Note the odor of the vapors given off. Confirm the presence of the gas by an appropriate chemical test.

(C) **Color Reactions of Proteins.** (1) **Biuret Reaction.** To 5 ml of the solution to be tested add 2 drops of very dilute (0.1 per cent) copper sulfate solution and shake well. Then add 2 ml of sodium hydroxide solution, mix, and allow to stand. A violet color is characteristic of the biuret reaction. Use the reaction for tests on the following solutions: *egg albumen*, *casein*, *glycine*, *oxamide*, and *biuret*.

(2) **Millon's Reaction.** Add a few drops of Millon's reagent to solutions of *gelatin*, *casein*, *egg albumen*, *glycine*, *resorcinol*, and *tyrosine*.

(3) **Xanthoproteic Reaction.** Add 1 ml of concentrated nitric acid to the solid protein and warm slightly. Apply the test to small amounts of solid *gelatin*, *casein*, and *egg albumen*.

(4) **Tryptophane Reactions.** To 2 ml of protein solution add 2 ml glacial acetic acid, and mix. Add this mixture very carefully to 5 ml of concentrated sulfuric acid, pouring it slowly down the side of the tube so that the two liquids do not mix. If the proteins contain tryptophane, a violet ring will form at the interface of the two liquids. In the same manner test solutions of *gelatin*, *casein*, and *egg albumen*.

(D) **Protein Plastics.** To 0.1 g of casein in a test tube add 1 ml of 6 N sodium hydroxide solution and 1 ml of water. Warm and shake until it dissolves. Pour one half of this solution on a watch glass, add 5 drops of formaldehyde, and stir with a rod. Examine both casein solutions after 5 minutes.

Experiment 52

PREPARATION OF SUBSTITUTED ANILINES

Introduction. The preparation of aniline was considered in Experiment 27. The object of this experiment is to illustrate the preparation of a few important substituted anilines. Assume, for example, that it is desired to prepare the three isomeric nitroanilines. The rules of substitution in the benzene ring indicate that it is possible to prepare the *ortho* and *para* isomers by nitration of aniline. Two problems arise upon consideration of the practical application of this rule. The first problem deals with the protection of the amino group in aniline from the oxidizing action of nitric acid. For this purpose acylation is employed, as acetanilide is easily prepared from aniline. The second problem deals with the proportions of *ortho* and *para* isomers which are formed by nitration, and their separation. This problem is solved experimentally by studying the factors which influence the reaction. It is found that at about 5° acetanilide combined with nitric-sulfuric acid mixture, yields mostly *p*-nitroacetanilide. Further, *o*-nitroacetanilide hydrolyzes at *p*H 10 more rapidly than the *para* isomer. Therefore the problem of preparing *p*-nitroaniline is solved by (*a*) acetylating aniline, (*b*) nitrating acetanilide at 5° with a nitric-sulfuric mixture, (*c*) warming the mixture of nitroacetanilides with sodium carbonate to hydrolyze the *ortho* isomer. The *p*-nitroacetanilide is filtered, and the filtrate which contains the soluble sodium salt of *o*-nitroacetanilide may be used to prepare small amounts of *o*-nitroaniline. (*d*) Finally, hydrolyzing the pure *p*-nitroacetanilide by heating with dilute sulfuric acid.

For the preparation of *o*-nitroaniline the method outlined above may be used. Nitration at a temperature of 40° is employed so as to increase the proportion of the *o*-nitroacetanilide to 25 per cent. Another variation is to treat aniline with excess of acetic anhydride and then with nitric acid. Acetanilide is first formed, which in the presence of acetic anhydride nitrates to give a larger proportion of the *ortho* isomer. The nitrating agent is assumed to be acetyl nitrate, CH_3COONO_3. Finally, a number of indirect methods are available, if heating under pressure is feasible. The methods are summarized by the following equations:

$$\underset{o\text{-Nitrobromobenzene}}{C_6H_4(NO_2)(Br)} + 2\ NH_3 \xrightarrow[\text{heat}]{\text{alcohol}} C_6H_4(NH_2)(NO_2) + NH_4Br$$

$$\underset{o\text{-Nitrophenol}}{C_6H_4(NO_2)(OH)} + 2\ NH_3 \xrightarrow[160^\circ]{H_2O} C_6H_4(NH_2)(NO_2) + NH_4OH$$

$$\underset{o\text{-Nitroaniline-}p\text{-sulfonic acid}}{C_6H_3(NH_2)(NO_2)(SO_3H)} + H_2O \longrightarrow C_6H_4(NH_2)(NO_2) + H_2SO_4$$

These reactions depend on the inductive effect of the nitro group on the other groups in the ring, which results in easier replacement. The sulfonic acid used in the last equation is obtained by first sulfonating acetanilide and then nitrating.

For the preparation of *m*-nitroaniline, nitrobenzene is nitrated to give *m*-dinitrobenzene. When this compound is reduced by an alkaline sulfide, the reduction can be controlled so that only one of the two nitro groups is reduced to form *m*-nitroaniline.

Somewhat similar methods are used in the preparation of bromoanilines. Consider, for example, the preparation of *p*-bromoaniline. The action of bromine on aniline gives quantitatively 2, 4, 6-tribromoaniline. If aniline is first acetylated and then brominated, *ortho*- and *para*-bromoacetanilides are formed with the *para* isomer predominating. The *ortho* compound is more soluble in alcohol than the *para* isomer, and thus can be removed by crystallization. The *p*-bromoacetanilide is then hydrolyzed. A variation of this method is to add bromine very slowly to aniline dissolved in a large excess of glacial acetic acid, when *p*-bromoaniline is directly formed, thereby eliminating acylation and hydrolysis.

(A) **Preparation of *p*-Nitroaniline. Acetylation.** Pour into an eight-inch tube 5 ml of glacial acetic acid, and 5 ml of acetic anhydride; add two small boiling stones. Add slowly 5 ml of aniline, and arrange a micro condenser for heating under reflux. Boil gently for 20–30 minutes. Pour contents of tube into 100 ml of water, cool, and filter with suction. Wash the crystals three times, using 5 ml of water for each washing. In order to dry the crystals, press down on the cake to drain, then press between filter paper, transfer to an evaporating dish, and dry over a water bath.

Nitration. Pulverize the crystals of acetanilide and place 5 g in a 250-ml beaker. Add 5 ml of glacial acetic acid and then, with stirring, 10 ml of concentrated sulfuric acid. Cool in an ice-salt mixture, and add through a dropper 2 ml of fuming nitric acid.

Stir well with a thermometer and regulate the addition of nitric acid so that the temperature does not rise above 5°. Remove the beaker from the ice-salt mixture, cover with a watch glass, and allow to stand for 30 minutes. Pour into a mixture of 10 ml water and 10 g of ice. Return the diluted material to the 250-ml beaker in which the reaction took place. Stir well, cool, and filter. Wash with water. Transfer the cake of crystals into a 250-ml beaker and suspend in 30 ml of water. Add gradually 5 g of sodium carbonate, with stirring. The reaction of the suspension should be distinctly alkaline. Heat almost to boiling, then cool to 40–50° and filter, washing with water twice. The cake of crystals is ready for hydrolysis.

Hydrolysis. Pour 8 ml of water into an eight-inch tube arranged for heating under reflux, and then add slowly 11 ml of concentrated sulfuric acid. Add the well-drained crystals from the last preparation, and two boiling stones. Boil gently for 20–30 minutes. Pour the clear hot solution into 125 ml of water and cool. Any solid which may separate out at this stage is *o*-nitroaniline; it indicates incomplete removal of the *o*-nitroacetanilide. The *para* isomer is more basic and is soluble in the acid present. Filter if necessary, and then precipitate *p*-nitroaniline by adding dilute sodium hydroxide solution until the acid is neutralized. Cool, filter with suction, and wash the crystals several times with 5 ml portions of water. To recrystallize, dissolve in hot alcohol (adding 0.2 g of charcoal), and filter. Add water to the filtrate until cloudiness appears, and cool. Filter and dry the crystals. The yield is 2.5–3 g. Determine the purity of the preparation by its melting point.

(B) Preparation of *m*-Nitroaniline (Sm.).

Nitration. Nitrate 8 ml of benzene, using the method given in Experiment 29 (A).

Preparation of the Dinitro Compound. Convert the nitrobenzene obtained in the above preparation, to *m*-dinitrobenzene. Use the method given in Experiment 29 (D).

Reduction. Place in a 250-ml beaker 5 g of *m*-dinitrobenzene and 50 ml of water. Prepare a solution of 12.5 g of sodium sulfide, $Na_2S.9H_2O$, in 12 ml of water. Heat the beaker containing the dinitrobenzene *in the hood* until the temperature rises to 95°. Lower the flame so that a temperature of about 90° is maintained, and add the sulfide solution with a dropper, stirring vigorously after the addition of each drop. To avoid breakage provide the end of the stirring rod with a short piece of rubber tubing. When the addition of the sulfide is complete, raise the temperature so that the mixture boils gently for 15–20 minutes, then cool in tap water.

Cover the beaker with a watch glass and allow to stand overnight. Filter the crude nitroaniline and wash with cold water. To remove any unchanged dinitrobenzene, add the cake of crystals to 150 ml of boiling 5 per cent hydrochloric acid, cool, and filter the solution from any undissolved dinitrobenzene. Precipitate the nitroaniline by addition of excess of aqueous ammonia. Filter the crystals and recrystallize from water. Dissolve the crystals in 250–300 ml of boiling water. Add 0.2 g of charcoal and 0.1 g of Filter-cel. Place a fluted filter paper on a Bunsen funnel and pass through it 100 ml of boiling hot water so as to heat it thoroughly. Filter the hot solution, and cool the filtrate to 5°. Cool, and filter the yellow crystals of *o*-nitroaniline, drain, and place on a drying disc. Determine the purity of the preparation by its melting point.

(C) **Preparation of 2,4,6-Tribromoaniline** (Sm.). Place 5 ml of glacial acetic acid in a small beaker. Add *carefully* 2 ml of bromine. Now add dropwise, with stirring, 1.2 g of aniline. Allow to stand for five minutes. Add 5 ml of water and cool. Filter the mass of crystals and wash with 5 ml of 50 per cent alcohol. A small amount is recrystallized from 90 per cent alcohol. The substance melts at 119°.

Caution: Be careful in measuring bromine. To measure small amounts, place about 10 ml of bromine in a small beaker, using the hood. It is advisable to wear rubber gloves. Place a small graduate near the beaker and with a dropper transfer the required amount of bromine into the graduate, being careful not to tilt the dropper too much. For smaller amounts than 2 ml it is advisable to weigh the bromine. A tube provided with a stopper is suspended securely by a wire from a small horn balance. Remove the stopper and place it on the pan. Add the required weight on the other pan. Take the beaker in one hand (covering it with a towel if rubber gloves are not available), and bring it near the lip of the tube. Transfer the required amount of bromine with the dropper. Stopper the tube and pour back the contents of the beaker into the bromine bottle. All operations should be done in a hood, with a good draft. When working with bromine always have available a solution of sodium thiosulfate.

(D) **Preparation of *p*-Bromoaniline** (Sm.). Place 10 ml of glacial acetic acid in an Erlenmeyer flask and add 2 g of aniline. Cool well in an ice-salt mixture and add very slowly dropwise, with stirring or shaking, 3.3 g of bromine (1.1 ml) in 15 ml of acetic acid. The addition should take 10 minutes. Allow to stand for 10 minutes; then add 15 ml of 10 per cent sodium acetate solution. Filter, and purify the crude monobromoaniline by recrystallization from 70 per cent alcohol.

Experiment 53

PREPARATION OF DIAZONIUM SALTS

NOTE: The object of this and of a number of the experiments which follow is to study the preparation of diazonium salts and their application to organic syntheses. For this purpose a number of choices may be made, depending on the time available. (*a*) If the time is short, the student may do sections (A) and (B) of this experiment; (*b*) the student may choose to prepare 0.15 moles of the diazonium salt according to section (C) of this experiment, and then use the semimicro method for the preparation of iodobenzene or chlorobenzene, phenol, phenylhydrazine, and a few azo dyes (Experiments 54, 55, 56, 57, and 58); in such case it is possible to complete the preparations in two laboratory periods; (*c*) if the macro method is used, then selection is made from Experiments 54, 55, 56, and 57.

Introduction. The action of nitrous acid on alkyl primary amines at ordinary temperatures causes replacement of the amino group by the hydroxyl, while the nitrogen atom of the amino group and the nitrogen atom from nitrous acid are evolved as free molecular nitrogen:

$$RNH_2 + HNO_2 \longrightarrow N_2 + ROH + HOH$$

This behavior is typical of alkylamines. The arylamines behave similarly at higher than room temperatures. However, at temperatures of 5° or lower, the intermediate compounds, known as *diazonium salts*, are formed. Because of their great reactivity they are used in the preparation of a large and diversified number of compounds. The formation of the diazonium salts is known as *diazotization* of the arylamine:

$$RNH_2 + 2\ HCl + NaNO_2 \longrightarrow \underset{\text{Aryl diazonium chloride}}{RN_2Cl} + NaCl + 2\ H_2O$$

If it is desired to isolate the diazonium salt, the amine is dissolved in alcohol or glacial acetic acid and diazotized by adding amyl or butyl nitrite and then the acid. Diazonium salts are unstable and explosive, and are not prepared in the dry state in any considerable quantities. Diazotization is usually carried out in aqueous solutions. In most cases the base is suspended in water and 2.2 moles of acid is added. One mole of acid is required to form the amine salt, and another to react with sodium nitrite for the liberation of nitrous acid. The excess of 0.2–0.5 moles of acid is used to prevent reaction of the diazonium salt with the unreacted base. The temperature is usually kept below 5° by immersing the vessel in an ice-salt mixture and also by adding crushed ice directly to the solution. The amount of water and ice added should be such that the concentration of the diazonium salt is 0.5 to 1.0 molar. In certain cases where the amine is a feeble base and the resulting diazonium salt is relatively stable, diazotization can take place even above 30°. In most diazotizations the solution of sodium nitrite is added very slowly, with stirring. In some cases, as in the diazotization of *p*-nitroaniline, the nitrite is cooled and added all at once. This prevents the reaction of the diazonium salt with the unreacted base.

If the base is slightly soluble in acid, as in the case of those arylamines which have very feeble basic properties, a large excess of acid is used, or a suspension of the finely divided base is diazotized. The base dissolves as fast as that portion which is in solution is diazotized. The aminosulfonic and aminocarboxylic acids are diazotized by first dissolving in alkali to form the sodium salt and then adding the calculated amount of nitrite. The mixture is cooled and added slowly to a solution of acid. The end of all diazotizations is recognized by the presence of free nitrous acid in the solution. As a test of this, a drop of the solution of the diazonium salt placed on starch-iodide paper produces a dark blue stain immediately, due to the oxidation of iodide by nitrous acid to iodine and action of the latter on starch.

In general, diazonium salts undergo many reactions and, as already stated, are not stable. Their reactions, for the purpose of discussion, may be divided into two groups: (*a*) reactions involving the replacement of the diazo group by another, such as Cl, Br, I, OH, CN; (*b*) reactions involving the union of other radicals with the diazonium compound.

(A) **Benzenediazonium Sulfate** (Solid). Place 1 ml of aniline in an eight-inch tube, and add 5 ml of ethanol (95 per cent); then very slowly add 1 ml of concentrated sulfuric acid. Rotate the tube and immerse it in cold water. Add drop by drop 1.5 ml of butyl or amyl nitrite at such a rate that the temperature is kept at 30–35°. Allow to stand for five minutes, and then immerse the tube in an ice bath. The crystals of the diazonium salt separate out. Filter the crystals with suction, using a micro funnel, and wash with a few milliliters of alcohol and then with 5 ml of ether. Dry with suction for two minutes; then with a spatula, cautiously remove the crystals on to a piece of paper and place in a tube at once. Yield, 1.0–1.3 g. Caution should be exercised, since the solid diazonium salt may explode if rubbed or struck.

(B) **Reactions of Diazonium Salts.** To the tube containing the diazonium salt (prepared in section [A]) add 10 ml of water and shake gently until solution is complete. Divide the solution equally among five test tubes, and perform the following tests.

(1) To the first tube add 2 ml of 10 per cent potassium iodide solution, and one drop of concentrated hydrochloric acid. Shake for a few seconds, and then place in a water bath kept at 40–50° for 5 minutes. Note the oily droplet of iodobenzene which separates at the bottom of the tube.

(2) To the second tube add 2 drops of dilute sulfuric acid, and warm in the water bath at 40–50° until evolution of nitrogen begins. Cool slightly in tap water so that the temperature does not rise above 50°. Note the odor. Devise a test to demonstrate that phenol is present in the reaction mixture.

(3) To the third tube add 2–3 drops of aniline. Shake, and add a drop of dilute sodium hydroxide solution. The precipitate is diazoaminobenzene.

(4) To the fourth tube add 1 ml of ethanol or methanol, and warm. Explain this reaction.

(5) To the last tube add 0.1 g of resorcinol and a pinch of sodium acetate. The azo dye which separates is 2,4-dihydroxyazobenzene.

(C) **Benzenediazonium Chloride Solution.** This stock solution is prepared for Experiments 54–57, using the semimicro technic. The directions, however, are applicable to the preparation of diazonium chloride in amounts of 0.01–1.0 moles. Place in a 250-ml beaker 0.15 moles of aniline (14 ml), 20 ml of water, and 0.375 moles of hydrochloric acid (30 ml of concentrated acid, sp. gr. 1.19). Cool in an ice bath until the temperature is close to 0°. Prepare a solution of 0.16 moles of sodium nitrite (11 g) in 40 ml of water. Add to the beaker containing the aniline salt 10 g of ice. Allow the nitrite solution to drop slowly into the aniline salt mixture, stirring well all the time. The temperature should not be allowed to rise above 5°. Continue adding the nitrite solution a milliliter at a time, with stirring, until a drop of the reaction mixture placed on starch-iodide paper gives an immediate deep-blue spot, indicating excess nitrous acid. Allow a few minutes to elapse after the last addition of the nitrite before testing with the iodide paper, since the rate of diazotization towards the end is slow. The excess of nitrous acid should not be large;[1] for this reason it is advisable to begin testing when 85–90 per cent of the calculated nitrite solution has been added. The volume of the solution at the end of the reaction should be about 120 ml. When the diazotization is complete, pour the solution into a graduate and transfer it to a 250-ml Erlenmeyer flask immersed in an ice-salt mixture. Add sufficient water to make up the volume to 150 ml. This solution is employed at once for Experiments 54–58, using the semimicro methods. Each 15 ml portion of this contains approximately 0.015 moles (2.1 g) of benzenediazonium chloride.

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[1] The excess of nitrous acid can be removed by the addition of small amounts of sulfamic acid.

Experiment 54

REPLACEMENT OF THE DIAZO GROUP BY IODINE

PREPARATION OF IODOBENZENE

Introduction. The diazo group, N_2X, is easily replaced by a number of other functional groups, such as OH, Cl, Br, I and CN. This affords a convenient method for the preparation of such derivatives as cannot be obtained by other methods except with great difficulty. The replacement of N_2X by a halogen group is accomplished by heating the solution of diazonium salt with cuprous halide (Sandmeyer reaction) or with finely divided copper (Gatterman reaction). In the preparation of iodides the catalytic effect of copper is not required; it is necessary only to pour the diazonium salt into a solution of potassium iodide and then to acidify the solution:

$$C_6H_5N_2Cl + KI \xrightarrow{HCl} C_6H_5I + N_2 + K^+ \, Cl^-$$

The present experiment illustrates the replacement of the diazo group by iodine, and Experiment 55 the use of cuprous halides in the replacement of the diazo group by chlorine.

(A) Preparation of Iodobenzene (Sm.). The solution prepared in Experiment 53 (C), is used. Place in a 150-ml beaker 15 ml (0.015 moles) of the cold benzenediazonium chloride solution, and add with stirring a solution of 3.0 g of potassium iodide in 20 ml of water. Allow to stand in the cold for 30 minutes and then add, with stirring, 3 ml of concentrated hydrochloric acid. Warm to 50° until the evolution of gas ceases. Make the solution alkaline with sodium hydroxide (5 ml 6 *N*) and allow the liquid to settle out. Pour out most of the upper aqueous layer and retain all the oil that settles to the bottom, with about 5 ml of the aqueous layer. The preparation may be discontinued at this point until the next laboratory period.

Arrange the apparatus as shown in Figure 50. Steam-distill until no more oil comes over, or until 10 ml of the distillate has been collected. Add 8 ml of ether, shake, and by means of the separatory tube withdraw the aqueous layer. Wash the ether solution successively with 5 ml of 5 per cent sodium hydroxide solution and 5 ml of water. To the ethereal solution add 0.2 g of calcium chloride and allow to stand for 10 minutes. Pour into a distilling tube and distill, collecting the fraction which boils at 185–190°. The yield is 1–1.5 g.

(B) **Preparation of *p*-Iodotoluene** (**Sm.**). Place in an eight-inch tube 2 g of *p*-toluidine, 7 ml of concentrated hydrochloric acid and 5 ml of water. Add two boiling stones and heat to gentle boiling until the base dissolves completely. Place the solution in a 150-ml beaker. Cool to 0°, add 5 g of ice, and diazotize with a solution of 1.5 g of sodium nitrite in 5–6 ml of water. Observe the directions for diazotization given in Experiment 53 (C). When the diazotization is complete, add slowly drop by drop, with stirring, a cold solution of 3.5 g of potassium iodide in 20 ml of water. Allow the mixture to stand in the cold for one hour. Filter the dark crystals which separate, wash with water and recrystallize from alcohol. The yield is 2–2.5 g.

(C) **Preparation of Iodobenzene** (**M.**). Place in a 500-ml Florence flask a solution containing 0.15 moles of benzenediazonium chloride, obtained by diazotising 14 ml of aniline in accordance to directions given in Experiment 53 (C). Instead of hydrochloric acid, an equivalent amount of sulfuric acid is used to prevent any formation of chlorobenzene. The solution should be kept cool. Add slowly a solution of 30 g of potassium iodide in 40 ml of water. Allow to stand for an hour at a temperature of about 5–10°. Add 10 ml of concentrated hydrochloric acid, fit the flask with an air condenser, and warm to 40–50° until the evolution of nitrogen ceases. Raise the temperature nearly to boiling, then cool in tap water, and add 50 ml of 6 *N* sodium hydroxide solution. Steam-distill the mixture until no more oily drops come over with the distillate. Separate the lower layer, and wash it with 100 ml of water containing 5 g of sodium carbonate and then with plain water. Dry with 2–3 g of calcium chloride, and distill, collecting the fraction which boils at 185–190°. The yield is 25–26 g.

Experiment 55

REPLACEMENT OF THE DIAZO GROUP BY CHLORINE

Introduction. In the preceding experiment it was shown that an aqueous solution of a diazonium salt treated with a solution of an alkali iodide gives iodobenzene. The replacement of the diazo group, N_2X, by chlorine or bromine atoms involves the catalytic action of copper salts. Thus, benzenediazonium chloride warmed with a solution of cuprous chloride and hydrochloric acid gives chlorobenzene; with cuprous bromide, bromobenzene is formed. The use of the cuprous salt is known as the *Sandmeyer method.* Instead of cuprous salts, finely divided copper may be used according to *Gatterman's method.*

The catalytic action of the cuprous salts is assumed to depend on the formation of addition compounds which aid in the elimination of nitrogen and direct the halogen to the nucleus. In the Sandmeyer method the diazonium salt solution is added to a freshly prepared solution of the cuprous halide at a temperature below 10°. The mixture is then warmed until the evolution of nitrogen ceases. In some cases better yields are obtained if the diazonium solution is added slowly to a boiling solution of the cuprous salt. In the Gatterman method the desired diazonium salt is prepared. In the case of bromide and iodide, the diazonium sulfate is prepared and is mixed with an excess of potassium bromide or iodide. Finely divided copper is added and the mixture is warmed until the evolution of nitrogen ceases. The finely divided copper may be prepared by adding zinc dust to copper sulfate solution. The object of this experiment is to illustrate both methods. For semimicro work either chlorobenzene or *o*-chlorotoluene may be used.

(A) Preparation of Chlorobenzene (Sm.) (Sandmeyer). The amount of benzene diazonium chloride required is 0.03 moles. If the solution prepared in Experiment 53 (C) is available, use 30 ml. Otherwise, place 2.8 ml of aniline, 10 ml of water, and 6 ml of concentrated hydrochloric acid in an eight-inch tube, cool, and diazotize in accordance with directions given in Experiment 53 (C), using 2.2 g of sodium nitrite dissolved in 10 ml of water. To prepare the cuprous halide solution, dissolve 3.8 g of copper sulfate,

$CuSO_4.5H_2O$, and 1.2 g of sodium chloride in 15 ml of water. Heat to effect solution. Add slowly a solution of 2 g of sodium bisulfite and 1 g of sodium hydroxide in 6 ml of water. Cool in tap water to about 20° and allow to stand for five minutes. Wash with water by decantation. Pour off most of the water, and add 3 ml of concentrated hydrochloric acid and 2 ml of water. Transfer to an Erlenmeyer flask, and add all at once the diazonium salt solution. Allow the mixture to stand for five minutes, and then heat gradually to 50–60°. Cool the solution, and remove the dark layer of chlorobenzene which separates out by means of a separatory tube. Extract the aqueous layer with 8 ml of ether, and unite the ether extract with the crude oily layer. Wash the mixture with 5 ml of water and 1 ml of sodium hydroxide solution and again with water. Dry with 0.5 g of calcium chloride, and distill. Collect the fraction which boils at 130–135°. The yield is about 2 g.

(B) **Preparation of *o*-Chlorotoluene** (Sm.) (**Gatterman**). Diazotize according to directions given in Experiment 53. Use 3.2 g of *o*-toluidine, 5 ml of water, 5 ml of concentrated hydrochloric acid, 5 g of ice, and 2.2 g of sodium nitrite dissolved in 8 ml of water. Dissolve in a 250-ml Erlenmeyer flask 18 g of copper sulfate, $CuSO_4.5H_2O$, in about 100 ml of hot water. Add in small portions, with shaking, 5 g of zinc dust until the color of cupric ion disappears. If the color persists, add more zinc dust in very small portions. Decant the liquid from the precipitated copper, and wash the latter twice with water. Add 5 ml of concentrated hydrochloric acid to dissolve any excess of zinc, and wash again with water. Add 15 ml of concentrated hydrochloric acid to the copper mass and cool to 5°. Pour the diazonium salt on to the copper mass all at once, and allow the mixture to stand for five minutes; then heat gradually and cautiously until the evolution of nitrogen begins; then cool, while the evolution of nitrogen proceeds. Finally, after the vigorous evolution of gas has ceased, heat to 60°. From this point on proceed as in section (A) above. In the final distillation collect the fraction which boils at 153–158°. The yield is about 2–2.5 g.

o-Bromotoluene is prepared by the same method. Use the same quantities of material, but substituting 48 per cent hydrobromic acid for the hydrochloric acid.

(C) **Preparation of *o*-Chlorobenzoic Acid** (Sm.). Use the same method as in sections (A) or (B) above. For diazotization use 4.2 g of *o*-aminobenzoic (anthranilic) acid and the same quantities of all other reagents. After the decomposition of the diazonium salt the solution is cooled, and the *o*-chlorobenzoic acid crystals which separate out are filtered. The crude acid is recrystallized by dissolving in 100 ml of water and 10 ml of 6 *N* sodium hydroxide solution. One gram of charcoal is added, the solution is warmed slightly, filtered, and acidified slowly with 11 ml of 6 *N* hydrochloric acid solution. The crystals are filtered and washed with water. The yield is about 2 grams.

(D) **Preparation of *o*-Chlorobenzene** (M.). Prepare benzenediazonium chloride according to the method described in Experiment 53 (C). Use twice the amounts given, namely: 0.3 moles of aniline (28 ml), 40 ml of water, 0.75 moles of hydrochloric acid (60 ml of concentrated acid), and 0.32 moles (22 g) of sodium nitrite dissolved in 80 ml of water.

While the diazotization is proceeding, prepare the solution of cuprous chloride. Dissolve in a 500-ml flask 38 g of copper sulfate, $CuSO_4.5H_2O$, and 12 g of sodium chloride in 150 ml of hot water. Add slowly, with shaking, a solution of 20 g sodium bisulfite and 10 g of sodium hydroxide in 50 ml of water. Cool in tap water to about 20° and allow to stand for five minutes. Wash with water twice by decantation. Drain as much as possible, add 30 ml of concentrated hydrochloric acid and 20 ml of water, and cool to about 5°. Pour the cold benzenediazonium chloride solution into the cuprous chloride mixture, with shaking. The double salt $C_6H_5N_2Cl.Cu_2Cl_2$ separates out. After 10 minutes place the flask on a water bath and warm gradually to 50°, shaking from time to time. Steam-distill the mixture and separate the chlorobenzene from the distillate. Wash successively with 25 ml of 5 per cent sodium hydroxide solution and 25 ml of water. Wash again carefully with 20 ml of cold concentrated sulfuric acid, and finally with 20 ml of water. Dry with 3–4 g of calcium chloride, and distill, collecting the fraction which boils at 130–135°. The yield is about 25 g.

Experiment 56

REPLACEMENT OF THE DIAZO GROUP BY A HYDROXYL GROUP

Introduction. When a solution of diazonium salt is heated, the diazo group is replaced by a hydroxyl group, giving phenols and nitrogen. This reaction is analogous to the action of nitrous acid on alkylamines at room temperature:

$$RN_2Cl + HOH \xrightarrow{H_2SO_4} ROH + HCl + N_2$$

The formation of phenols by such reactions is best brought about by using diazonium sulfates. Diazonium chlorides give variable amounts of chloro compounds, along with phenols. The presence of two or three nitro or chloro groups in the nucleus increases the stability of diazonium salts, so that heating under pressure is required for the replacement of the diazo group.

(A) Preparation of Phenol (Sm.). Place in a 250-ml Erlenmeyer flask 45 ml of the benzenediazonium chloride solution (0.045 moles) prepared in Experiment 53 (C). Add 6 drops of concentrated sulfuric acid, provide the flask with a thermometer, and warm carefully to 40–50° until evolution of nitrogen begins. Cool the flask to below 50° and do not allow the temperature to rise above 55°. Continue heating until the evolution of nitrogen ceases. Cool to 20°, and then extract with two 10-ml portions of ether and one 5-ml portion. To extract, pour the ether into the flask, close the latter with a solid rubber stopper, and shake; cool the flask and wait until the two layers separate. Then pour off most of the ether into an eight-inch tube and, using the separatory stopper, withdraw the aqueous layer back into the flask. Pour the ethereal extracts into a small (125-ml) flask, and dry them with 1 g of calcium sulfate. The experiment may be discontinued at this point. During the next laboratory period, distill off most of the ether until 5–6 ml of liquid remain. Pour the residue into a distilling tube and distill off the remaining ether. Raise the temperature and distill the phenol, collecting the fraction which boils at 179–184°. The yield is about 1.5 g.

(B) Preparation of Phenol (M.). Place in a liter beaker 350 ml of water, add slowly 35 ml of concentrated sulfuric acid, and then

31 ml of aniline. Cool, and diazotize as directed in Experiment 53 (C). Allow to stand for about twenty minutes at room temperature. Heat at 40–50° until evolution of nitrogen begins, being careful not to allow the temperature to go above 55°, and cooling if necessary. When the evolution of nitrogen has stopped, steam-distill the reaction mixture from a liter Florence or round-bottom flask until 150 ml of distillate is collected. Add 10 g of salt, and extract the product with three 50-ml portions of ether. Dry the ether extracts with 3–4 g of anhydrous calcium sulfate or potassium carbonate, and distill off the ether. Provide the distilling flask with an air condenser and distill cautiously, collecting the fraction which boils at 179–184°. Cool the distillate, and add a minute crystal of phenol if crystallization is slow. The yield is about 17–18 g.

Caution: Care should be exercised not to allow hot phenol to come in contact with the skin, for it causes severe burns.

(C) **Preparation of *o*-Cresol (Sm.).** Place in a 250-ml flask 5 g of *o*-toluidine, 10 ml of water, and 5 ml of concentrated sulfuric acid. Cool in an ice-salt mixture, and when the temperature reaches 5° add 10 g of ice. Add all at once a solution of 3.8 g of sodium nitrite dissolved in 12 ml of water and cooled to 10°. Allow to stand for 10 minutes; if there is an excess of nitrous acid, add small quantities of urea or sulfamic acid until the nitrous acid is removed (test). Heat the solution to 50° until evolution of nitrogen begins, then cool so that the temperature does not rise above 55°. One gram of copper powder (see Experiment 55 [B]), if added to the mixture before heating, will increase the yield. From this point on proceed as in section (A) of this experiment. After the removal of the greater part of the ether, the residue is transferred to a distilling tube, fractionated, and the portion which boils at 188–194° collected. The yield is about 3 g.

Experiment 57

REDUCTION OF THE DIAZO GROUP

PHENYLHYDRAZINE

Introduction. When diazonium salts are reduced, they form arylhydrazines ($RNHNH_2$), which are regarded as derivatives of hydrazine, $H_2N.NH_2$. When a diazonium salt is added to a solution of bisulfite, it forms the diazonium sulfonate, which, when heated, is reduced by the excess bisulfite to phenylhydrazine sulfonate. Addition of hydrochloric acid gives the phenylhydrazine hydrochloride, which is slightly soluble in an excess of hydrochloric acid. These reactions are represented by the following equations:

$$C_6H_5N_2Cl + Na_2SO_3 \longrightarrow C_6H_5N_2SO_3Na + NaCl$$

$$C_6H_5N_2SO_3Na + NaHSO_3 + H_2O \longrightarrow C_6H_5NHNHSO_3Na + NaHSO_4$$

$$C_6H_5NHNHSO_3Na + HCl + H_2O \longrightarrow C_6H_5NHNH_2H^+Cl^- + NaHSO_4$$

In order to reduce an orange dye which is formed when the diazonium salt is added to the bisulfite solution, a small amount of zinc and acetic acid is added. To prepare the base, the hydrochloride is treated with excess 30 per cent sodium hydroxide solution, and the oily base is extracted with ether. The ethereal extract is dried and, after removal of ether, is distilled under reduced pressure. Substituted phenylhydrazines, such as *p*-nitrophenylhydrazine and *p*-bromophenylhydrazine, are prepared in the same manner. Arylhydrazines are strong bases forming characteristic salts, which are important reagents in the identification of aldehydes, ketones, and sugars (see preparation of phenylhydrazones and osazones).

(A) **Preparation of Phenylhydrazine Hydrochloride** (Sm.). For this preparation use the diazonium salt solution prepared in Experiment 53 (C). Dissolve in a 150-ml beaker 3 g of sodium bisulfite in 8 ml of water; to this add a solution containing 1.2 g of solid sodium hydroxide dissolved in 4 ml of water and adjust the *p*H to 6. This is accomplished by addition of a few drops of dilute alkali or acid. Test the *p*H by removing a drop of the sulfite solution with a stirring rod to 5 ml of distilled water and adding 2–3 drops of bromocresol purple or Universal indicator. Unless the *p*H is adjusted, the reaction proceeds in other directions and a tar is formed. Cool the solution to 20°, and add rapidly, with stirring, 15 ml of the benzenediazonium salt solution. Heat the mixture to 60–70°, and add 4 ml of glacial acetic acid. Sift in, in small portions, 1 g of zinc dust, and stir. The solution on reduction becomes colorless. Allow the excess of zinc dust to settle, and then decant the liquid into a 250-ml beaker. Wash the zinc with 5 ml of water and unite with the main portion. Add 20–25 ml of concentrated hydrochloric acid,[1] and cool in an ice-salt mixture. The experiment may be discontinued at this point. In such case, cover the beaker with a watch glass, and set aside without cooling. Afterwards cool to 5°, filter the crystals with suction, press with spatula, and wash with 2 ml of ice cold water. The yield is about 1.5 g.

(B) Preparation of Phenylhydrazine (M.). Diazotize 0.45 moles of aniline. Use a one-liter beaker 42 ml of pure aniline, 60 ml of water, 30 g of ice, 90 ml of concentrated hydrochloric acid, and 33 g of sodium nitrite dissolved in 90 ml of water. Observe all the directions given in Experiment 53 (C). While diazotization is in progress prepare the sulfite solution. Use 45 g of sodium bisulfite and 36 g of sodium hydroxide, and follow the directions given in section (A) above. For reduction use 30 ml of glacial acetic acid and 6–8 g of zinc dust. After reduction filter the solution by suction. Transfer the filtrate into a liter beaker and add one third of its volume (200–300 ml) of concentrated hydrochloric acid.[1] Allow to crystallize overnight, cool to 0°, and filter through suction. Wash with 10–20 ml of ice cold water.

Place the wet crude salt in a beaker, cool by means of running water, and add (using the hood) sufficient solution of 30 per cent sodium hydroxide to decompose the salt and cause the base to rise as an oil to the top. Avoid breathing the fumes given off by phenylhydrazine, as they are very toxic. Cool, and transfer to a separatory funnel, washing the beaker with 20 ml of ether. Extract twice with 50-ml portion of ether, and dry the ethereal solution of the base with solid sodium hydroxide. Transfer the ether solution into a 250-ml Claisen flask and distill off the ether by means of a water bath. Remove the bath, and arrange for distillation under reduced

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[1] Use the hood, as sulfur dioxide is evolved.

pressure (see pages 238–239). Collect the portion which boils at 116–124° at 10–12 mm pressure. The yield is 25–30 g.

Caution: Phenylhydrazine is highly poisonous. Wash at once any liquid which has come in contact with the skin first with a 2 per cent acetic acid solution and then with soap and water.

Experiment 58

PREPARATION OF AZO AND DIAZOAMINO COMPOUNDS

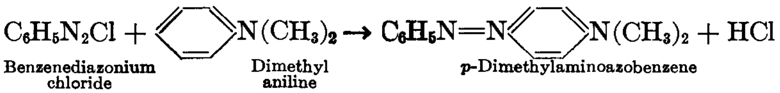
NOTE: If the student has followed the semimicro method, using the stock solution of the diazonium salt prepared in Experiment 53 (C), the following preparations are recommended: (A), (B), or (C), and (D) or (E). For macro work, sections (C) and (D) are recommended. For section (C) diazotize 7 ml of aniline in accordance with directions given in Experiment 53 (C), and then use five times the quantities given in section (C) below. For section (D) the amounts given (or double) may be used.

Introduction. In neutral solutions a diazonium salt reacts with primary amines to form diazoamino compounds:

$$C_6H_5N_2Cl + H_2NC_6H_5 \longrightarrow \underset{\text{Diazoaminobenzene}}{C_6H_5N_2NHC_6H_5} + HCl$$

This accounts for the precaution of having an excess of acid during diazotization; otherwise the diazonium salt, as it forms, would combine with the unreacted base. The diazoamino compounds are not very stable. They can be made to rearrange to the more stable azo compounds.

When an aryl hydroxy or amino derivative is added to the diazonium salt solution, a union of the diazo group with the added aryl compound occurs, which is known as *coupling*. In this union the *para* hydrogen atom of the amino or hydroxy compound reacts. If the *para* position is already occupied then the *ortho* hydrogen atom reacts. If both are occupied, no coupling takes place.



The position of coupling reactions in amino and hydroxy naphthalene compounds is more involved. If the amino or hydroxy group is in the β-position (2-position), then coupling takes place in the α-position (adjacent). If the amino or hydroxyl group is in the α-position, then coupling takes place in the 4- or 8-position. Generally speaking, hydroxy compounds couple more readily than amino compounds.

The *p*H of the solution exerts an important influence on the rate of coupling and hence often on the direction of the reaction. The hydroxy compounds couple at a range of *p*H 5 to 9. Phenols if soluble may be added directly, and the *p*H adjusted to 8 by means of sodium acetate or similar salt. It is more common to dissolve or suspend phenol or naphthol in alkali before adding it to the diazonium salt solution. The azo dye is separated and filtered. When the hydroxy compound contains a carboxyl or sulfonic acid group, the azo compound is separated as the sodium salt by saturating the solution with sodium chloride or another salt. The amino compounds couple at a range of *p*H 3.5–7.0. The base is dissolved in an acid (acetic or hydrochloric), after which the mixture is neutralized by the addition of sodium acetate. The aminoazobenzene, $C_6H_5N=NC_6H_4NH_2$, which is the simplest of the azo dyes, gives a yellow solution. By introducing other groups, and also by coupling with naphthalene derivatives, the color of the compound may be varied. In this manner it is possible to obtain different compounds exhibiting wide variations in color and brilliance. Those which can be imparted to textile fibers and are not removed by washing or easily faded by light are known as *dyes.*

By reduction, the azo compounds are first changed to the hydrazo compounds. Further reduction produces fission of the nitrogen-to-nitrogen linkage, and two molecules of amine are formed:

$$RN{=}NR' \xrightarrow{[H]} RNH{-}NHR' \xrightarrow{[H]} RNH_2 + R'NH_2$$

The color of azo dyes is destroyed by such reduction. This reduction is useful in the preparation of *p*-diamines and aminophenols, and also in determining the structure of the dye.

(**A**) **Preparation of Diazoaminobenzene.** Place in a 150-ml beaker 5 ml of water, 1 ml of aniline, and 1 ml of concentrated hydrochloric acid. Stir, and add 15 ml (0.015 moles) of the benzenediazonium chloride stock solution prepared in Experiment 53 (C). Add 1.5 ml of 6 *N* sodium hydroxide solution drop by drop while stirring. Allow to stand, and proceed with section (B). Later filter the compound, wash several times with water, press, and remove to paper to dry. The yield is 1.8–2.2 g.

(**B**) **Preparation of 2,4-Dihydroxyazobenzene.** Dissolve 2.0 g of resorcinol in 5 ml of water and add to it 15 ml of the benzenediazonium chloride solution; stir, and add 2 g of sodium acetate dissolved in 8 ml of water. Allow to stand in the cold; later, filter the dye, wash repeatedly with water, and place on paper to dry. The yield is about 3 g.

(C) Preparation of Sudan I (Benzeneazo-β-Naphthol). Dissolve 2.2 g of β-naphthol by heating in 5 ml 6 *N* sodium hydroxide solution and 5 ml of water; when dissolved add 10 ml of water and cool to about 5°. Add 15 ml (0.015 moles) of benzenediazonium chloride slowly while stirring. Allow to stand in the cold; later, filter the dye, wash repeatedly with water, press with a cork, and remove to a paper to dry. The yield is about 3 g.

(D) Preparation of Methyl Orange. Add 2.6 g (0.015 moles) of sulfanilic acid to 20 ml of water, and then add 3 ml of 6 *N* sodium hydroxide solution. Warm slightly until solution is complete. Add 1 g of sodium nitrite, stir until the salt is dissolved, and cool to 25°. Pour this mixture, with constant stirring, into a beaker which contains 30 ml of water, 40 g of crushed ice, and 2 ml of concentrated sulfuric acid. Allow to stand for half an hour, adding ice if the temperature rises above 5°. Add a solution of 2 ml of dimethylaniline in 2 ml of hydrochloric acid. Stir, allow to stand for 15 minutes, and add 12 ml of 6 *N* sodium hydroxide and 50 ml of saturated salt solution. Cool for 10 minutes. Filter by suction, and wash the crystals with 10 ml of cold saturated salt solution. Press the crystals on the filter into a cake to drain well. To recrystallize, suspend the cake in 100–125 ml of distilled water and heat until solution is complete at 90–95°, adding more water if necessary. Filter the hot solution, and cool. Filter the crystals with suction, wash with alcohol and finally with ether. The yield is 3.5–4.0 g.

(E) Preparation of *p*-Nitroaniline Red. Place in a 250-ml Erlenmeyer flask 4.2 g of *p*-nitroaniline, 20 ml of water, and 10 ml of concentrated hydrochloric acid. Heat at 80–90° until the hydrochloride of the amine is formed. Pour the acid mixture into a 250-ml beaker, cool to room temperature, and add 10 g of ice. Prepare a solution of 2.3 g of sodium nitrite dissolved in 10 ml of water. Cool to room temperature, and add the solution to the base all at once. Add 4.1 g of β-naphthol dissolved in 5 ml of water and 10 drops of 6 *N* sodium hydroxide solution. Allow to stand for 20 minutes, then add 2 g of sodium acetate dissolved in 8 ml of water. After 15 minutes, filter the dye, wash repeatedly with water, and place on a paper to dry. The yield is about 5 g.

(F) Reduction of the Azo Group. (1) To a small amount of one of the azo dyes suspended in water add 2 ml of concentrated hydrochloric acid, and then small amounts of zinc dust until no further color remains. Write the equation for the reaction. Repeat the procedure, using sodium hydrosulfite.

(2) Place 2 g of Sudan I in 10 ml of alcohol in an eight-inch tube. Provide the tube with a reflux condenser, and warm for five min-

utes until most of the dye dissolves. Add a solution of 2 g of stannous chloride dissolved in 6 ml of concentrated hydrochloric acid, and heat for ten minutes until the color is discharged. Decant the solution into a small beaker and cool in an ice-salt mixture; crystals of 1-amino-2-naphthol hydrochloride separate. Filter, and wash the crystals with dilute hydrochloric acid. Save for the preparation of naphthoquinone (Experiment 60 [C]).

Experiment 59

PREPARATION OF SULFONIC ACIDS

NOTE: Great caution should be exercised in handling fuming sulfuric acid and, in general, all hot sulfonating mixtures. *Goggles should be worn.*

For semimicro work section (A) or (C) is recommended. For macro work, beside the preparation of sulfanilic acid (section B), sections (C) and (D) may be adapted by increasing the quantities given 4–5 times and using a 250-ml flask.

Introduction. It will be recalled that one of the most common methods of distinguishing between aromatic and aliphatic hydrocarbons is the difference in the rates of their reactions with sulfuric acid. Aromatic hydrocarbons readily form sulfonic acids when heated with concentrated sulfuric acid at temperatures varying from 80° to 200°. Saturated paraffin hydrocarbons, on the other hand, do not react with sulfuric acid under comparable conditions. A number of saturated paraffins are sulfonated directly by using fuming sulfuric acid and heating under pressure, but the sulfonic acids of the lower paraffin hydrocarbons are prepared by reacting alkyl halides with alkali sulfites. The sulfonic acids of the aromatic hydrocarbons are of much greater importance than the sulfonic acids of paraffins.

The general method for the preparation of a monosulfonic acid is to heat the aromatic compound with excess of concentrated sulfuric acid at temperatures which vary from 80–200° or even higher. The completion of the reaction is indicated by complete solubility of a small sample diluted with water. During sulfonation water is formed and consequently there is a dilution of the sulfonating medium:

$$C_6H_6 + HOSO_2OH \longrightarrow C_6H_5SO_3H + H_2O$$

For this reason an excess of 30–40 per cent or more than the calculated amount of sulfuric acid is used. Increase in the rate of sulfonation is obtained by the addition of sulfur trioxide to sulfuric acid. Ordinary concentrated sulfuric acid contains about 96–98 per cent H_2SO_4, the rest of the liquid being water. Sufficient sulfur trioxide can be added to convert this water to sulfuric acid and thus obtain 100 per cent acid. Addition of still more sulfur trioxide to 100 per cent sulfuric acid gives a sulfonating mixture known as fuming sulfuric acid, or oleum. For laboratory preparations fuming acid containing 5–25 per cent of sulfur trioxide is employed. The effectiveness of fuming acid is illustrated in the sulfonation of anthraquinone. If concentrated sulfuric acid is used, a temperature of 250° is required, while with fuming acid containing 20–30 per cent sulfur trioxide a temperature of 120° is sufficient. In general, fuming acid is used for the introduction of the second and third sulfonic acid groups and for the sulfonation of compounds containing nitro groups and other substituents which inhibit sulfonation. The presence of hydroxyl and amino groups is of aid to sulfonation. For example, phenol sulfonates with greater ease than benzene, while nitrobenzene requires fuming sulfuric acid. Another sulfonating agent is chlorosulfonic acid.

$$RH + ClSO_2OH \longrightarrow RSO_3H + HCl$$

Chlorosulfonic acid is used in special cases because it sulfonates at a particular position. For example, toluene with sulfuric acid yields mostly *p*-sulfonic acid, while with chlorosulfonic acid chiefly *o*-sulfonic acid is formed. The reaction with chlorosulfonic acid may proceed further to form the sulfonylchloride, discussed in Experiment 68. A number of catalysts (iodine, mercury, vanadium salts) are used to accelerate sulfonation, particularly in polynuclear compounds.

The introduction of the sulfonic acid group into nonpolar hydrocarbon molecules increases their solubility to such an extent that it is difficult to effect their separation from aqueous solutions. They cannot be distilled without decomposition. They are usually separated by means of their sodium, calcium, or barium salts. The reaction mixture is poured into water. The alkali salt in many cases is separated by the addition of sodium chloride, potassium chloride, sodium acetate, ammonium chloride, and other salts. A more general method is to neutralize the diluted mixture with calcium, barium, or lead carbonate, and filter from the insoluble sulfate, the sulfonate being soluble. The filtrate which contains the salts of sulfonic acid is concentrated by evaporation to crystallization. The sodium salt is obtained by boiling one of the salts with solution of sodium carbonate. The precipitated carbonate of calcium or barium is filtered, and the filtrate is evaporated to obtain the sodium sulfonate. The amino sulfonic acids, having both a proton-repelling and a proton-accepting group, form some type of internal salt and hence their solubility in water is not great. A number of aminosulfonic acids may be separated either from the cold reaction mixture or by diluting with water and filtering the precipitated aminosulfonic acid. Since the filtration of concentrated sulfuric acid is difficult, dilution with water is more convenient.

(A) **Preparation of Sulfanilic Acid** (Sm.). Place in an eight-inch tube which is immersed in a beaker of cold water 6 ml of concentrated sulfuric acid and 4–5 ml of fuming sulfuric acid (15–20 per cent SO_3). Add dropwise 3 ml of aniline. The solid which separates is aniline sulfate. Provide the tube with a cork through which is fitted a piece of glass tubing 6–8 mm in diameter and 20–25 mm in length. Heat the mixture in an oil bath at 180° for about 1 hour Cool to room temperature, and add the contents very slowly to 20 ml of water. Cool to 5–10°, and filter the crystals. Wash twice with 5 ml of water. To purify the crude acid, suspend in 25 ml of water, heat to 80°, then add dropwise, with stirring, dilute sodium hydroxide solution until solution is complete. Add 0.2 g of charcoal and a pinch of Filter-cel, and filter with suction. Add to the filtrate dilute hydrochloric acid, with stirring, until the reaction is distinctly acid to the indicator. Cool, filter the crystals with suction, wash once with distilled water, and dry on a paper disc. The yield is about 3 g.

(B) **Preparation of Sulfanilic Acid** (M.). Place 23 g (23 ml) of aniline in a 250-ml round bottom or Florence flask. Add slowly and cautiously 74 g (40 ml) of concentrated sulfuric acid. After each addition of 5 ml of acid, shake and cool the flask. Attach an air condenser to the mouth of the flask, and heat in an oil bath at 180–190° for above 5 hours. If a drop of the sulfonating mixture is diluted in a test tube with 5 ml of dilute alkali, and the resulting solution is clear, the sulfonation is complete. If droplets of aniline are present the heating is continued for one to two hours longer.

The time required for sulfonation may be reduced to one hour if 25 ml of fuming sulfuric acid (containing 15–20 per cent sulfur trioxide) is added cautiously to the mixture of acid and aniline prepared as directed above. The reaction mixture is heated for one hour at 180–190° and tested for completion of the sulfonation. When the reaction is complete, cool to room temperature, then pour cautiously, with vigorous stirring, into 300 ml of cold water. Filter the crystals of the crude acid, and wash several times with cold water. Purify the crude acid by dissolving in 200 ml of warm water and adding dilute sodium hydroxide until solution is complete. Add a gram or two of charcoal and a pinch of Filter-cel. Stir and heat to 80–90°, and filter with suction. Acidify the solution with dilute hydrochloric acid, and cool to 10–15°. Filter the crystals with suction, wash with cold water, press to drain the liquid, and dry on paper or on a porous plate. The yield is about 22 g.

(C) **Preparation of Sodium Benzenesulfonate** (Sm.). Place in an eight-inch tube 15 ml of fuming sulfuric acid which contains 6–8 per cent sulfur trioxide. Clamp the tube securely on a stand so that it rests inside of an empty 250-ml beaker. Wear your goggles. Place a thermometer in the tube, and by means of a dropper add 5 ml of benzene over a period of about 10 minutes, in portions of 5–6 drops at a time. After adding each portion, stir the acid cautiously with a thermometer until the benzene layer goes into solution before adding another portion. Keep the temperature of the reaction mixture at 35–45° by adding water to the beaker if the temperature rises above 50°. When all the benzene has been added and dissolved completely, pour the acid mixture very slowly and cautiously, with stirring, into 50 ml of water containing 10 g of common salt in solution. Add in small portions at a time 3 g of solid sodium carbonate to neutralize part of the acid. Place the beaker in an ice-salt mixture and allow to stand for 30 minutes, with occasional stirring. If crystallization does not begin immediately on cooling, scratch the walls of the beaker lightly with the stirring rod. Filter by suction, and press the crystals to remove the mother liquor as completely as possible. Wash with 3–4 ml of cold saturated salt solution, then with 3–4 ml of alcohol. Drain well, and dry on a filter paper or porous plate. If a pure product is desired, recrystallize from ethanol. For the preparation of benzenesulfonyl chloride the crude salt is satisfactory. The yield is about 5–6 g.

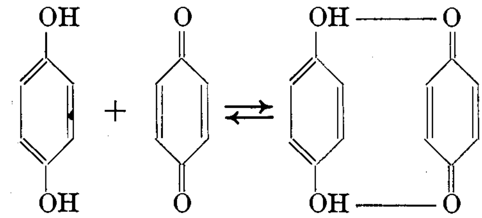
(D) **Preparation of Calcium β-Naphthalenesulfonate** (Sm.). At temperatures below 100° α-naphthalenesulfonic acid is the main product of the sulfonation of naphthalene. At temperatures above 150° the β-isomer is the chief product. Place 5 ml of concentrated sulfuric acid in an eight-inch tube, add 3 ml of fuming sulfuric acid, and heat the tube in an oil bath to 100°. Add in small portions 5 g of finely powdered naphthalene. Stir with the thermometer immersed in the reaction mixture while adding the naphthalene. When all the naphthalene has been added, heat at 170° for 1 hour. Allow contents of tube to come to room temperature, then pour into 75 ml of water. Add slowly, with stirring, a suspension of 12 g of calcium hydroxide in 60 ml of water, until the solution is just alkaline. Remove the calcium sulfate by filtration, washing the precipitate with 25 ml of hot water. Evaporate the filtrate until crystals begin to separate out. Allow the dish to stand for 24 hours, then cool and filter the crystals. The yield is about 5–6 g.

Experiment 60

PREPARATION AND PROPERTIES OF QUINONES

Introduction. The quinones are intermediate products in the oxidation of the aromatic nucleus. They may be prepared in some cases by the direct oxidation of aromatic hydrocarbons. For example, anthracene, naphthalene, and phenanthrene are oxidized to the corresponding quinones by chromic acid mixtures. Quinones are prepared more conveniently by oxidation of primary aromatic amines, particularly the *p*-substituted amines. *p*-Benzoquinone is obtained by the oxidation of aniline, *p*-toluidine, sulfanilic acid, *p*-aminophenol, and other similar compounds. Similarly the α-naphthoquinone is obtained by oxidation of 1,4-aminonaphthol, and β-naphthoquinone by the oxidation of 1,2-aminonaphthol. In the laboratory, although it is possible to prepare *p*-benzoquinone by the oxidation of aniline with acid-dichromate mixture, the method is tedious and the yield poor. Since hydroquinone is used extensively as a photographic developer and is made industrially, it is more convenient to prepare quinone by its oxidation.

The quinones may be regarded as unsaturated diketones derived from cycloolefins, and closely related to aromatic compounds. They exhibit great reactivity with a variety of reagents. They are readily reduced and oxidized, and undergo both olefinic and carbonyl reactions. Equimolecular proportions of *p*-benzoquinone and hydroquinone yield a crystalline molecular compound, quinhydrone.



Hydroquinone Quinone Quinhydrone

Quinhydrone is utilized in a half-cell used for the measurement of hydrogen ions.

(A) **Preparation of *p*-Benzoquinone** (Sm.). Arrange for steam distillation as shown in Figure 50. Place in the eight-inch tube 15 ml of water, 3 ml of concentrated sulfuric acid, and 3 g of hydroquinone. Connect all the apparatus, using for receiver an eight-inch tube immersed in ice water. Raise the cork of the tube containing the hydroquinone and add 4 g of solid manganese dioxide. Pass steam until 6–8 ml of distillate has been distilled. Filter the cooled distillate with suction, wash with cold water, press, and dry. Store the crystals in a dark bottle. The yield is about 2–2.5 g.

(B) **Preparation of *p*-Benzoquinone** (M.). Use the apparatus shown in Figure 48, with 5–10 times the amounts given in section (A). The water in the jacket of the condenser should not be run rapidly, as clogging of the condenser may occur from crystallization of the quinone. The distillate should run warm from the condenser to the adapter. The adapter should fit well inside the receiver. The latter should be immersed in an ice-salt mixture.

Caution: The fumes of the quinone are very irritating to the eyes and care should be exercised to protect them.

(C) **β-Naphthoquinone** (Sm.). Prepare 5 g of 1-amino-2-naphthol hydrochloride according to the directions given in Experiment 58(F2). If a smaller amount is already available, proceed with the oxidation, using proportionate amounts. Dissolve the aminonaphthol hydrochloride in 40–50 ml of water, using a small beaker and heating to about 30°. Filter the solution in a 250-ml Erlenmeyer flask, and add all at once, with shaking, a freshly prepared solution of 29 g of ferric ammonium alum, $Fe_2(SO_4)_3\cdot(NH_4)_2SO_4\cdot24H_2O$ in 125 ml of water and 5 ml of hydrochloric acid. If ferric ammonium alum is not available use 8 g of ferric chloride, $FeCl_3.6\ H_2O$, dissolved in 25 ml of water and 3 ml of concentrated hydrochloric acid. In either case prepare the solution of the ferric salt by heating till it dissolves, filtering the solution into a flask, and cooling to about 30°. The β-naphthoquinone separates within a few minutes after the addition of the oxidizing solution. Filter by suction, and wash several times with water. Drain the crystals and place on paper to dry. The yield is about 3–3.5 g.

(B) **Properties of Quinones.** (1) Dissolve 0.2 g each of quinone and hydroquinone in 4 ml of alcohol in separate test tubes. Mix the two solutions, allow to stand for a few minutes and add 10 ml of water. Shiny green crystals of quinhydrone separate.

(2) Place a few crystals of benzoquinone in 2 ml of water, add 5 drops of sodium hydroxide solution, and shake gently. The solu-

tion turns rapidly brown, then black, due to oxidation. Repeat, using naphthoquinone if available.

(3) Prepare 2–3 ml of Tollen's reagent (pages 192–193), and add a crystal of benzoquinone. Shake gently and observe the result.

(4) Tests 2 and 3 illustrate the ease with which quinone is oxidized. The present test illustrates the ease of reduction. Place in a test tube a few crystals of benzoquinone and add 5 ml of water. Add about 0.1 g of sodium hydrosulfite in 2–3 portions, and heat. The solution may turn green or brown due to the intermediate formation of quinhydrone. If the solution does not decolorize, add more hydrosulfite. Cool, and observe whether the hydroquinone crystallizes. The reaction may be reversed by the addition of a few drops of ferric chloride solution.

Experiment 61

PREPARATION OF AROMATIC HYDROCARBONS BY THE FRIEDEL-CRAFTS REACTION

Introduction. The object of this and of the two following experiments is to illustrate the application of the Friedel-Crafts reaction to the synthesis of organic compounds. In the present experiment the preparation of aromatic hydrocarbons will be considered.

The Friedel-Crafts synthesis involves the union of a relatively active compound, like a halide, with a relatively stable hydrocarbon in the presence of an anhydrous halide of aluminum, iron or zinc. For example, when a mixture of benzyl chloride and benzene are treated in the cold with aluminum chloride, a vigorous reaction takes place with elimination of hydrogen chloride resulting in the union of the phenyl and benzyl radicals to form diphenylmethane:

$$C_6H_5CH_2\boxed{Cl + H}H_5C_6 \xrightarrow{AlCl_3} C_6H_5CH_2C_6H_5 + HCl \tag{1}$$

$$RX + HAr \longrightarrow R\text{—}Ar + HX \tag{2}$$

Equation (2) represents the general equation for the reaction. The radical R may be an alkyl, aryl, or acyl radical and the radical Ar any simple or complex aryl radical. Besides aryl, alkyl, and acyl halides, a number of other reactive compounds, such as acid anhydrides, carbon dioxide and monoxide, and olefins, can be made to react in presence of aluminum chloride. This synthesis has been used successfully for the preparation of many hydrocarbons, aldehydes, ketones, and carboxylic acids.

In the preparation of hydrocarbons an alkyl, aryl, or aralkyl halide is mixed with an excess of an aromatic hydrocarbon, and anhydrous aluminum chloride is added in small portions. The reagents must be free from moisture. If the reactants are not liquid or the reaction is very vigorous, a solvent is used. Benzene, nitrobenzene, carbon disulfide, or *o*-dichlorobenzene may be employed as solvents. When polyhalides are used, more than one molecule of the hydrocarbon may react. For example, benzene with chloroform yields triphenylmethane, and benzene with carbon tetrachloride gives triphenylmethyl chloride:

$$CHCl_3 + 3\ C_6H_6 \xrightarrow{AlCl_3} CH(C_6H_5)_3 + 3\ HCl$$

$$CCl_4 + 3\ C_6H_6 \xrightarrow{AlCl_3} (C_6H_5)_3CCl + 3\ HCl$$

The use of such a powerful reagent as aluminum chloride gives rise to many side reactions and complications. Consider, for example, the reaction in equation (1). Besides diphenylmethane the reaction gives anthracene, *p*-dibenzylbenzene, *o*-dibenzylbenzene, and some tar of unknown composition. It is reasonable to expect that if a catalyst makes possible the introduction of a group into a molecule it will also produce a migration of groups within the molecule, and disruption, as well as more extensive condensations and polymerizations. For example, if methyl chloride is passed into a mixture of benzene and aluminum chloride, the amount of toluene formed is small, while a large amount of dimethyl, trimethyl, and other polysubstituted benzenes is formed. When isobutyl chloride reacts with benzene in the presence of aluminum chloride the main product is *tert*-butyl benzene. Isobutyl chloride under the effect of the catalyst forms isobutylene, which, on addition of hydrogen chloride, gives *tert*-butyl chloride. The isomerization of alkyl halides under the influence of aluminum chloride must be taken into consideration in this type of synthesis.

The amount of aluminum chloride used varies with the type of reaction. In the preparation of hydrocarbons the amount of aluminum chloride used varies from 0.2 to 0.3 moles for each mole of halogen compound reacted. In using acyl chlorides for the preparation of ketones the amount of aluminum chloride is about mole per mole, while with anhydrides two moles of the salt are used. Technical grades of aluminum chloride give as good results as the chemically pure substance. In many cases the granular lumpy commercial material is to be preferred to the pure colorless powder. The latter is far more hygroscopic and more difficult to handle, particularly when powdered.

(A) **Diphenylmethane** (**Sm.**). Arrange an eight-inch tube with micro condenser and outlet for the gaseous reaction product, as shown in Figure 45. Fit the mouth of the tube with a two-hole cork, one hole for the condenser and the other for a tube bent at right angles and leading to the gas absorption tube. Place enough water in the absorption tube so that the gas outlet is just above the level of the liquid. Place in the reaction tube 5 g of benzyl chloride and 15 ml of pure anhydrous benzene (distilled over sodium metal and kept over fused calcium chloride). Raise a beaker containing ice water under the reaction tube. Weigh rapidly into a dry six-inch test tube 2.1 g of anhydrous aluminum chloride, and cork the tube immediately. Add the anhydrous salt to the reaction mixture in small amounts, raising the cork momentarily. Shake the mixture, and keep the reaction from becoming violent by adding ice to the surrounding bath. The addition takes about 10 minutes. Remove the ice bath and allow the reaction tube to stand for about 30 minutes. Decompose the oily addition product by pouring it slowly into a beaker containing 15 g of ice and 10 ml of concentrated hydrochloric acid. Wash the tube with a few milliliters of ice water and add to the beaker. Transfer to a separatory tube, add 5 ml of benzene, and withdraw the lower aqueous layer. Wash the benzene layer with 3 ml of dilute hydrochloric acid to remove any aluminum salts, then with 3–4 ml of water. Dry with 1.0 g of anhydrous calcium chloride, and transfer to an eight-inch distilling tube. Add two boiling stones, and remove most of the benzene by distillation from a water bath. Change the receiver, and heat by means of a small direct smoky flame until the temperature rises to 250°. Change the receiving tube and resume distillation, collecting the portion which boils at 255–265°. After cooling, by scratching the sides of the tube with a glass rod or seeding with a small crystal of the pure material, the oil is caused to solidify. The yield is 3.5–4 g. Pure diphenylmethane boils at 262°.

(**B**) **Preparation of Diphenylmethane** (**M.**). Use the apparatus shown in Figure 46 without the separatory funnel. Place a pail on the base of the stand and arrange the flask so that it is well immersed in ice water. Use 25 g of benzyl chloride, 100 ml of benzene, and 10 g of anhydrous aluminum chloride. Add the chloride in five to six portions by raising the cork on top of the condenser momentarily, and observe the same procedure and directions as given in section (A). Use a separatory funnel to separate the benzene layer, and a distilling flask for the fractionation. The yield is 17–20 g.

(C) **Preparation of Triphenylmethyl Chloride** (**Sm.**). Use the same apparatus and procedure as described in section (A). Place in the tube 10 ml of dry benzene and 3.2 g of dry carbon tetrachloride, and add as directed 2.4 g of aluminum chloride. When half of the chloride has been added, remove the ice water surrounding the reaction tube and add the remaining chloride in small portions. When all the chloride has been added, raise a small water bath over the reaction tube and heat for 30 minutes. Decompose the addition product by pouring it into a mixture of 10 g of ice and 10 ml of concentrated hydrochloric acid. Separate the benzene layer, and extract the aqueous layer with 5–6 ml of benzene. Dry the combined benzene solutions with 1 g of calcium chloride. Transfer to an eight-inch distilling tube, and distill the benzene from a water bath. Pour the residue into a small beaker; rinse the tube with 3–4 ml of ether and add to the residue. Cool to 10°, and allow to crystallize. Filter the crystals with suction, and wash twice with a few milliliters of cold ether. The yield is 4–4.5 g. If colored, it may be recrystallized by dissolving it in 5 ml of hot benzene and adding 20 ml of petroleum ether.

(D) Preparation of *tert*-Butyltoluene (Sm.). Use the same apparatus as for section (A). Place in the eight-inch tube 15 ml of toluene and 4 g of aluminum chloride. Add 4 g of *tert*-butyl chloride, 4–5 drops at a time over a period of half an hour. After half of the chloride has been added stir the reaction mixture with a glass rod. When the addition is complete place a small water bath under the eight-inch tube, and heat to 90–100° for about 30 minutes.

Decompose with 15 g of crushed ice and 10 ml of water. Separate the top layer by means of the micro separatory tube and transfer it to a tube containing 1 g of calcium chloride. Distill the dry mixture of toluene and butyltoluene from an eight-inch distilling tube. Collect the fraction boiling at 180–190°. The yield is about 3 g. The hydrocarbon is used for the preparation of trinitro-*tert*-butyltoluene.

Experiment 62

PREPARATION OF KETONES BY THE FRIEDEL-CRAFTS REACTION

Introduction. In the preceding experiment a general discussion of the Friedel-Crafts reaction was given, which should be reviewed. The object of the present experiment is to illustrate the application of the Friedel-Crafts reaction to the synthesis of simple ketones.

When an aryl hydrocarbon is reacted with an acyl halide or anhydride, hydrogen chloride is liberated and the acyl group unites with the nuclear carbon:

$$C_6H_5\boxed{H + Cl}\underset{\text{Acetyl chloride}}{COCH_3} \xrightarrow{AlCl_3} \underset{\text{Acetophenone}}{C_6H_5COCH_3} + HCl$$

$$2\ C_6H_5H + \underset{\text{Acetic anhydride}}{(CH_3CO)_2O} \xrightarrow{AlCl_3} \underset{\text{Acetophenone}}{2\ C_6H_5COCH_3} + H_2O$$

$$C_6H_5H + \underset{\text{Benzoyl chloride}}{C_6H_5COCl} \xrightarrow{AlCl_3} \underset{\text{Benzophenone}}{C_6H_5COC_6H_5} + HCl$$

In the preparation of ketones by reacting acyl chlorides one mole of aluminum salt must be used for every mole of chloride. When 0.5 mole is used the yield drops considerably, confirming the assumption that a complex is formed between the aluminum chloride and the ketone. With anhydrides it is necessary to use two moles of aluminum chloride for each mole of the anhydride. The addition of such a large amount of aluminum chloride produces a viscous reaction mixture; hence it is necessary to stir in order to secure better mixing and elimination of the gaseous hydrogen chloride. The latter is sometimes eliminated by drawing a slow stream of dry air through the reaction mixture.

(A) **Preparation of Acetophenone** (Sm.). Arrange an eight-inch tube with micro condenser and outlet for the gaseous reaction product as shown in Figure 45. Fit the mouth of the tube with a two-hole cork, one hole for the condenser and the other for a glass tube bent at right angles and leading to a gas-absorption tube. Place water in the latter so that the delivery tube is just above the level of the liquid. In the eight-inch test tube place 12 ml of pure anhydrous benzene, and fit the cork with a condenser. Weigh rapidly into a dry six-inch test tube 10 g of anhydrous aluminum chloride, and cork the tube immediately. Raise the cork of the eight-inch tube and add the aluminum chloride to the benzene all at once. Raise a beaker containing ice water under the reaction tube. Place in a small beaker 3 ml (3.3 g) of acetic anhydride and cover it with a watch glass. Add the anhydride a few drops at a time (use a dropper), raising the cork of the reaction tube momentarily. The addition takes about 10–15 minutes. Shake the mixture from time to time. If there is a tendency to cake, use a stirring rod to stir the mixture, and place the rod in a dry test tube for later use. After all the acetic anhydride has been added, remove the cold bath, and allow the tube to stand at room temperature for 10 minutes. Heat the tube (using a water bath) for 15–20 minutes. Cool, and pour slowly the contents of the reaction tube into a mixture of 20 ml of concentrated hydrochloric acid and 20 g of ice. Add 5 ml of benzene, transfer in two portions to a separatory tube, and withdraw the aqueous layer. Pour the benzene into a small Erlenmeyer flask, and extract the aqueous portions with 10 ml of ordinary benzene. Unite the benzene solutions, and wash with 4–5 ml of dilute (5–10 per cent) sodium hydroxide. Dry the benzene solution with 1.0 g of anhydrous calcium chloride, and transfer to an eight-inch tube. Add two boiling stones, and remove most of the benzene by distillation from a water bath. Change the receiver, and heat by means of a small smoky flame until the temperature rises to 190°. Change the receiving tube and resume distillation, collecting the portion which boils at 193–202°. The yield is 2–3 g.

(B) Preparation of Acetophenone (M.). Arrange a 500-ml Florence or round-bottom flask with a reflux condenser as shown in Figure 46, without the separatory funnel. Fit the top of the condenser with a two-hole cork, one hole for a small separatory funnel and the other for the gas delivery tube. Place a small pail of ice water on the base of the stand and arrange the flask so that it is immersed in the water. Use 10 times the amounts of reagents given in section (A), and the same procedure for the reaction. The acetic anhydride is added slowly through the separatory funnel over a period of half an hour. It is not necessary to use a stirring rod to mix the reaction mixture as is done in the semimicro method, but the contents of the flask should be shaken frequently. After the addition heat the flask for half an hour, and decompose the reaction mixture as directed in section (A). Use a separatory funnel to separate the benzene layer and proportionate amounts of the solvent.

The benzene solution is dried with 15 g of calcium chloride, and the solvent is removed by distillation from a water bath. Transfer the remaining oil to a small distilling flask for the final distillation. The yield is 25–30 g.

(C) **Preparation of Benzophenone** (Sm.). Use the arrangement of apparatus described in section (A). Place in the eight-inch reaction tube 4 ml of pure anhydrous benzene, 4 g of benzoyl chloride, and 10 ml of dry carbon disulfide.

Caution: Use care in handling carbon disulfide. It is exceedingly volatile and inflammable. It even becomes ignited on contact with a hot surface.

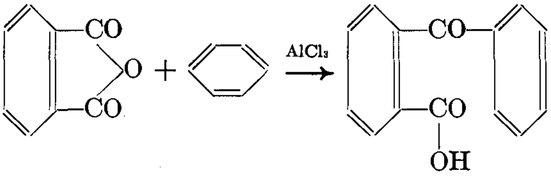
Weigh rapidly 4 g of aluminum chloride into a dry test tube provided with a cork. Add the chloride in small portions over a period of 10 minutes. Place a water bath under the reaction tube and using a burner with a small smoky flame, heat it at about 45–50° for one hour or so. Arrange the tube for distillation (Figure 39). Do not use a flame, but add to the surrounding bath hot water which has been heated in *another* part of the laboratory. Change the water 2–3 times, adding more hot water until 10–11 ml of distillate has been collected. Transfer the distilled disulfide to a bottle before proceeding further. Add to the residue in the reaction tube, in small portions, a mixture of 10 g of ice and 3 ml of concentrated hydrochloric acid. Stir with a glass rod, and arrange for steam distillation. Steam-distill for 5 minutes. Cool the tube, and extract three times with 8 ml portions of ether. Filter the ether if necessary, and wash once with 5 ml of water and twice with 5-ml portions of dilute (5–10 per cent) sodium hydroxide. Dry the ethereal solution with 1 or 2 g of anhydrous calcium chloride and recover the ether by distillation from an eight-inch tube. Towards the end of the distillation transfer the oil to a six-inch distilling tube. Rinse with two 1–2-ml portions of ether to transfer the oil completely. Remove all traces of ether, and then heat directly by means of a small luminous flame. Arrange the delivery tube in the receiver so that it is considerably below the micro condenser. Collect the fraction which boils at 290–305°. The yield is about 3–4 g.

Experiment 63

PREPARATION OF *o*-BENZOYLBENZOIC ACID

Introduction. In Experiments 61 and 62 a general discussion of the Friedel-Crafts reaction was given and its application to the synthesis of hydrocarbons and ketones. It is advisable to review the discussion given in those experiments. The object of the present experiment is to illustrate the application of this reaction to the synthesis of keto acids.

When a mixture of phthalic anhydride and an aryl hydrocarbon is acted upon by aluminum chloride, one of the acyl groups unites with the hydrocarbon radical, thus forming a keto acid. Benzene with phthalic anhydride forms *o*-benzoylbenzoic acid:



Phthalic anhydride　　*o*-Benzoylbenzoic acid

Two molecules of aluminum chloride for each molecule of the anhydride are employed in the reaction. If chlorobenzene is used in place of benzene a substituted *o*-benzoylbenzoic acid is formed (4′-chloro-2-benzoylbenzoic acid). The preparation of these substituted keto acids is of industrial importance, as by cyclization they form anthraquinone derivatives.

(A) **Preparation of *o*-Benzoylbenzoic Acid** (Sm.). Arrange apparatus as in Experiment 62 (A). Place in a reaction tube 3 g of powdered phthalic anhydride and 15 ml of pure anhydrous benzene. Set under the tube a small beaker of ice water so that it can be raised to immerse tube and moderate the reaction if necessary. Weigh rapidly in a dry test tube 6 g of aluminum chloride, and cork immediately. Add about a fifth of the aluminum chloride by raising momentarily the cork of the reaction tube. If the reaction does not begin within a few minutes, raise a 250-ml beaker half-full of water at 30–35°, so that the lower part of the reaction tube is immersed for a minute or two until the reaction begins. Add the remaining aluminum chloride in small portions over a period of 10 minutes, shaking the tube from time to time. Allow to stand for 5–10 minutes until the vigorous reaction has subsided, then place in a water bath and reflux for one hour.

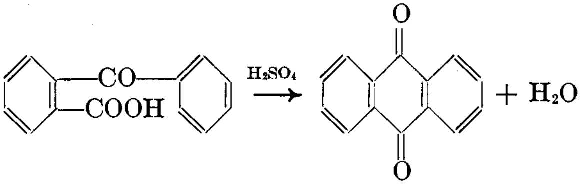
Cool, and add slowly a mixture of 10 g of ice and 2 ml of concentrated hydrochloric acid. It is advisable in the beginning to add only a few drops at a time and stir well with a rod to avoid vigorous decomposition. Remove the benzene by steam distillation. Separate the benzene from the distillate and place in a bottle. Cool the residue until it solidifies, scratching the sides of the tube with a glass rod. Decant the aqueous layer; if it contains solid particles filter and return the solid to the tube. Add 5 ml of water to the tube, stir, and decant as above. Add to the residue 15 ml of 10 per cent solution of sodium carbonate and two boiling stones, and reflux gently for 15–20 minutes. The acid dissolves, forming the sodium salt, and leaving small amounts of hydrated aluminum oxide in suspension. Remove the flame, allow to cool for a minute and then add, a little at a time, 0.2 g of charcoal and 0.1 g of Filter-cel. Avoid adding the charcoal in one portion, as frothing will occur. Filter with suction, and wash the residue with 5 ml of hot water. Place the filtrates in a small beaker, cool, and acidify cautiously with dilute hydrochloric acid. Cool to 10° for 15 minutes, and filter the crystals. Wash the crystals with a few milliliters of cold water, and dry. If the product is colored it is purified by dissolving in dilute sodium hydroxide, heating with a small amount of charcoal, and precipitating the acid, after filtration, as above. The crystalline form of the acid prepared in this manner is the monohydrate, and melts at 94.5°. It can be used directly for Experiment 64.

(B) Preparation of *o*-Benzoylbenzoic Acid (M.). Use the same procedure as in section (A). Arrange a 500-ml round-bottom or Florence flask as shown in Figure 46, without the separatory funnel. Add the aluminum chloride in small portions through the top of the condenser, raising the cork momentarily. Use 15 to 20 times the amount of reagents given in section (A).

Experiment 64

PREPARATION OF ANTHRAQUINONE BY RING CLOSURE

Introduction. Anthraquinone may be prepared by direct oxidation of anthracene with chromic acid. The hydrogen atoms at positions 9 and 10 are more reactive and are oxidized. Most of the anthraquinone used industrially for the preparation of alizarine is prepared from *o*-benzoylbenzoic acid. When this acid is heated with concentrated sulfuric acid at about 100° dehydration takes place with ring closure:



o-Benzoylbenzoic acid Anthraquinone

The hydrogen atom in the ortho position to the carbonyl group unites with the hydroxyl group of the carboxyl to effect the ring closure. The preparation of *o*-benzoylbenzoic acid from benzene and phthalic anhydride (Experiment 63) and the dehydration of this keto acid to anthraquinone considered in the present experiment illustrate the building up of polynuclear compounds from simpler benzene derivatives.

As mentioned in the preceding experiment, derivatives of benzene may be used to combine with phthalic anhydride, thus forming substituted benzoylbenzoic acids. For example, chlorobenzene yields chlorobenzoylbenzoic acid. Substituted phthalic anhydrides may be employed in place of phthalic anhydride. These substituted benzoylbenzoic acids are important intermediates in the preparation of anthraquinone vat dyes.

(A) **Preparation of Anthraquinone** (Sm.). Place in an eight-inch test tube or a small Erlenmeyer flask 3–4 g of *o*-benzoylbenzoic acid, and add 5 ml of concentrated sulfuric acid for each gram of the keto acid. Heat in a steam or water bath for 1 hour. Stir gently with care, using a glass rod which has a rounded end to avoid scratching the tube, until the solid dissolves. Remove the tube from the bath and allow it to acquire the temperature of the room. Pour the mixture slowly into 50–75 g of ice and an equal amount of water. Filter the precipitated anthraquinone, and wash twice with water, then with 4 ml of water and 1 ml dilute sodium hydroxide, and finally with warm water. The crude anthraquinone may be purified either by sublimation or by recrystallization from 100 ml of glacial acetic acid. For this purpose use a 250-ml Erlenmeyer flask provided with a two-hole stopper, one hole for the micro condenser and the other for a short piece of glass tubing to condense any vapors which may escape and also for the purpose of having an open system. Add two clean boiling stones, and heat by means of a small flame until the solid is dissolved. Place a mat of glass wool in a small glass funnel, and use a well-ventilated hood. Filter the hot acid solution, using caution, as the acid vapors are irritating to the respiratory membranes and inflammable. Cool the solution to 20°, filter the crystals, and dry on a watch glass in the hood or dessicator. The yield is about 3 g.

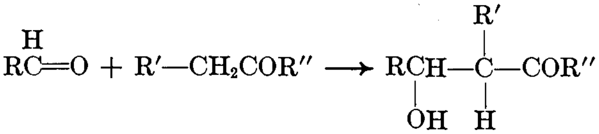
Experiment 65

CONDENSATIONS OF CARBONYL COMPOUNDS

(Preparation of Benzalacetophenone, Benzoin, and Cinnamic Acid)

NOTE: The directions for the experiments are for semimicro work. For macro work, use five times the quantities given; instead of an eight-inch tube, use a 250–500 ml flask, a Liebig condenser instead of a micro condenser, a distilling flask instead of a distilling tube. Use the same directions and allow about 50 per cent more time.

Introduction. The preceding experiments illustrated a type of reaction which is often referred to as a *condensation*. The term condensation is used in a general manner at times to designate any reaction which involves a union of one carbon atom to another. The term is also used in a restricted manner to designate certain types of reactions in which more complex substances are obtained from one or two simpler substances, usually accompanied by elimination of water or another simple inorganic compound. As previously noted in connection with Experiment 34, aldehydes and ketones react with other aldehydes, acids, esters, and amines, and give rise to more complex substances. Many of these reactions are named after the investigator or with reference to the product, followed by the word condensation, synthesis or reaction. Thus we have *Claisen condensation*, *Perkins synthesis* or *reaction*, *Schiff's reaction*, *Knoevenagel reaction*, *benzoin condensation*, *aldol condensation*, *Cannizzaro reaction*, *Tischtschenko reaction*, and other names. This practice is rather unfortunate, for it leads to the erroneous conclusion that there is little relation between these reactions. A careful study will disclose that many of these reactions involve union (*a*) of aldehydes with other aldehydes or ketones; (*b*) of aldehydes and acids; (*c*) of aldehydes and esters. Therefore, all these reactions are essentially reactions which involve *union of the carbonyl group of one molecule with a carbon atom of another molecule which is situated in an α-position to another carbonyl or a carboxyl*;



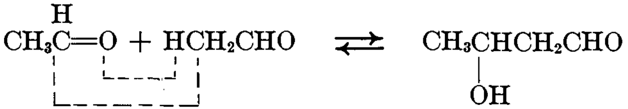
$$\overset{H}{RC}{=}O + R'{-}CH_2COR'' \longrightarrow \underset{OH}{RCH}{-}\overset{R'}{\underset{H}{C}}{-}COR''$$

(R″=H, OH, or a radical)

The general equation above merely indicates the beginning. The ultimate direction depends on the environment, temperature, catalyst nature of the aldehyde, and other factors.

Though the use of special names is considered unfortunate from the point of view expressed above, the usage is widespread in chemical literature, and the student will do well to get acquainted with the specific application of each. The most important are:

(1) **Aldol Condensation.** This involves the reaction between two molecules of an aldehyde or a molecule of aldehyde and ketone, having α-hydrogen. The reaction is catalyzed by many weakly alkaline salts.



$$\underset{\text{Acetaldehyde}}{CH_3\overset{H}{C}{=}O + HCH_2CHO} \rightleftharpoons \underset{\text{Aldol}}{CH_3\underset{OH}{CH}CH_2CHO}$$

Acetaldehyde Aldol

The reaction represented by the equation is the first step, which is reversible. Loss of water by the hydroxyaldehyde results in an unsaturated compound.

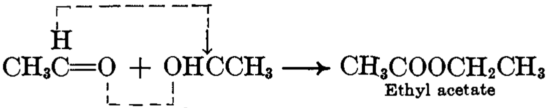
$$\underset{\text{Aldol}}{CH_3CHOHCH_2CHO} \xrightarrow[Al_2(PO_4)_3]{\text{Heat}} \underset{\text{Crotonic aldehyde}}{CH_3CH{=}CHCHO} + H_2O$$

A similar reaction may occur between an aldehyde and a ketone to form an unsaturated ketone.

$$\underset{\text{Benzaldehyde}}{C_6H_5CHO} + \underset{\text{Acetophenone}}{C_6H_5COCH_3} \longrightarrow \underset{\text{Benzalacetophenone}}{C_6H_5CH{=}CHCOC_6H_5} + H_2O$$

This latter reaction is sometimes called *Claisen condensation.*

(2) **Tischtschenko Reaction.** This involves the reaction between two molecules of an aldehyde which may or may not have α-hydrogen, accompanied by oxidation of one carbonyl to carboxyl and the reduction of the other carbonyl to alcohol. The product is an ester. The reaction is catalyzed by alkoxides.



$$\underset{\text{Acetaldehyde}}{CH_3\overset{H}{C}{=}O + OH\overset{\downarrow}{C}CH_3} \longrightarrow \underset{\text{Ethyl acetate}}{CH_3COOCH_2CH_3}$$

Acetaldehyde Ethyl acetate

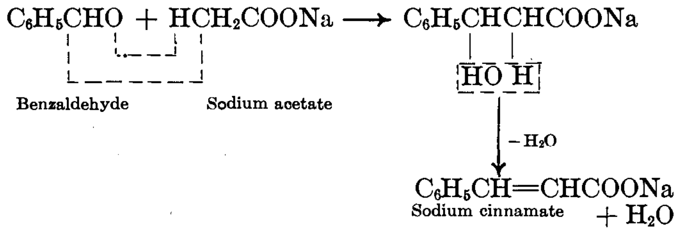
(3) **Cannizzaro Reaction.** This involves the reaction between two molecules of aldehyde having no α-hydrogen. The first step may be the formation of an ester as above, followed by hydrolysis. Both reactions are essentially oxidation of one carbonyl to carboxyl and reduction of the other carbonyl to alcohol. The two carbonyl carbon atoms serve as oxidant and reductant. The reaction is catalyzed by strong alkali.

$$\underset{\text{Benzaldehyde}}{2\ C_6H_5CHO} + NaOH \longrightarrow \underset{\text{Benzyl alcohol}}{C_6H_5CH_2OH} + \underset{\text{Sodium benzoate}}{C_6H_5COONa}$$

(4) **Benzoin Condensation.** This involves the reaction of two molecules of aromatic aldehyde having no α-hydrogen with the formation of an α-hydroxyketone. The reaction is catalyzed by cyanide ion.

$$\underset{\text{Benzaldehyde}}{2\ C_6H_5CHO} \longrightarrow \underset{\text{Benzoin}}{C_6H_5CHOHCOC_6H_5}$$

(5) **Perkins Reaction.** This involves the reaction between an aromatic aldehyde and a carboxylic acid having α-hydrogen. The reaction is catalyzed by acid anhydrides.



$$\underset{\text{Benzaldehyde}}{C_6H_5CHO} + \underset{\text{Sodium acetate}}{HCH_2COONa} \longrightarrow \underset{HO\ H}{C_6H_5CHCHCOONa} \xrightarrow{-H_2O} \underset{\text{Sodium cinnamate}}{C_6H_5CH{=}CHCOONa} + H_2O$$

(6) **Knoevenagel Reaction.** This involves the reaction of an aldehyde with malonic ester or β-keto esters. The reaction is catalyzed by amines.

$$\underset{\text{Benzaldehyde}}{C_6H_5CHO} + \underset{\text{Malonic ester}}{CH_2(COOC_2H_5)_2} \longrightarrow \underset{\text{Benzalmalonic ester}}{C_6H_5CH{=}C(COOC_2H_5)_2} + H_2O$$

The object of this experiment is to illustrate a few of the above reactions.

(A) **Preparation of Benzalacetophenone** (**Sm.**). Place in an eight-inch tube a solution of 1 g of sodium hydroxide in 8 ml of water and 6 ml of alcohol. Cool in an ice-salt mixture. Add 2.6 g of acetophenone (2.6 ml); shake well, and immerse again in the cold bath. Add 2.3 g (2.2 ml) of freshly distilled pure benzaldehyde, close tube with a solid rubber stopper, and shake vigorously. Allow to stand at room temperature for one hour, shaking vigorously at intervals, and keeping the temperature at 20–25° by cooling. Heat the mixture to 60° for 20 minutes, then cool to about 5°. Filter the product with suction, and wash several times with water until the washings are free from alkali. If a pure product is desired, recrystallize from alcohol. The yield is about 2 g.

(**B**) **Preparation of Benzoin** (**Sm.**). Arrange an eight-inch tube for reflux. Place in the tube 5 ml (5.2 g) of freshly distilled benzaldehyde and 6 ml of alcohol. Add a solution of 0.5 g of sodium cyanide in 4–5 ml of water. (**Caution:** Use extra care in weighing and dissolving the cyanide. Use the hood. In washing the beaker which contained the cyanide rinse first with 2 ml of sodium hydroxide solution, and use a large volume of water for washing it in the sink.) Boil the mixture gently on a water bath for 20 minutes. Pour the solution into a beaker, and cool. Filter the mass of crystals, and wash several times with water. Drain well, and dry. The yield is about 4 g. If a pure product is desired, recrystallize from 35–40 ml of hot alcohol.

(**C**) **Preparation of Cinnamic Acid** (**Sm.**). Arrange an eight-inch tube with an air reflux condenser made of a glass tube 6 mm in diameter and 350 mm in length. Place in the tube 5 ml (5.2 g) of freshly distilled benzaldehyde, 7 ml of acetic anhydride, two boiling stones, and 2.5 g of freshly fused and finely pulverized sodium acetate. (For preparation of anhydrous sodium acetate, see page 354.) Heat the mixture in an oil bath at 170–180° for 4 hours. In the beginning the temperature may be kept at 150–160° for one-half hour. When the reaction is complete, add the contents of the tube while hot to 30 ml of water in a beaker, and stir. Add small amounts of solid sodium carbonate until the reaction of the solution is just alkaline. Filter rapidly, and wash the residue with a few milliliters of hot water. Cool the filtrate, and extract the unchanged benzaldehyde with 10 ml of ether. Withdraw the aqueous layer and reject the ethereal solution (place in the proper bottle). Add 0.3 g of charcoal, stir, and filter. Acidify the solution with dilute hydrochloric acid. Cool, filter with suction, and wash the crystals with small portions of cold water. The yield is about 3–4 g. If the product melts lower than 133°, recrystallize from hot water.

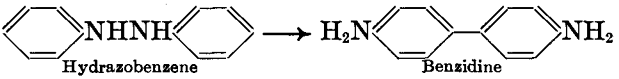
Experiment 66

THE BENZIDINE REARRANGEMENT

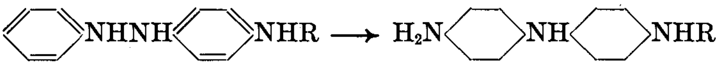
NOTE: The directions are designed for semimicro work. For macro use five times the amounts given.

Introduction. In the preparation of organic compounds a large number of reactions are employed. All of these may be grouped as follows: (1) replacement within a molecule of one group by another; (2) union of two or more simpler molecules to form a larger one; (3) disruption of a larger molecule to form smaller ones. Another method is to cause a rearrangement of the atoms within a molecule and thus obtain a different substance than the original. The classical synthesis of urea from ammonium cyanate is an example of this type of reaction. The object of this experiment is to illustrate the preparation of an organic compound by employing a reaction involving a molecular rearrangement. Only the type illustrated by this experiment will be discussed. The various types of molecular rearrangements are many and the student is referred to an advanced text for a complete list.

The benzidine rearrangement involves the action of strong mineral acids on hydrazobenzene to form 4,4′-diaminodiphenyl, or benzidine.



As shown by the above equation, the rearrangement involves rupture of the N–N bond and rotation of the radicals. Another method of stating the rearrangement (which makes no assumption as to the mechanism) is that it involves a migration of the amino to the *para* positions. When these positions are occupied by another group an incomplete arrangement, called *semidine* rearrangement, takes place.



Other rearrangements closely related to this type are those reactions in which there is a migration of amino groups (or atoms attached on the amino group) to the *para* position. The following serve as examples: *diazoaminobenzene* to p-*aminoazobenzene*; *phenylhydroxylamine* to p-*aminophenol*; *acetanilide* to p-*aminoacetophenone*.

Among the important molecular rearrangements are the following: (*a*) pinacol-pinacolone, involving the change of a substituted 1,2-glycol to a ketone; (*b*) benzil-benzilic acid, involving the change of an aromatic diketone to a hydroxy acid; (*c*) Beckmann rearrangement, which involves the change of an oxime to a substituted amide.

The object of this experiment is to prepare hydrazobenzene, rearrange it to benzidine, and finally eliminate the two amino groups to form biphenyl.

(A) Preparation of Benzidine (Sm.). Prepare about 2 g of hydrazobenzene according to Experiment 30. Dissolve in a small flask 2 g of hydrazobenzene in 15 ml of ether. Place 8 ml of concentrated hydrochloric acid and 8 ml of water in an eight-inch test tube and provide with solid rubber stopper. Cool in an ice-salt mixture. Add the ethereal solution slowly by means of a dropper to the cold diluted acid, and shake vigorously after each addition. When all the hydrazobenzene solution has been added, allow to stand 10 minutes, and add 10 ml of concentrated hydrochloric acid. Allow the tube to remain in the cold bath 15 minutes longer. Filter the benzidine hydrochloride with suction. Wash the crystals with 5 ml of dilute (1:1) hydrochloric acid and finally with two 5 ml portions of ether, and dry on a paper disc. The yield is about 2 g.

If the hydrochloride is not used for the preparation of biphenyl it may be converted to the free base by neutralization. Dissolve the salt in about 100 ml of hot water to which a few drops of hydrochloric acid have been added. Filter the solution, cool to about 20°, and add 20–25 ml of 10 per cent sodium hydroxide. Cool to 10°, filter with suction, and wash with water. The yield is about 1 g. If a very pure product is desired, recrystallize from hot water or alcohol.

(B) Reduction of Benzidine to Biphenyl (Sm.). Place in a small beaker (150 ml) 2 g of benzidine hydrochloride, 10 ml of water, and 4 ml of concentrated hydrochloric acid. Cool to 0° and add 5 g of ice and a solution of 1.1 g of sodium nitrite dissolved in 5 ml of water. Stir until the diazotization is complete, that is, until all the material has dissolved, and a test with iodide paper shows presence of nitrous acid. Add 15 ml of ethyl alcohol, and sift in 5 g of zinc dust, in small portions over a period of 5 minutes, stirring after each addition. Remove the beaker from the ice bath and allow to stand for an hour, stirring from time to time. Do not allow the temperature of the solution to rise above 30°. The reduction can be considered complete when the mixture has changed from red and become colorless. Cover the beaker with a watch glass, and allow the mixture to stand overnight. Boil gently for a minute, and filter while hot. Wash the zinc oxide with 10 ml of hot alcohol. Allow the filtrate to cool, and then slowly add an equal volume of water. Cool in an ice bath, and filter the crystals. The crude biphenyl can be crystallized from alcohol. The yield is about 0.5 g.

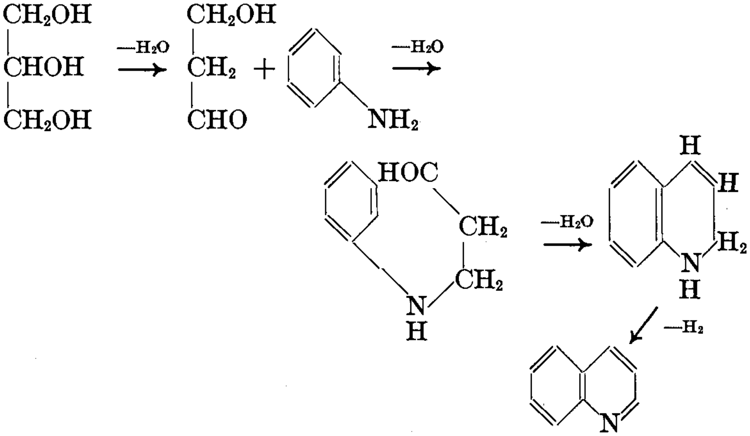
Experiment 67

PREPARATION OF HETEROCYCLIC COMPOUNDS

QUINOLINE

NOTE: The yields obtained by the macro method are far better than those obtained by the semimicro procedure.

Introduction. Quinoline is a heterocyclic compound containing a pyridine ring fused with a benzene nucleus. In Skraup's method, used in this experiment, the starting point is aniline and glycerol. These, when heated with nitrobenzene and sulfuric acid, react vigorously to form quinoline. One method of explaining this reaction is to assume that sulfuric acid acts on glycerol to form 3-hydroxypropanal which reacts with aniline to form a partially reduced quinoline, and this by dehydrogenation gives quinoline.



Nitrobenzene acts as an oxidizing agent, and is reduced to aniline. After the reaction is completed the mixture is steam-distilled. The distillate contains water, aniline, and quinoline, with smaller amounts of impurities.

Aniline cannot be separated from quinoline by distillation. Both form salts and therefore cannot be separated by means of acids.

Several chemical methods are used. In one method the mixture of aniline and quinoline is acylated either with acetic anhydride or with sulfochloride. The aniline forms a derivative and the quinoline remains unaffected. A second method treats the mixture with sodium nitrite and sulfuric acid. The aniline is converted into the diazonium salt and the quinoline forms the sulfate. The solution is made alkaline and steam-distilled; the diazonium salt changes to sodium phenoxide, and quinoline is distilled. In the third method, the mixture is separated by means of hydrochloric acid and zinc chloride. Quinoline chlorozincate, $(C_9H_7N)_2H_2ZnCl_4$, is sparingly soluble in water and is separated from the soluble aniline salt.

The Skraup synthesis can be used with a number of substituted arylamines. *p*-Toluidine forms 6-methylquinoline and *o*-toluidine 8-methylquinoline. Both quinoline and pyridine are cyclic tertiary amines and react with acid to form salts (pyridinium and quinolinium salts) and with alkyl halides to form quaternary salts.

(**A**) **Preparation of Quinoline** (**Sm.**). Arrange a 250-ml Erlenmeyer flask with a two-hole cork. Through one hole fit a micro condenser and through the other a glass tube 6–8 mm in diameter and 500–600 mm in length. Place the flask on the pan of a trip balance and weigh successively, in the order named, 2 g of finely pulverized ferrous sulfate, $FeSO_4.7H_2O$, 20 g of anhydrous glycerol, 6.0 g of redistilled aniline, and 4 g of redistilled nitrobenzene. Mix the reagents thoroughly, place the flask near the condenser, and add slowly, with shaking, 10 ml of concentrated sulfuric acid. Add two boiling stones and connect at once with the condenser.

Heat the flask cautiously over a wire gauze. As soon as the first sign of boiling appears, remove the flame at once, and allow the reaction to proceed for 10 minutes. When the vigorous reaction has subsided, boil for 2.5 hours. Cool, and add 30 ml of water and a solution of 20 g of sodium hydroxide in 25–30 ml of water. Add the sodium hydroxide very slowly by means of a long funnel. Steam-distill the mixture (Figure 48) until about 150 ml of distillate has been collected and no drops of oil pass over. As each 50 ml of distillate is collected in an Erlenmeyer flask, it is extracted with two 15-ml portions of ether. The combined ether extracts are placed in a 250-ml Erlenmeyer flask and distilled to recover the ether. Use the Erlenmeyer flask for a boiling flask and an eight-inch tube fitted with a micro condenser as a receiver. Dissolve the residue in a mixture of 10 ml of concentrated hydrochloric acid and 20 ml of water. Warm to 50°, and add a solution of 6 g of zinc chloride in 4 ml of 6 *N* hydrochloric acid and 6 ml of water. Stir well, cool, and allow to stand for 15 minutes. Filter the salt with suction, and wash with a small amount of very dilute hydrochloric acid. Transfer the quinoline salt into an eight-inch tube with 5–6 ml of water, and add slowly a solution of 6 g of sodium hydroxide in 8 ml of water. The precipitate of zinc hydroxide which forms at first redissolves as sodium zincate. Extract the quinoline with two 10 ml portions of ether. Dry the ethereal solution with 1–2 g of sodium hydroxide pellets. Transfer the dry ethereal solution into an eight-inch distilling tube and distill the ether from a water bath. Remove the water bath, change the receiver, and heat by a small luminous flame. Collect the portion which boils at 234–238°. The yield is about 3–4 g.

(**B**) **Preparation of Quinoline** (**M.**). The results are generally better by the macro method. Use five times the amount of reagents, and a 500-ml reaction flask. The condenser should be very efficient. Use same precautions given for the micro method in starting the reaction, and allow it to proceed without external application of heat for 15–20 minutes. Boil for four hours. Transfer the mixture to a two-liter Florence flask for steam distillation. Steam-distill until about 1500–1700 ml of distillate has been collected. Use three 60-ml portions of ether with a separatory funnel to extract the distillate, and for the remainder of the experiment proportionate amounts of reagents. After the final extraction and recovery of ether use a small flask for the final distillation. If a vacuum pump is available, use a small Claisen flask and distill under diminished pressure. Collect the fraction which boils at 116–122° at 20 mm pressure.

(**C**) **Tests for Properties of Pyridine and Quinoline.** (1) To 5 ml of water add 2 drops of pyridine and a long range indicator, and note the *p*H. Repeat, using quinoline.

(2) Place 5 drops (0.3 ml) of pyridine in a test tube. Place a thermometer in the tube, and add 5 drops of methyl iodide. Considerable heat is evolved, and the quaternary salt separates on cooling. In another tube repeat the test with quinoline. The quaternary salts may be recrystallized from 4–5 ml of alcohol and filtered. The pyridinium salt melts at 117° and the quinolinium at 72°.

(3) To 4 ml of water and a drop of the base add a drop of ferric chloride solution. Observe any change.

(4) To 2 ml of dilute hydrochloric acid and 1–2 drops of the base add a few crystals of sodium dichromate. Quinoline forms a sparingly soluble dichromate.

Experiment 68

PHYSIOLOGICALLY ACTIVE COMPOUNDS

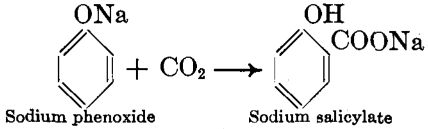
Introduction. Strictly speaking, all foreign substances, including foods, act on the human body with some physiological activity, though many times this cannot be measured accurately. The term *physiologically active compounds* is used here in a restricted sense to designate substances which, when taken internally in amounts of one gram or less, have a *pronounced* physiological action. For example, 300 milligrams of acetanilide taken internally has a pronounced effect in diminishing pain and body temperature in fever. When 50 milligrams or less of ethyl-*p*-aminobenzoate is placed on the tongue, the latter is benumbed and a temporary local anesthesia results. One milligram of *o*-sulfobenzoic imide placed on the tongue produces about the same effect as 500 milligrams of sugar.

The knowledge of the relationship between molecular groups in an organic compound and the physiological activity is still in its infancy. In spite of this, the contributions of the organic chemist in this field have been tremendous. Sometimes by accident, and many times by deliberately planned experiments, an observation is made which indicates that a particular compound has certain desirable properties. The position of the various groups present in the molecule is changed, and related compounds are prepared one after the other, each being tested for an increase or decrease of the desirable properties. In this manner, out of thousands of compounds prepared during the past fifty years, a few have found permanent application in safeguarding health, alleviating pain, and combatting disease. The many thousands of the other compounds are recorded in the literature and thus form the heritage of our chemical knowledge. Progress in organic chemistry would have been extremely slow if this knowledge (which to the layman may appear as useless) had been lost.

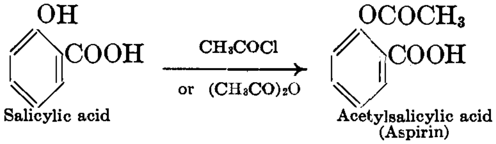
The object of the present series of experiments is to give directions for the preparation of a few of the better known organic compounds which possess pronounced physiological activity. The semimicro method is used throughout, but it can be easily adapted to the macro method by multiplying the quantities given by 4 or

5 times, using flasks instead of tubes, and allowing 50 per cent more time for the reaction.

(A) **Acetylsalicylic Acid (Aspirin).** Salicylic acid and its derivatives were among the first synthetic organic compounds to be used for therapeutic purposes. The sodium salt of salicylic acid, the methyl and phenyl esters, and the acetyl derivative of salicylic acid are extensively used to diminish pain (as *analgesics*) and to reduce the temperature of the body (as *antipyretics*). The most widely used is the acetyl derivative which is sold under the name *aspirin*. Salicylic acid is prepared industrially by the carbonation of sodium phenoxide, at 180–200° at atmospheric pressure or 120–130° at a pressure of a few atmospheres.



Acetylsalicylic acid is prepared by acetylation of the hydroxycarboxylic acid. Acetic anhydride or acetyl chloride may be used for the acetylation.

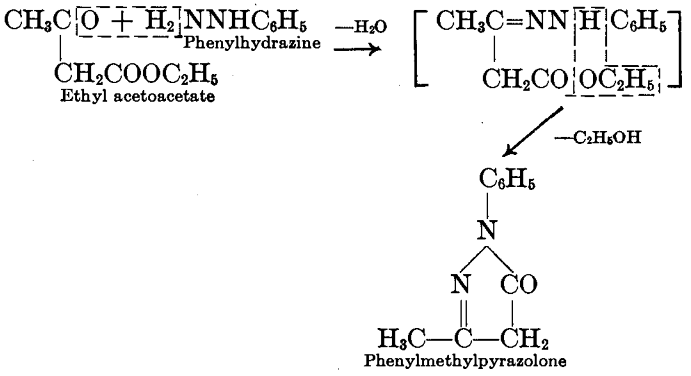


Directions are given for both methods. The acetyl chloride method is more rapid but at the same time more expensive.

(1) Place in an eight-inch tube 3 g of salicylic acid, 4 ml of glacial acetic acid, 4 ml of acetic anhydride and two boiling stones. Arrange a micro condenser for heating under reflux. Heat with a small luminous flame, and boil the mixture gently for 45 minutes. Remove the flame, cool slightly, and pour the reaction mixture, with vigorous stirring, into 100 ml of water. Cool to 5–10°, and allow to stand for 15 minutes. Filter the crystals, and wash several times with water. Press the crystals to drain the water as much as possible, and transfer to a beaker for crystallization. Add 20 ml of methanol or ethanol, and heat in the water bath until the crystals are dissolved, adding more alcohol if necessary. Add 0.2 g of charcoal and a pinch of Super-cel, and filter. Add water to the filtrate slowly, with stirring, until a permanent cloudiness appears. Cool, and then add 50 ml of water. Filter the crystals, wash with water, and dry on a paper disc. The yield is 2.5–3.0 g.

(2) The reaction should be performed in a hood. Place in an eight-inch tube 3 ml of pyridine. Insert a thermometer in the tube, and clamp securely in a stand. Weigh 3 g of finely powdered salicylic acid, and place in a dry tube. Place in a small beaker 3 ml of acetyl chloride, and cover the vessel with a watch glass. Place the beaker on a wire gauze resting on a ring stand so that the mouth of the beaker is flush with the mouth of the tube. Add the salicylic acid to the pyridine and stir for 30 seconds. Remove the watch glass from the beaker containing the acetyl chloride. With a dropper add a few drops of acetyl chloride, then stir. Continue the addition slowly, noting the temperature. Cool by raising a beaker of cold water under the tube if the temperature rises above 50°. When all the acetyl chloride has been added, place the tube in a steam bath and heat for 3–4 minutes. Add to the reaction mixture 1 ml of water, drop by drop, then 5 ml of alcohol. Pour, with vigorous stirring, into 100 ml of cold water, and allow to stand for 15 minutes. Filter the crystals, and wash several times with water. Purify the crude crystals as directed in section (1). The yield is 2.5–3 g.

(**B**) **Phenyldimethylpyrazolone** (**Antipyrine**). This compound, as its common name indicates, is an *antipyretic*, which means that it reduces the body temperature in fever. It exerts also a strong analgesic effect, and is used as a sedative in disturbances accompanied by pain. It is prepared by condensation of ethyl acetoacetate with phenylhydrazine. The first product is a phenylmethyl pyrazolone.



The keto ester exhibits typical carbonyl properties, and reacts first with phenylhydrazine to form a phenylhydrazone shown in the above equation in brackets. The phenylhydrazone on heating loses a molecule of alcohol and forms the heterocyclic pyrazolone. The hydrogen atom attached to the nitrogen is reactive, and when the compound is heated with methyl iodide it is replaced by a methyl group forming the dimethyl derivative.

NOTE: The student may choose the preparation of the pyrazolone without the methylation step. This reaction involves heating the mixture in a sealed glass tube under pressure. In case a bomb furnace is not available, directions are given so that heating of the small bomb-tube may be performed in a five-gallon can containing boiling water (in a hood). The procedure as described is considered safe provided reasonable precautions are taken. If the tube explodes (not an uncommon behavior of sealed glass tubes when heated) the damage consists only in throwing a spray of water in the hood or tilting the bath.

(1) **Phenylmethylpyrazolone.** Place in a small evaporating dish (50 ml) 4 g of phenylhydrazine and 5 g of ethyl acetoacetate. Cover the dish with a watch glass and place on a 250-ml beaker containing water, with a few boiling stones. Place the beaker and dish in the hood and boil gently for one hour, stirring the oily mixture from time to time. Allow the mixture to cool, and add 15 ml of acetone and 5 ml of ether. Stir, and cool in an ice-salt mixture for one hour. At the end of this period the syrupy mass should solidify. Using a small pestle, slowly grind the solid and transfer it to a micro suction funnel. Filter the mass, and wash with two 5 ml portions of ether. Recrystallize from water or from a mixture of 40 parts of alcohol and 60 parts of water. The pure compound melts at 127°. The yield is 4–5 g.

HEATING UNDER PRESSURE

(2) **Phenyldimethylpyrazolone.** Prepare a semimicro bomb tube as directed on page 360. Introduce into the tube 4 g of finely pulverized phenylmethylpyrazolone prepared according to directions given in the preceding paragraphs. Add 5 ml of methanol and 4 g of methyl iodide. Cool the tube by immersing in an ice-salt mixture. *Put on your goggles.* Then seal the tube as directed on page 361. Place in an upright position until the seal is at the temperature of the room. Wrap the tube tightly in a small piece of paper and twist the ends. If a bomb furnace is available, place the tube in the iron jacket with the capillary at the open end. Place the tube in the bomb furnace in accordance with instructions posted in the bomb furnace room. Place the thermometer in the top of the furnace. Raise the temperature gradually in about 20 minutes to 115–125° and adjust the heating so that the temperature does not

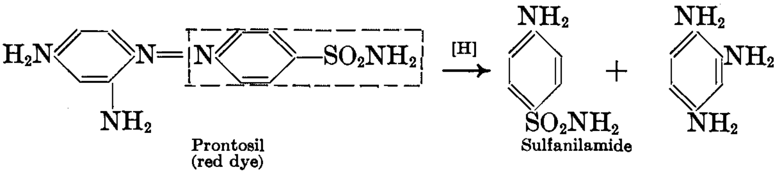
rise higher. Note the temperature every hour, and heat for eight hours. When cold, remove tube and open according to directions posted in the bomb room or as directed below.

If a bomb furnace is not available, place the wrapped tube in a piece of iron pipe one inch in diameter and 8–9 inches in length such as can be obtained from any hardware store. Stopper each end of the pipe with an old two-hole rubber stopper. Prepare a water bath from an empty five-gallon tin can. Remove the top with a can opener and hammer the edges inward. Wear canvas gloves while opening the can to guard against cuts. Place the can in the hood on four bricks so arranged that a flat burner will fit underneath. Put the pipe with the tube on the bottom of the can and add water until the level is above the three-quarter mark. As many as 20 tubes can be handled at one time. When more than one tube is to be heated, the short pieces of pipes are provided with metal tags with numbers stamped on the tag. Place a cover (wood or Transite) on top of the can, and heat the water to boiling. Adjust the flame so that the boiling is gentle and little steam escapes. Add water every 3–4 hours. No further attention need be paid unless the tube explodes. This usually happens if the seal was not made properly or a strain was placed on the glass in making the seal. If more than one tube explodes at the same time, the force of the explosion may be sufficient to displace and tilt the can slightly, so that the water may put the burner out. Should an explosion occur, the gas should be turned off and the bath inspected.

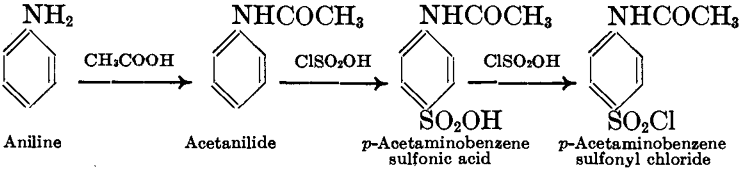
Heat the tube for a total of 15 hours. The heating is discontinued when there is no attendant in the laboratory and at night, and resumed the next day. The time is reckoned from the time when the bath reaches a temperature of 95–100°. Wear your goggles. Remove the pipe after the bath has cooled and the water drained. Holding it in a horizontal position, place it flat on the floor of the hood. Remove the rubber stoppers and with a rod gently push the tube so that the capillary just projects out of the pipe. Insert some crumpled paper at the other end and insert the stopper so that when the pipe is placed upright the end of the capillary protrudes about 10 mm above the mouth of the pipe. Clamp the pipe securely on an iron stand so that the lower end of the pipe dips into a liter beaker containing an ice-salt mixture. Heat the extreme end of the capillary by means of a strong pointed flame. If, on softening, the glass is not blown out, allow to cool for a minute or so and then touch the heated part by means of a wet piece of cotton wrapped at the end of a rod. If the upper end of the capillary does not crack, reheat and repeat the application of water. Knock off the cracked end of the capillary with a file. Allow the glass to cool, and remove the tube from the pipe.

Fit one end of a short piece of stout rubber tubing over the opening of the capillary, and connect the other end to the short arm of a glass tube bent as shown in Figure 39. The long arm of this glass tube fits through a two-hole rubber stopper into an eight-inch test tube that has a side arm. Through the other hole of the stopper fit a semimicro condenser. Put the bomb tube into a beaker containing warm water (30–35°) and apply suction at the side tube. The alcohol boils off under diminished pressure in 5–10 minutes. Disconnect the reaction tube, and with a file make a deep mark at the base of the capillary. By a quick stroke of the file knock off the capillary end so as to make the opening of the tube larger. By means of a wash bottle add 3–4 ml of water to the residue, and warm until it dissolves, adding more water if necessary. Add a piece of litmus paper to the solution and then, drop by drop, 6 *N* sodium hydroxide solution until an oil separates at the top and the reaction becomes slightly alkaline. Shake after the addition of each 2–3 drops, and avoid excess of alkali. By means of a small funnel add 5 ml of benzene, shake gently, and transfer the contents of the tube, completely and without loss, into a clean eight-inch tube. Wash the reaction tube with two 4-ml portions of benzene, and add washings to the main portion. Insert separatory stopper, shake contents gently for a few seconds, and then separate the benzene layer. Extract the aqueous layer again with two 5–6-ml portions of benzene. Unite the benzene solutions in one tube, add a small boiling stone, and reflux gently in a water bath for one hour. Decant the clear solution into another tube, and distill off the benzol until the volume of the solution is 5 ml. Place the solution in a beaker while hot, cover with a watch glass, and cool. If a considerable amount of material crystallizes on the sides of the tube while pouring, dissolve it in a minimum amount of benzene and add to the main portion. Filter the crystals with suction, press, and wash with a few drops of benzene. The yield is 2–2.5 g. The pure compound melts at 113°.

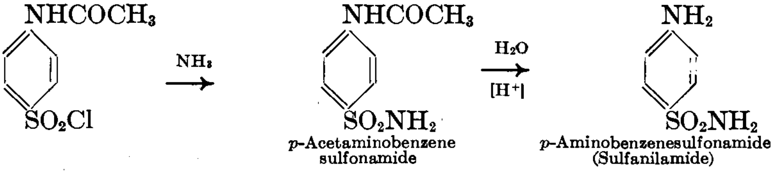
(C) **Sulfanilamide.** This compound is a recent addition to therapeutics from the synthetic organic compounds. It has found wide and successful application in the treatment of infectious diseases caused by streptococci and pneumococci. It was discovered as a result of observations on the activity of a red dye prepared from sulfanilic acid and *m*-phenylene diamine. Systematic work proved that the activity of the dye was due to its reduction product, *p*-aminobenzenesulfonamide, or sulfanilamide.



In considering the synthesis of this compound several alternatives are possible. Two will be considered. Aniline may be sulfonated to sulfanilic acid, and after acetylation the chloride may be prepared by the action of phosphorus pentachloride. The acyl chloride, on ammonolysis, will give the acetylated sulfonamide. The other possibility is to use chlorosulfonic acid and introduce the sulfo and chloro groups simultaneously. Aniline is acetylated, and the acetanilide is sulfonated with excess of chlorosulfonic acid. The sulfonic acid group is introduced first, and by further reaction the acid chloride is formed:



The sulfochloride is ammonolyzed to the amide and the acetyl group is removed by hydrolysis.



(1) **Acetanilide.** Prepare 6 g of acetanilide according to directions given in Experiment 52(A).

(2) ***p*-Acetaminobenzenesulfonyl Chloride.** Place 4 g of dry acetanilide in an eight-inch distilling tube. Heat until it melts, and cool for a minute in air and then by rotating in a beaker containing tap water. Arrange the tube as shown in Figure 53. Use a solid cork in place of a stopper with the condenser. Place a beaker containing ice water under the tube so that it is immersed in it. Pour into the tube, all at once, 10 ml of chlorosulfonic acid, and replace the stopper.

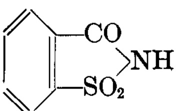
Caution: Be careful in handling chlorosulfonic acid, as it causes severe burns if it comes in contact with the skin.

If the reaction does not start at once, lower the ice bath, and introduce a rod in the tube and cautiously break the acetanilide adhering to the tube. Replace the cork, and use the cold bath to moderate the reaction if it is too vigorous. When most of the acetanilide has dissolved, place a beaker with water under the tube and heat at 80–90° for 15 minutes. Cool, and pour very slowly, with stirring, into a mixture of 50 g of ice and 50 ml of water. This operation should be performed *in the hood* and *goggles should be worn.* Rinse the reaction tube with 10 ml of water, and unite with the main portion. After 10 minutes filter the mass, breaking any lumps that may have formed. Wash with three 5 ml portions of water, press the cake to drain the water as much as possible, and use directly for the next preparation.

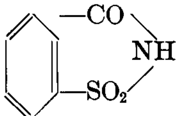
(3) ***p*-Acetaminobenzenesulfonamide.** Transfer the cake of crude chloride into an eight-inch tube, add 12 ml of concentrated aqueous ammonia, and stir the mixture with a glass rod. Place the tube in the hood and allow to stand for 15 minutes. Heat in a water bath to 60° for 15 minutes. Cool and filter the amide, washing with 5 ml of water. Press the cake well.

(4) ***p*-Aminobenzenesulfonamide.** Transfer the crude amide into an eight-inch tube arranged for heating under reflux. Add 3 ml of concentrated hydrochloric acid, 12 ml of water, and one or two boiling stones. Boil gently for 30 minutes. Add 5 ml of water, 0.2 g of charcoal, and a pinch of Super-cel, and filter into a small beaker. Neutralize by adding slowly 3–4 g of sodium bicarbonate until the mixture is just neutral to litmus. Aqueous ammonia or ammonium carbonate may be used for the neutralization. Cool in an ice bath, and filter the crystalline *p*-aminobenzenesulfonamide. Wash the crude product with a few milliliters of water, press, and transfer the cake into a small beaker. Add 30 ml of water and heat to boiling, adding more water if necessary, until the solid is completely dissolved. Stir into the hot solution 0.1 g of charcoal and a pinch Super-cel. Filter through a Bunsen funnel which has been heated by passing through a fluted filter paper about 50 ml of hot water. Collect the filtrate in a small beaker. Cover the beaker with a watch glass, and cool in an ice bath for 20 minutes. Filter the needle-like crystals with suction, and wash with the minimum amount of cold water. Place on a paper disc to dry. The melting point of the pure substance is 163–164°. The yield is about 2.5 g.

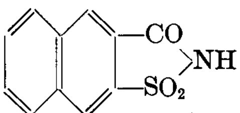
(D) **Saccharin.** If one is asked why sugar is sweet, the obvious answer would be, "It is the nature of the substance to be sweet. A dog barks and, when provoked, bites, and in the same manner sugar is sweet and quinine bitter." If, however, we consider the difference in the physiological action of *o*-sulfobenzoic imide and its *para* isomer, the above answer is not very satisfying.



o-Sulfobenzoic imide
(very sweet)



p-Sulfobenzoic imide
(tasteless)

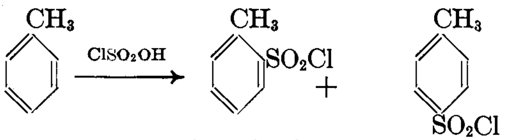


1-Sulfo-2-naphthoic imide
(bitter)

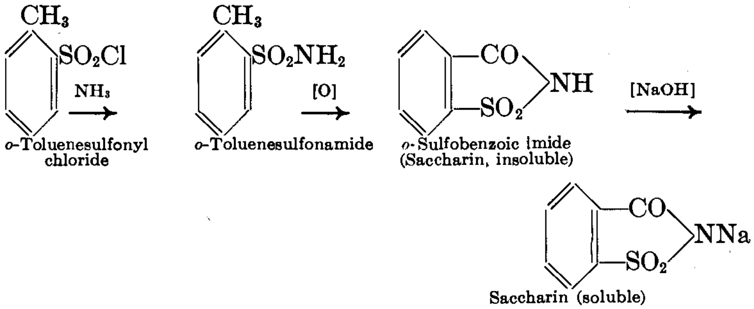
The ortho compound is over 500 times sweeter than sugar and the *para* isomer tasteless. If a methyl group is introduced in the *ortho*-isomer the sweetening power decreases to about one-half. The analogous compound of naphthalene (1-sulfo-2-naphthoic imide) is distinctly bitter. Unfortunately there is no adequate theory to account for this striking variation in properties.

Saccharin is prepared industrially and is used as a sugar substitute. It should be made clear, however, that in substituting saccharin for sugar only the taste stimulus is involved. Sugar is an energy-producing food, while saccharin has no food value. In small doses it is non-toxic and exerts a mild antiseptic action. Saccharin was discovered in 1879 by an American research student, C. Fahlberg, while working with Ira Remsen at Johns Hopkins University. Fahlberg was struck by the sweet taste of his food. On investigation this was traced to material adhering to his hands carried from the laboratory where he was working on the preparation of *o*-sulfobenzoic amide. The present experiment illustrates one of the methods used in the preparation of saccharin.

Tolúene is first treated with chlorosulfonic acid to form *o*- and *p*-toluenesulfonyl chlorides, which are separated. The *o*-sulfonyl chloride is then treated with ammonia to form the amide and finally the methyl group is oxidized to the carboxylic acid. The carboxyl and the amino groups are reacted to form a cyclic imide:



Toluene *o*-Toluenesulfonyl chloride *p*-Toluenesulfonyl chloride



The use of chlorosulfonic acid illustrates one method by which the direction of sulfonation is altered. It will be recalled (page 289) that the usual method of sulfonation gives a preponderance of the *para* isomer.

(1) **o- and p-Toluenesulfonyl Chlorides.** Place 30 g (19–20 ml) of chlorosulfonic acid in an eight-inch tube and immerse the tube in an ice bath. (**Caution:** Use care in handling chlorosulfonic acid, as it causes severe burns if it comes in contact with the skin.) When the temperature is 0° add dropwise, with a dropper, 6 g of toluene, and stir with a thermometer. The temperature is not allowed to rise above 50°. After all the toluene has been added, stir the mixture from time to time for 4 hours. Keep the tube in the ice bath and allow the temperature to rise slowly to 5°, but do not let it rise above this temperature.

The product of the reaction is a mixture of *o*-sulfonyl chloride, which is an oil, and the *para* isomer, which melts at 67°. Pour the reaction mixture *very slowly* and *cautiously* into a beaker containing 50 g of ice and 50 ml of water. Keep the mixture at a temperature of 15° for 10 minutes, then decant the supernatant liquid, consisting of water and the oily *o*-sulfonyl chloride. Filter the *para* isomer and add the filtrates in the tube. Add 5–6 ml of ether, and with the separatory tube remove the aqueous layer.

(2) **o-Toluenesulfonamide.** The solution containing the *o*-toluenesulfonyl chloride is arranged for distillation and most of the ether is removed. Do not heat above 40°. A better procedure is to remove the ether by connecting the tube with a water-suction pump. Cool the tube in an ice-salt mixture and add, drop by drop, 5 ml of concentrated aqueous ammonia. Allow to stand in the cold for about five minutes, then heat at 40–50° for 10 minutes. Filter the crude *o*-toluenesulfonamide, and dissolve the crystals in 6 ml of water and 6 ml of 6 *N* sodium hydroxide. Add 0.3 g of charcoal and a pinch of Filter-cel. Stir the solution for a few minutes, and

filter with suction. Place the filtrate in a beaker, wash the residue and filter tube with a small amount of water (1 or 2 ml), and unite with the amide portion of the filtrate. Precipitate the amide by adding slowly 5 ml of 6 *N* hydrochloric acid. Note that the amount of acid added is insufficient to neutralize all the alkali. This fractional precipitation removes any *para* isomer that may be present. Filter the pure amide, and dry on a paper disc. Neutralize the filtrate, and obtain a small amount of crude amide. Filter separately and dry. Determine the melting point to obtain information as to its purity. Outline a method for determining the approximate amounts of the two isomers. Pure *o*-toluenesulfonamide melts at 133°.

(3) ***o*-Sulfobenzoic imide.** Place 3.5 g of the *o*-toluenesulfonamide in an eight-inch tube. Add a solution of 1 g of sodium hydroxide in 25 ml of water, and place in a water bath at a temperature of 40–50°. Add slowly (a few crystals at a time) 5.1 g of potassium permanganate, and stir with a rod after each addition. Allow to stand for 10 minutes. Add a small amount of bisulfite until the color of any unused permanganate is discharged. Filter the manganese dioxide and acidify slowly with hydrochloric acid, until it is acid to methyl red. Filter any unchanged sulfonamide which separates at this point, and save the filtrate. Add 6 *N* hydrochloric acid slowly until all the saccharin is precipitated. Cool, filter, and wash with water. Dry on a paper disc. Place a minute amount on the tongue and note the effect.

Experiment 69

PREPARATION OF DYES AND INDICATORS

Introduction. Dyes are colored organic compounds which are able to impart their color to textile fibers or other materials in such a manner that the colored fiber is relatively stable (fast) to washing and light. One method of classifying dyes is on the basis of the particular atomic groupings (chromophore groups) present in their molecules, which are assumed to be responsible for the color properties. For example, all dyes which contain the N═N linkage are classified as azo dyes. Other classes of importance are: triphenylmethane, pyronines, phthaleins, anthraquinone and indigoid dyes.

Dyes are also classified on the basis of their application. The water-soluble dyes which are the salts of sulfonic acid or phenolic compounds are named *acid dyes*; those which are the salts of amino compounds are called *basic*. If the dyeing is accomplished without use of mordants the dyes are called *direct*. Dyes which require the use of metallic oxides, tannin, and other substances to give fast shades are called *mordant* dyes. The water-insoluble dyes are known as *vat* dyes. The insoluble colored substance is reduced in a fermentation "vat" or by hydrosulfite to a soluble form which is applied to the fiber then oxidized by air to the insoluble color. Finally *ingrain* dyes are produced by performing one or more of the chemical reactions used for the preparation of the dye directly on the fiber.

The simplest way of dyeing a fiber is by a direct dye. The dye is dissolved in water so that its concentration is about 0.02 to 0.1 per cent. The amount of dye depends on the weight of the cloth. For light shades the amount of dye is 0.05–0.3 per cent, and for deep shades 4–10 per cent, of the weight of the cloth. A small amount of sulfated alcohol soap is added to reduce the surface tension of the solution and thereby aid in the penetration of the dye. Inorganic salts are added to the dye bath, such as sodium chloride for cotton dyes and sodium sulfate for wool dyes, in amounts varying from 5 to 10 per cent. The fiber is steeped in the dye bath and heated at 80–100° until the proper shade has been attained, and then washed with water. For some basic dyes the practice is to steep the fiber after it is removed from the dye bath in a weak solution of acetic acid. After washing the fiber is dried. The object of this experiment is to illustrate the preparation of a few dyes, and also to prepare a few dyes which find extensive application in the laboratory as indicators.

SEMIMICRO CONSTANT-TEMPERATURE BATH

In the preparation of dyes it is often necessary to heat the reaction mixture 3–10 hours at a particular temperature, which may vary from 110° to 180°. The usual procedure of using oil baths is highly unsatisfactory. Whether the mixture to be heated is 5 or 100 g, an oil bath cannot be heated by a flame and adjusted to keep a constant temperature even within a range of 10°. The pressure of the gas in the main varies from hour to hour; a small flame is easily extinguished by drafts; these conditions, and the time required to watch the process, are difficulties which call for some other arrangement. The semimicro constant-temperature bath which is described has been used with satisfactory results for a number of years.

Use the semimicro water bath shown in Figure 2(*b*), page 13. Paint twice with sodium silicate the seam where the top fits on the main body of the bath, allowing the first coat to dry before the second coat is applied. After the second coat is dried, paint with one coat of lacquer or varnish. This forms a leak-proof joint. The top of the bath has one extra large, one large, and two small openings for ordinary heating of tubes and for the steam distillation setup. Stopper two of the small openings with solid corks, painting each with sodium silicate. In the large opening insert a cork with a hole carefully bored so that a six-inch tube fits snugly through it. Cut off the closed end of the six-inch tube by making a deep file mark 10 mm from the closed end and touching it lightly, with the hot end of a glass rod previously heated to fusion over a hot flame. Anneal the broken rim and allow to cool. Insert the broken end through the cork so that it protrudes 10 mm from its end. Place the cork in the large opening of the bath. Place a micro condenser loosely at the top opening of the glass tube to condense the vapors of the boiling liquid.

The extra large opening is fitted with a cork having a diameter of 45 mm or more at the top. A hole is bored through this large cork to fit an eight-inch tube which protrudes about 50 mm into the interior of the bath. In this manner the lower end of the tube is surrounded by the vapors of the boiling liquid within the bath. The cork is inserted into the extra-large opening, and painted with a coat of lacquer.

The liquid within the bath is determined by the temperature which is desired. For a temperature of 105–110° toluene is used; for 115–120° commercial *sec*-amyl alcohol is used; for 130–135°, chlorobenzene or xylene; for 180°, aniline. One hundred milliliters of the liquid is distilled, and the fraction which boils within 1–2° of the recorded boiling point is collected. About 60–80 ml of the liquid is sufficient since only a small amount is refluxing when in operation. A few boiling stones are added each time the bath is used. The complete setup of the bath as used for the preparation of dyes is shown diagrammatically in Figure 63. The bath is placed on an asbestos-centered wire gauze and heated by means of a small flame. However, since most of the liquids used are inflammable it is advisable, when the heating is to be done with little attention, to use a small electric plate. A hot plate 100 mm in diameter is commercially available at a cost of about $3.00–$4.00. The heating is adjusted so that there is a small constant condensation of vapors at the surface of the micro condenser. If the lowest adjustment on the hot plate produces vigorous boiling, place one more thickness of absestos between the plate and the metal bath. When heating at 180° the micro condenser is pulled almost to the top to permit the hot vapor to cool somewhat before striking the surface of the cold condenser. In this way the open six-inch tube serves as an air

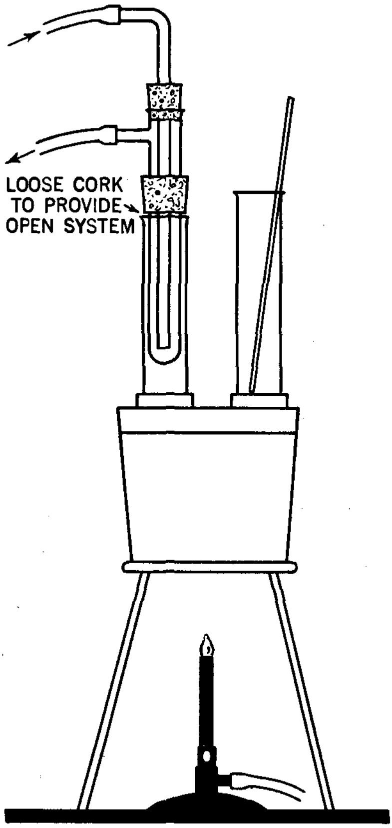
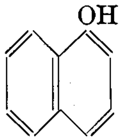


Fig. 63. Semimicro constant-temperature bath

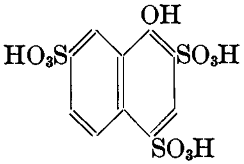
condenser. The bath may be used for different temperatures by changing the liquid. The large cork is removed and the discolored liquid is poured into a bottle through a funnel. The residual liquid is wiped off with a rag placed through the opening and rotated about so as to clean the walls of the vessel. It is then recharged with the proper liquid. The discolored liquid is used over and over again without purification except an occasional filtration to remove the sludge. The constant temperature bath may be converted back to a regular steam bath by removing the silicate seal. If the cement adheres tenaciously, boil the vessel in water.

NITRO AND NITROSO DYES

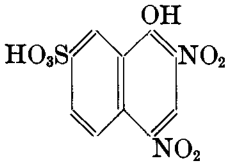
The nitro and nitroso derivatives of a few aromatic hydroxy compounds are used as yellow-green dyes. The nitro compounds are prepared by direct action of nitric acid in presence of sulfuric acid, or by first sulfonating and then nitrating the sulfonic acid. In the preparation of naphthol yellow, *α*-naphthol is first sulfonated to the 2,4,7-trisulfonic acid, which on nitration undergoes replacement of the sulfonic acid groups at positions 2 and 4 by nitro groups.



α-Naphthol

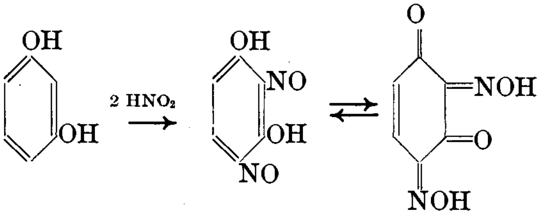


α-Naphthol-2,4,7-trisulfonic acid



Naphthol Yellow S

Nitrosoresorcinol illustrates the preparation and properties of the nitroso dyes. The action of nitrous acid on the hydroxy compound gives the dye. These nitrosophenols are isomeric with the quinone oximes.which may also be prepared by the action of hydroxylamine on the quinones.



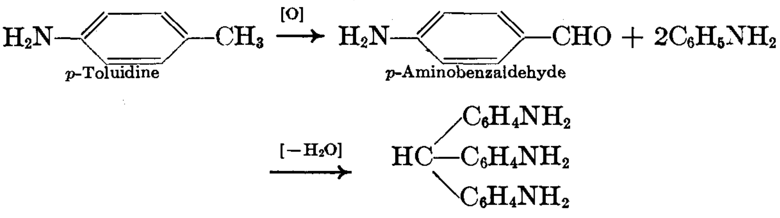
Resorcinol Dinitrosoresorcinol Di-*o*-quinonedioxime

(A) **Preparation of Naphthol Yellow S.** Place 20 ml of concentrated sulfuric acid in an eight-inch test tube and heat to 100° in a water bath. Place a thermometer in the tube, and add 5 g of finely powdered commercial α-naphthol in about 1–2 minutes. Prepare a standard temperature bath for heating at about 120°, and transfer the tube into this bath. Heat for 3 hours. Remove the tube and allow to cool to room temperature, then pour with vigorous stirring into 30 ml of water. Place in a 250-ml beaker 5 ml of concentrated nitric acid and 1.5 ml of water. Cool in an ice bath, and add slowly the solution of the naphthol trisulfonic acid prepared above, keeping the temperature at 30–35°. After two minutes add slowly 4 ml of concentrated nitric acid, and stir. After five minutes remove the beaker from the ice bath, allow to stand for 15 minutes at room temperature, then warm to 50° for 10 minutes. Cool, and add 30 ml of saturated salt solution. Filter the nitro compound, and wash three times with saturated salt solution. Remove the cake to a 250-ml beaker and add 30 ml of water. Heat to 80°, and add solid sodium carbonate until the solution is neutral. Add 4 g of solid potassium chloride, and cool. Filter the precipitated dye, and dry on a filter disc or a porous plate.

(B) **Preparation of Dinitrosoresorcinol (Fast Green).** Place 80 ml of water and 2 g of resorcinol in a 250-ml beaker. Cool in an ice-salt bath, and add 4 ml of concentrated hydrochloric acid. Add 10 g of ice, then slowly, with stirring, add a solution of 2.6 g of sodium nitrite in 10 ml of water. If the temperature rises above 5° add more ice. When all the solution has been added, allow to stand in the bath for 30 minutes. Filter the yellow brown crystals with suction, and wash with 5 ml of ice water. Dry on a paper disc or porous plate. The yield is about 3 g.

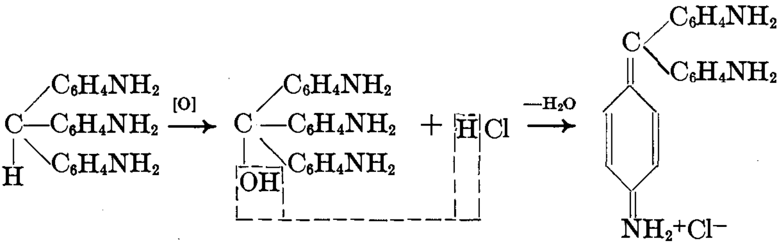
TRIPHENYLMETHANE DYES

The preparation of fuchsine illustrates the formation of a typical triphenylmethane dye but does not show the relations of the colored substance to the compounds which are formed in the intermediate steps. These may be represented by equations. When *p*-toluidine is oxidized it forms *p*-aminobenzaldehyde, which condenses with aniline to form triaminotriphenylmethane.



Triaminotriphenylmethane

The tertiary hydrogen of the triamino compounds (leuco base) is easily oxidized to the carbinol (color base) which under the influence of hydrochloric acid dehydrates to form a highly colored hydrochloride. In the dehydration one of the phenyl groups rearranges to a quinonoic structure which has chromophoric properties:



Triaminotriphenylmethane (leuco base) (1) Triaminotriphenylcarbinol (color base) (2) Pararosaniline hydrochloride (dye) (3)

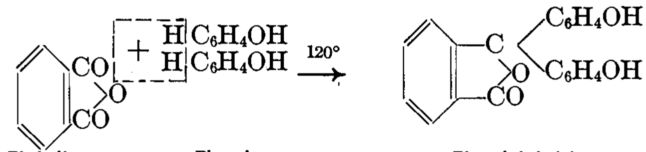
In the preparation of commercial fuchsine aniline is heated with a mixture of *ortho* and *para* toluidine. *p*-Toluidine is oxidized to the aminoaldehyde which condenses with one molecule of both aniline and *o*-toluidine to form homorosaniline hydrochloride. At the same time there is also formed pararosaniline hydrochloride owing to the reaction of two molecules of aniline with the aldehyde. The differences in the structure of leuco base, color base, and dye are shown by comparison of their respective formulas (1), (2), and (3).

(C) **Preparation of Rosaniline Hydrochloride (Fuchsine).** Place an eight-inch test tube attached to a wire on a horn balance and weigh accurately 1 g of aniline and 4 g of mixed toluidines (64 per cent *o*-toluidine and 36 per cent of *p*-toluidine). Remove the tube, mark it No. 1 and place it in the rack. Place a six-inch test tube on the balance and weigh accurately 0.4 g of aniline 1.7 g of mixed toluidines and 3.9 g of nitrobenzene. Remove the tube, mark it No. 2 and place it on the rack. Weigh in another six-inch tube 0.2 g of iron powder. Remove the tube and mark it No. 3.

Add exactly 4 ml of concentrated hydrochloric acid to tube No. 1 and 6.5 ml of the same acid to tube No. 3. The addition in the latter case should be very slow. When most of the hydrogen has evolved from the action of the acid on the iron, place a loose cork in the mouth of the tube. If all the iron has not dissolved, warm slightly and add more acid, avoiding excess. Clamp tube No. 1 securely on a stand, and place a thermometer in the tube. Heat by means of a small smoky flame, moving it to and fro over the sides until the temperature indicated by the thermometer is 130°. Allow to cool to 100°, and add all at once the contents of tube No. 2, draining the tube as completely as possible. Resume heating until the thermometer indicates a temperature of 100°. Remove the flame and add by means of a dropper the solution of ferrous chloride contained in tube No. 3. Remove the thermometer and place on the reaction tube a cork holding a glass tube 6–8 mm in diameter and about 600 mm in length, to serve as an air condenser. Place the reaction tube into a constant temperature bath charged with aniline to maintain a temperature of about 180°. Heat for 3 hours, then test for the completion of the reaction. Shut off the flame, raise the cork momentarily, dip a glass rod in the reaction mass, and withdraw a small droplet. Replace the cork and allow the rod to cool. If the droplet solidifies to a green mass the reaction is completed. If it is incomplete, heat for an additional hour or two. Remove the tube from the constant temperature bath, and steam-distill (see Figures 49 and 50) to remove most of the unchanged amines and nitrobenzene. Discontinue when the amount of oily substance condensing is very small. Remove the tube and pour off as much as possible of the viscous reaction mixture into a 250-ml beaker. Complete the transfer by washing repeatedly with a total of 35 ml of boiling water. Add to the mixture, with stirring, 14 drops of concentrated hydrochloric acid, and then 2 g of salt. Boil the mixture for 2 minutes and cool to 70°. Decant the supernatant liquid, which contains the soluble hydrochlorides of the amines, and retain the oily residue, which solidifies upon cooling. Using the spatula, break the green mass, and add 100 ml of water and 1 ml of concentrated hydrochloric acid (15 drops). Filter the solution through a fluted filter paper. Cool to 60°, and filter again. Add 2–3 g of salt and stir until it dissolves. Cool for 1 hour, and filter the crystals of the hydrochloride. Wash with a few milliliters of salt solution. Drain by suction, and dry.

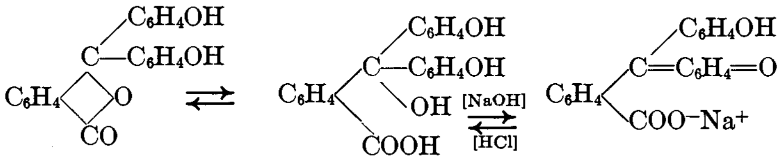
INDICATOR DYES
PHTHALEINS AND SULFONPHTHALEINS

The phthaleins and sulfonphthaleins are closely related to the triphenylmethane dyes. Their chief importance is due to their extensive use as indicators in determining the hydrogen concentration of solutions. The simplest of the phthaleins is phenolphthalein, which is formed by the condensation of one mole of phthalic anhydride and two moles of phenol in the presence of a dehydrating agent, such as sulfuric acid or zinc chloride.



Phthalic anhydride Phenol Phenolphthalein

Phenolphthalein is a white solid. It is assumed that in aqueous solutions an equilibrium is set up between several forms represented by the following structures.



Anhydride form colorless (1) Acid form colorless (2) Ion form colored (3)

Addition of sodium hydroxide shifts the equilibrium point to the right and increases the amount of colored ion (3) so that an intensely colored monosodium salt is obtained. If, on the other hand, hydrochloric acid is added to the solution the equilibrium point shifts to the left, giving the colorless forms (2) and (1). It is this shift of equilibrium in dyes which are weak acids or weak bases that renders them useful as indicators. The hydrogen ion concentration of a solution at which phenolphthalein exists half dissociated (form 3) and half undissociated (form 2) corresponds roughly to the ionization constant of the indicator. The midpoint in the color change gives information as to the useful range of the indicator. Phenolphthalein has the half-color change at *p*H 9.00 and its useful range is *p*H 8.3–10.0. This means that phenolphthalein is colorless at all hydrogen ion concentrations below *p*H 8.3, and then begins to change gradually at *p*H 8.3, reaching the maximum color change at *p*H 10.00. It is possible, by judicious selection, to obtain a series of dyes which give color changes at all concentrations of hydrogen and hydroxyl ion between the acidity of a 0.1 *N* acid and the basicity of 0.1 *N* base. This interval is the range covered by *p*H 1.0 and *p*H 13.0.

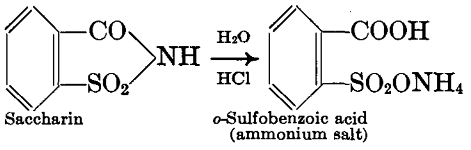
The procedures given in sections (D), (E), (F), and (G) are intended to illustrate the preparation of a number of useful indicators. Phenolphthalein is not selected because it is available at a very low price. *o*-Cresolphthalein has about the same range (*p*H 8.2–9.8) as phenolphthalein, while thymolphthalein is useful at *p*H 9.4–10.6. Both are formed by essentially the same method as phenolphthalein.

(D) Preparation of *o*-Cresolphthalein. Place in an eight-inch tube 4.5 g of phthalic anhydride and 6 g of *o*-cresol. Put a stirring rod in the tube and heat over a small flame to dissolve the anhydride. Place the tube on the rack, and weigh rapidly 6 g of fused zinc chloride prepared according to directions given on page 133. It is not necessary to have the zinc chloride freshly fused if the conditions for storage are followed as set forth. The weighing of zinc chloride must be as rapid as possible and it should be added immediately to the reaction mixture. The weight can be approximate, providing it is slightly over. The preparation goes well with either 6 or 7 grams. Add the zinc chloride to the mixture of cresol and phthalic anhydride, and stir at once. Place the tube in the standard temperature bath arranged for heating at 105–110° (see page 329), and heat for 5–6 hours. At the end of the heating period add 10 ml of water, stir until the melt is dissolved, and transfer to a beaker containing 100 ml of water and 5 ml of concentrated hydrochloric acid. If the dye separates as a solid, filter and wash several times with water. Transfer the lumps into a mortar, pulverize, add 5 ml of dilute hydrochloric acid and 5 ml of water, and then wash back into the suction filter. If the material separates as an oil it indicates that the melt was not properly disintegrated with water. In this case heat the beaker until the mixture boils then cool to 5° and filter as directed above. Transfer the crude *o*-cresolphthalein into a 250-ml beaker. Add 15 ml of 10 per cent sodium hydroxide solution, and stir or warm slightly until the phthalein has completely dissolved. Add 50 ml of water and set aside to cool. Filter through a fluted paper, and wash the residue with 25 ml of water. Add to the filtrate dilute hydrochloric acid until a drop of the liquid is distinctly acid to litmus paper. Cool and filter. Wash with water and dry in air. The yield is about 4–5 g.

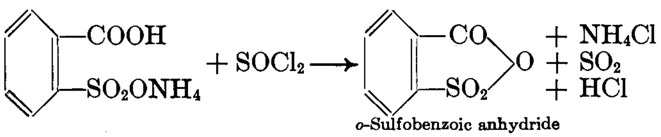
(E) **Preparation of Thymolphthalein.** Prepare the reaction mixture, following the same procedure as in section (D). Use 6 g of thymol, 3.7 g of phthalic anhydride, and 3–4 g of zinc chloride. Heat for 8 hours at 105–110°. Cool, and add 20 ml of a mixture of equal parts of ether and benzene. Provide the tube with a micro condenser, and reflux in the water bath for fifteen minutes to dissolve the unreacted thymol. Cool, and decant the solvent. Add 30 ml of methanol, heat to dissolve the phthalein, and pour the hot extract into a beaker. Repeat the extraction with 10–15 ml of alcohol. The residue consists of zinc chloride. Save it for future reference, if the yield of the phthalein is low. Add to the alcoholic extract water in small amounts until precipitation begins, and then cool. After an hour filter the crystals of thymolphthalein. If the product is colored, dissolve in the minimum amount of hot alcohol and precipitate by slow addition of water.

(F) **Preparation of Sulfonphthaleins.** The preparations described involve: (1) hydrolysis of *o*-sulfobenzoic imide (saccharin) to the ammonium salt of *o*-sulfobenzoic acid; (2) preparation of *o*-sulfobenzoic anhydride; (3) preparation of phenolsulfonphthalein (phenol red); (4) bromination of phenolsulfonphthalein to tetrabromo derivative (bromophenol blue); (5) preparation of *o*-cresolsulfonphthalein (cresol red); (6) bromination of *o*-cresolsulfonphthalein to the dibromo derivative (bromocresol purple).[1] The equations for the steps are:

Step 1



Step 2



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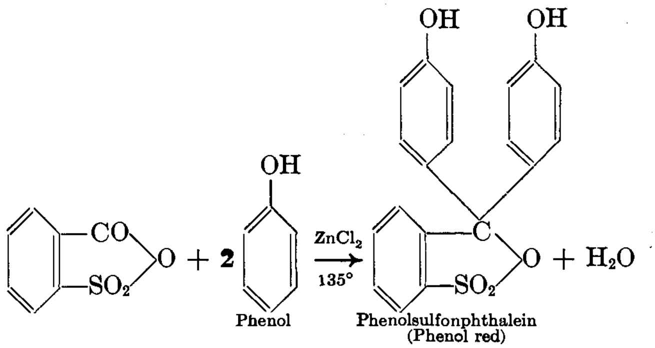
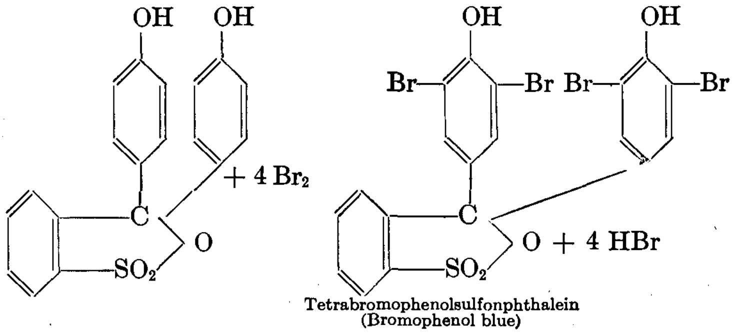
[1] It is possible to complete the entire series of preparations in 10 hours of actual working time.

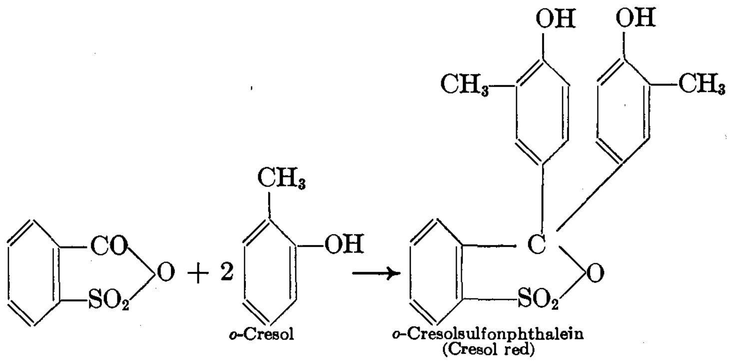
Step 3



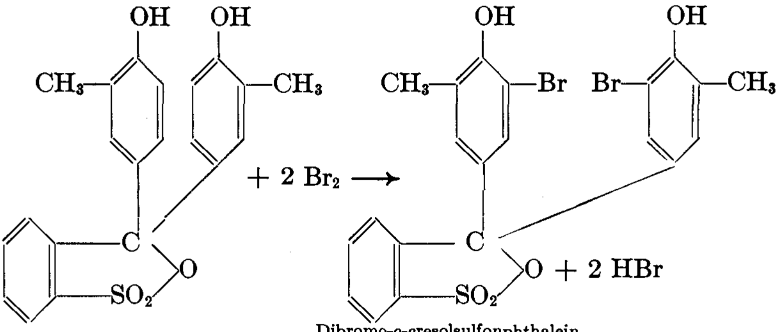
Step 4



Step 5



Step 6



Dibromo-*o*-cresolsulfonphthalein
(Bromocresol purple)

(1) **Preparation of *o*-Sulfobenzoic Acid Salt.** Place in a 250-ml Erlenmeyer flask 30 ml of water, 8 ml of hydrochloric acid, and 2 boiling stones. Place a two-hole cork in the flask. Insert a micro condenser through one of the openings of the cork so that it protrudes about 40 mm into the flask. Heat the dilute acid until it boils gently, and add over a period of one hour 10 g of insoluble saccharin in small portions, raising the cork momentarily to make the addition. If the boiling is gentle it is not necessary to pay any further attention except to add the saccharin every 10 minutes or so. Boil for 1 hour or longer after the addition of saccharin has been completed, until a clear solution has been obtained. Pour the hot solution into a beaker, and rinse the flask with 2 ml of water. Cool the solution, and filter the crystals with suction. Wash with 5 ml of acetone, and remove the filtrates to an evaporating dish. Transfer the crystals to a paper disc to dry. Evaporate the filtrates to dryness over a 250-ml beaker of boiling water or steam bath. Cool, add 5 ml of methanol, and transfer the residue to a suction filter and drain. Discard the filtrates and unite the second crop of crystals with the first. Dry on an evaporating dish over a water bath, and determine the weight. The yield is 14–14.5 g.

(2) **Preparation of *o*-Sulfobenzoic Anhydride.** Pulverize the dry salt obtained in the previous preparation to very fine powder. Place in a dry 250-ml Erlenmeyer flask 14–14.5 g of the salt. Fit on the flask the same cork, with condenser, that was used in the previous preparation. Place a bent glass tube through the second opening and connect, by means of a short piece of rubber tubing, with a glass tube leading to a gas absorption vessel (see Figure 45, page 141). Raise the cork and add all at once 18 ml of thionyl chloride and 5 ml of benzene.

Caution: Wear goggles and avoid breathing the fumes from thionyl chloride.

Raise a water bath under the flask and heat at 60–70° for 10–12 hours. Remove cork and arrange for distillation. Use a one-hole cork on the flask and connect by means of a glass tube to a regular micro receiving setup. Distill the mixture of thionyl chloride and benzene until the amount of the distillate collected is about 8 ml. Add 80 ml of dry benzene to the residue in the flask and *replace* the micro condenser on the mouth of the flask so that the benzene can be refluxed for 10–15 minutes. While the benzene is refluxing place a Bunsen funnel over a 250-ml Erlenmeyer flask with a folded filter paper in the funnel. Put the apparatus in the hood. Pour the hot benzene extract into the folded filter paper.

Caution: See that no flames are in the vicinity, as benzene fumes ignite easily.

Place 20 ml of additional benzene in the reaction flask, heat under reflux until the benzene begins to boil, then wash the residue in the filter paper with the hot benzene. Add 1–2 boiling stones to the benzene solution and arrange the flask for distillation, using the same setup as for the distillation of the excess thionyl chloride. Use a 250-ml Erlenmeyer flask for receiver instead of a test tube. Heat by means of a water bath, and distill the solution to dryness. Remove the last traces by connecting the flask, provided with a one-hole rubber stopper holding a short glass tube, with a water-suction pump for a few minutes. With a glass spatula (flattened glass rod), remove the anhydride to a tared bottle, cork, and save for the succeeding preparations. If the anhydride is not used within a week it is best to stopper the bottle with a solid rubber stopper. The yield of crude anhydride is 11–11.5 g.

(3) **Preparation of Phenolsulfonphthalein.** Place in an eight-inch tube 5 g of crude anhydride from the previous preparation, 7 g of phenol, and 5 g of fused zinc chloride. Place a rod in the tube, and stir well, heating slightly over the flame so as to melt the phenol. Place in the constant temperature bath, and heat for 3–4 hours at 130–135°, stirring from time to time, more frequently during the first hour. If the mixture has a tendency to froth stir well with the rod, and add a few drops of alcohol. If this does not break the froth, remove the tube from the bath, and cool, then resume heating. When the reaction is complete add to the dye melt 25 ml of water, and allow the water to boil, stirring from time to time so as to disintegrate the melt. Pour the contents of the tube while

hot into a 250-ml beaker and rinse with two 10-ml portions of warm water. Filter the crude dye with suction, and wash with two 20-ml portions of water. Transfer the wet cake back into the 250-ml beaker and add 20 ml of 10 per cent solution of sodium carbonate. Warm for 2 minutes, and allow to stand for 5 minutes. Filter through a folded filter paper into a 250-ml beaker, and wash the residue with two 10-ml portions of water. Add the filtrate very slowly, with stirring, to a mixture of 20 ml of concentrated hydrochloric acid and 30 ml of water. Break the froth by stirring, and control it by the rate of addition of the carbonate solution. Heat to about 60–80°, and cool. Filter with suction, wash twice with 5 ml of distilled water and dry on a paper disc. The dye is obtained in the form of a brilliant red powder. The yield is 4.5–5.5 g. Prepare a solution of the indicator and test the color changes as directed in the Appendix.

(4) **Preparation of Tetrabromophenolsulfonphthalein.** Place in an eight-inch tube 3 g of phenol red and add 10 ml of glacial acetic acid. Stir with a glass rod which is left in the tube. Add 2 ml of bromine dissolved in 5 ml of glacial acetic acid.

Caution: See directions and precautions in measuring and handling bromine on page 269.

Stir for a few minutes, place the tube in a beaker containing warm water at 60°, and allow the mixture to come to room temperature slowly. Place a rubber stopper loosely in the tube and allow to stand overnight in the hood. It is not safe to place the tube in the drawer because hydrogen bromide is given off. Place a filter paper on the micro Buchner funnel, wet with water and dry with suction. Add to the filter 2 ml of glacial acetic acid and apply suction. Discard liquid in the filter tube. Stir the brominated mixture and pour on the prepared filter. Suck dry and replace filtrate in the reaction tube; rinse any adhering crystals into the funnel. Repeat until all the bromo derivative has been transferred to the funnel. Disconnect suction, and add by a dropper 2 ml of glacial acetic acid. Apply suction and repeat washing. Finally wash with 4 ml of benzene, press to remove all the liquid, and spread crystals on a paper disc placed on a watch glass. Dry by placing watch glass in the hood near the suction vent. The crystals should be dried within one hour. When dry, place crystals in tared bottle. The yield is about 4 g. Prepare a solution of the indicator and test the color changes as directed in the Appendix.

(5) **Preparation of *o*-Cresolsulfonphthalein.** Follow the same procedure in preparing the reaction mixture as in preparation of

phenol red. Use 5 g of the anhydride, 6 g of *o*-cresol, and 4 g of zinc chloride. Heat for 4 hours in the constant temperature bath at 115–120° (see page 330). Add 25 ml of water and 2 ml of dilute hydrochloric acid, and disintegrate the melt until the water boils. Pour contents of tube while hot into a 250-ml beaker, and rinse with two 10 ml portions of warm water (30–40°). Press to drain the water, and dry first on a paper disc and then on an evaporating dish over a water bath. Pulverize the mass, and place in a 150-ml beaker. Add a mixture of 10 ml of ether and 10 ml benzene. Stir for a few minutes to dissolve any adhering *o*-cresol, and filter by suction. Wash with 5 ml of ether, and dry the glistening crystals on a paper disc. The yield is 5–5.5 g. Prepare a solution of the indicator and test the color changes as directed in the Appendix.

(6) **Preparation of dibromo-*o*-cresolsulfonphthalein.** Follow the same procedure as in the bromination of phenol red, using 3 g of *o*-cresolsulfonphthalein, 1 ml of bromine, and the same amount of solvent. The yield of the bromo derivative is 2.5 g. Prepare a solution of the indicator and test the color changes as directed in the Appendix.

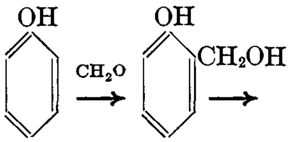
Experiment 70

SYNTHETIC POLYMERS

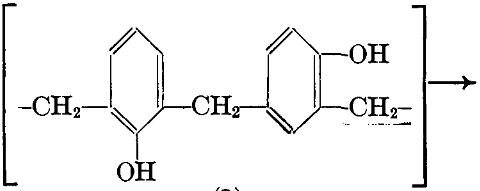
Introduction. Polymerization reactions were considered briefly in connection with the study of olefins, aldehydes and ketones. The object of the present experiment is to make a further study of polymerization reactions which are finding extensive industrial application.

Polymerization reactions involve the union of a number of similar molecules to form a single complex molecule. A *polymer* is any compound, each molecule of which is formed out of a number of molecules which are all alike, and which are called *monomers*. In many cases polymerization can be reversed and the polymer be resolved to the monomer. Many polymerization reactions which are of industrial importance involve in the initial stages *condensations*, that is, reactions in which elimination of water or other simple molecules takes place. Compounds which polymerize have some type of unsaturation in the molecule. Olefins, unsaturated halides, esters, aldehydes, dicarboxylic acids, anhydrides, amino acids and amides are among the important groups of compounds which are used in industrial polymerization reactions. The commercial products produced by polymerization reactions may be conveniently classified into (*a*) *resinoids*, or synthetic resins; (*b*) *elastomers*, which possess rubber-like properties; and (*c*) *fibroids*, used as textile fibers. Two types of resinoids are illustrated in this experiment: Bakelite, formed from phenol and formaldehyde, and methacrylate resin formed from an unsaturated ester.

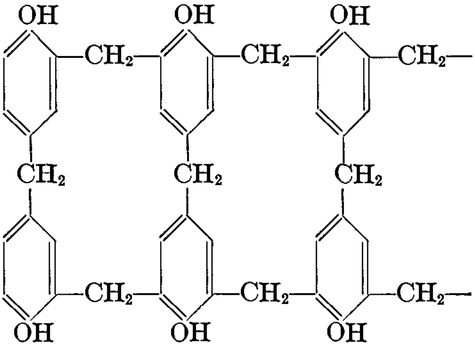
In the formation of a Bakelite resin the initial reaction of phenol and formaldehyde gives *o*-hydroxybenzyl alcohol (1), which reacts with more phenol and formaldehyde to give a linear structure (2), and finally, by development of cross linkages, gives a three-dimensional molecule (3). At stage (2) the product is fusible but at stage (3) it is permanently hard and non-fusible. A filler (such as sawdust) and other materials are incorporated at stage (2) to yield opaque plastic materials which can be machined like brass or wood, or the product at stage (2) can be placed in a mold and then hardened.



(1)

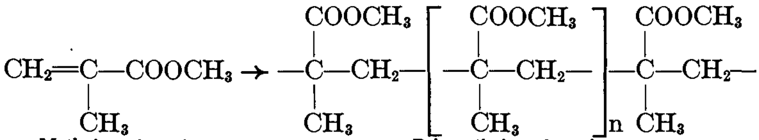


(2)



(3)

The acrylate resinoids are esters of acrylic and methacrylic acid. Methyl methacrylate, $CH_2{=}C(CH_3)COOH_3$, is a liquid ester which polymerizes to a transparent resin of high tensile strength. The polymerization is brought about by catalysts such as peroxides and heat. The polymerization is assumed to take place by addition to form linear molecules:



$$CH_2{=}\underset{\displaystyle CH_3}{\underset{|}{C}}{-}COOCH_3 \rightarrow -\overset{\displaystyle COOCH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}-CH_2-\left[-\overset{\displaystyle COOCH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}-CH_2-\right]_n-\overset{\displaystyle COOCH_3}{\overset{|}{\underset{\displaystyle CH_3}{\underset{|}{C}}}}-CH_2-$$

Methyl methacrylate
(monomer)

Polymethyl methacrylate
(polymer)

Styrene or vinylbenzene, $C_6H_5CH=CH_2$, polymerizes rapidly to transparent hard resins which are also assumed to have a linear structure.

The elastomers are chiefly obtained by the polymerization of olefins and diolefins. The polymers are assumed to have a linear structure. A similar linear structure is assumed for the polyamides (Nylon), which have structural similarities to proteins.

(A) **Preparation of Phenol-Formaldehyde Resin.** Place in an eight-inch tube 5 g of phenol, 15 ml of 40 per cent formaldehyde solution, and 3 ml of concentrated aqueous ammonia. Heat the tube for a few minutes with a small flame until the solution becomes opaque and milky. Cool the tube, and decant the upper layer, retaining the lower viscous material. Add 10–12 drops of acetic acid to the viscous material and heat in a water bath at 60° for thirty minutes. Pour some of the liquid into a glass tube 6 mm in diameter and 100–150 mm in length, sealed at one end. Place the remainder in a small clean test tube made of thin glass. Label both tubes, and place in oven at 80° until the next laboratory period. Break the tubes cautiously to obtain the clear transparent resin.

(**B**) **Depolymerization of Methacrylate Resin.** Place 8 g of methacrylate resin powder[1] in an eight-inch distilling tube, and arrange for distillation. Heat the tube gradually with a small luminous flame, moving it to and fro over the sides of the tube until the solid melts and begins to distill. Note the temperature at which distillation takes place. Do not distill to dryness, but discontinue the distillation when the residue is about 2 ml. Add a crystal of hydroquinone to the receiving tube, and transfer the liquid to a 6-inch distilling tube. Distill cautiously and note the boiling point. The yield is about 5–6 g of the methacrylate monomer.

(C) **Preparation of Methacrylate Resin.** Prepare a tube 6–8 mm in diameter and 100–150 mm in length. Add about 30 mg of benzoyl peroxide to 5 ml of methacrylate monomer, stir, and fill the tube. Place in a water bath, and heat at 80° for 30–45 minutes, then cork and set aside upright for several days. When polymerization is complete, remove the rod by cautiously breaking the tube.

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[1] This powder is commercially available.

APPENDIX

I. LABORATORY ACCIDENTS AND FIRST AID

In case of *fire* or *accident* call the laboratory instructor *at once* if possible. But there are times when seconds count, and the student should be ready in such cases to administer first aid to himself and others and to put out a fire before it spreads.

Fire from burning reagents. If the liquid in a beaker or flask catches fire, the source of heat should be removed and the flame extinguished by placing a watch-glass or a damp cloth over the opening of the vessel. If the vessel is large, use an asbestos blanket and, if necessary, a fire extinguisher—but not water. If a carbon-dioxide fire extinguisher is available, use it by directing the discharge nozzle first toward the edge of the fire and then toward the middle. If a carbon tetrachloride fire extinguisher is used, **ventilate the room at once**, as vapors of this substance are toxic.

For burning oil, if carbon dioxide is not available, use a mixture of sand and sodium bicarbonate, or of sand and ammonium chloride. **Do not use water**, as it will only spread the fire.

Burning clothing. If the clothing should catch fire, remove it if possible, or avoid running, as this will fan the flame. Smother the flame by wrapping the body in a laboratory coat or, preferably, in a woolen blanket kept under the first-aid cabinet for that purpose.

Burns. The basis for the treatment of all burns is to maintain sterility and to promote granulation and the formation of new tissues. In the case of burns from chemicals, the first important aid is **immediate washing with water**, followed by washing with a very dilute solution of another substance that will neutralize the chemical which caused the injury. Following are specific treatments.

(*a*) **Burns from fire.** For slight burns in which the skin is not broken, apply one of the following ointments: *Unguentine, Butesin Picrate, Tannic Acid Jelly*, or *Crystal Violet Jelly*.

The ointment is applied to the skin and, if necessary, the part is bandaged. The use of cotton is to be avoided. If the pain is severe, a compress moistened with a 3 per cent solution of aluminum acetate, $Al_2O(C_2H_3O_2)_2 \cdot 4\,H_2O$, may be applied and left until the pain is relieved. Then the skin should be dried, and either ointment or antiseptic talcum powder should be applied.

When the burn is large and severe, call a physician at once. If emergency treatment is required and a physician is not available within fifteen minutes, place the patient on a cot and cover him with blankets, but be careful to avoid touching the burned parts. Remove adhering clothing from the burned parts and cover with one of the jellies mentioned above, pending the physician's arrival. In order to relieve the severe pain, apply compresses with aluminum acetate or a gauze moistened with 1 to 2 per cent aqueous solution of a local anesthetic.

(*b*) **Chemicals in the eye.** Wash the eye immediately with a large amount of water. If the chemical is an acid, flushing with water should be followed by application of a 1 per cent solution of sodium bicarbonate. An eye cup is very convenient for this purpose. If the chemical is an alkali, flushing with water should be followed by application of a 1 per cent solution of boric acid. After washing with water and dilute neutralizing solution, a drop of sterile olive oil[1] should be applied and the patient should be taken to a physician. Injuries to the eye require a specialist's care.

(*c*) **Acids and alkalies on the skin.** Wash with large amounts of water. In the case of acids, follow by application of a paste of sodium bicarbonate and allow to remain for 15–20 minutes. Then remove the excess, dry, and cover the skin with an ointment. In the case of alkalies, after washing with water, rinse the affected parts with a saturated boric acid solution or a 1 per cent solution of acetic acid. Then dry the skin and cover with tannic acid jelly.

(*d*) **Bromine burns.** Wash at once with water and a 2 per cent solution of sodium thiosulfate. Cover immediately with glycerin and follow with an ointment.

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[1] The author uses olive oil which contains 1–2 g of ethyl *p*-amminobenzoate per 100 ml and which has been heated to 110° for a few minutes. For the same purpose an ophthalmic ointment containing 2 per cent butyn sulfate may be used.

(*e*) **Organic substances.** Rinse at once with water and remove any insoluble part by washing with ethyl alcohol. This may be followed by washing with soap and water. Dry the skin and apply an ointment.

Cuts. If the cut is a minor one, allow it to bleed for a few seconds, wash it with water, and then apply a prepared bandage with an antiseptic center. If a ready-made bandage is not available, apply an antiseptic from the first-aid cabinet and then cover the wound with a sterile 1- or 2-inch bandage. In case of profuse bleeding, wash the cut and apply a bandage, using pressure about four inches above and below the cut to diminish circulation and to aid clotting. Continuous pressure should not be maintained for more than five minutes. When a clot has formed, apply a mild antiseptic and call a physician.

II. SUGGESTED LIST OF APPARATUS FOR ELEMENTARY ORGANIC CHEMISTRY

SEMIMICRO

Locker Equipment (*Returnable*)

1	Beaker, Pyrex	25 ml
1	Beaker, Pyrex	50 ml
1	Beaker, Pyrex	100 ml
2	Beakers, Pyrex	150 ml
2	Beakers, Pyrex	250 ml
*1	Beaker, Pyrex	400 ml
2	Condensers, Finger (Sm.)	
2	Distilling tubes or flasks (Sm.)	10 ml
1	Distilling tube or flask (Sm.)	25 ml
*1	Distilling tube or flask, Claisen Sm.	25 ml
1	Calcium chloride tube (Sm.)	
1	Cylinder, graduated	10 ml
2	Erlenmeyer flasks	25 ml
1	Erlenmeyer flask	125 ml
1	Evaporating dish	30 ml
1	Fractionating column (Sm.)	
2	Funnels	50 mm
1	Mortar and pestle	65 mm
2	Pipette droppers (medicine droppers)	
1	Pipette dropper, graduated at 0.5 and 1 ml	
1	Porcelain perforated disc (beveled edge)	20 mm
1	Thermometer	360 or 300°
4	Test tubes, Pyrex	200 × 25 mm (8-inch)
12	Test tubes, Pyrex	150 × 20 mm (6-inch)
6	Test tubes, Pyrex	100 × 12 mm (4-inch)
1	Test tube, Pyrex	200 × 25 mm (with side arm)
1	Watch glass	50 mm
1	Watch glass	75 mm
1	Ignition test tube, Pyrex	150 × 20 mm or 150 × 18 mm
1	Bath for heating (Sm.)	
1	Burner (Sm.)	
2	Clamps (Hoffman, screw)	
4	Clamps, burette	
1	Cork-borers	set 1–8, 1–6
1	Spatula, Monel blade	(Sm.)
1	Test-tube rack, organic (Sm.)	
1	Test-tube holder	
1	Pair of goggles	
6 ft.	Rubber tubing $\frac{3}{16}$ inch	(5 mm)
1 ft.	Rubber tubing $\frac{1}{8}$ inch	(3 mm)
3 ft.	Burner-tubing (rubber)	6 mm
1	Wing top for burner	

Nonreturnable Equipment

10	Paper drying discs	
25	Filter-paper circles	10 cm
25	Filter-paper circles	22 mm
5 ft.	Glass tubing	4 mm, soft
1 ft.	Glass rod	4 mm, soft
1 ft.	Glass tubing	6 mm, soft
1	File, rat tail	100 mm
1	File, triangular	100 mm
1	Wire gauze (asbestos centered)	125 mm
1	Test-tube brush	32 mm
1	Test-tube brush	15 mm
2	Boxes of matches	
*12	Bottles for preparations (with Bakelite screw cap)	8 ml
25	Labels	
*6	Corks	No. 8
*6	Corks	No. 12
*1	Cork	No. 20
2	Vials of litmus paper	
1	Towel	

Permanent Equipment for Loan or Side Bench

Chlorine dispersers (Sm.)	
Manometer	
Refractometer (Fisher)	
Plastic-pan hand balance	
Weights	100 mg to 25 g
Desiccators	
Glass stopcock	
Melting-point apparatus	
Polarimeter	
Ring stands, medium	
Rings	
Rubber stoppers	
Suction pump	
Manometer	

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* Starred items may be omitted from the locker and placed in the stockroom to be withdrawn as needed.

MACRO

Locker Equipment (Returnable)

1	Adapter	
1–2	Beakers	25 ml
2	Beakers	150 ml
2	Beakers	250 ml
1	Beaker	400 ml
1	Beaker	800 ml
1	Beaker	1000 ml
1	Calcium chloride tube	
1	Condenser, jacket	400 mm
1	Condenser inner tube (air condenser)	500 mm
1	Cylinder, graduated	100 ml
1	Cylinder, graduated	1–10 ml
1	Distilling flask	50 ml
2	Distilling flasks	125–250 ml
2	Erlenmeyer flasks	50 ml
1	Erlenmeyer flask	125 ml
1	Erlenmeyer flask	250 ml
1	Evaporating dish	30 ml
1	Filtering flask	250 or 500 ml
1–2	Flasks with round bottom and short neck	200 ml
1	Flask with round bottom and short neck	500 ml
	or Florence flask	500 ml
1–2	Funnels, short stem	65–75 mm, diameter
1	Buchner funnel	90–100 mm
1	Separatory funnel	125 or 250 ml
1	Mortar and pestle	65 mm
1–2	Pipette droppers (medicine droppers)	
1	Pail	about 150 mm diameter
1	Thermometer	360°
1	Watch glass	75 mm
1	Watch glass	100 mm
1	Spatula, porcelain or stainless steel	
3	Test tubes, Pyrex	200 × 25 mm (8-inch)
12	Test tubes, Pyrex	150 × 20 mm (6-inch)
6	Test tubes, Pyrex	100 × 12 mm (4-inch)
1	Test-tube holder	
1	Test-tube rack	
1–2	Burners (Bunsen)	
2	Clamps, burette	
2–3	Clamps for condenser with holders (Universal)	
1	Cork-borers set (1–9)	
1	Pair of goggles	
1	Wing top for burner	
1	Cork ring	120–150 mm
6	ft. Rubber tubing for condenser	
3	ft. Rubber tubing for burner	
½	ft. Rubber tubing	5 mm

Nonreturnable Equipment

6	Bottles for liquid preparations (narrow mouth with Bakelite screw cap)	25 ml
6	Bottles for solid preparations (wide mouth with Bakelite screw cap)	25 g
5	ft. Glass tubing	6 mm
2½	ft. Glass tubing	8 mm
2	ft. Glass rod tubing	4–5 mm
25	Filter paper circles (to fit Buchner funnel)	9–10 mm
25	Filter paper circles	12.5 cm
25	Labels	
10	Paper discs for drying *or* 2–3 porous plates	12–15 cm
1	File, rat tail	100 mm
1	File, triangular	100–125 mm
2	Boxes of matches	
1	Test-tube brush	32 mm
1	Test-tube brush	15 mm
1	Towel	
1–2	Wire gauze (asbestos centered)	100 mm
6	Corks, No. 10	
6	Corks, No. 14	
12	Corks, assorted	
2	Vials of litmus paper	

Permanent Equipment for Loan or Side Bench

Addition tubes	
Gas bottles	
Distilling flasks, Claisen	125, 250, 500 ml
Flasks with round bottom and short neck	1000 ml
Florence flasks	1000 and 2000 ml
Fractionating columns	
Funnel, hot-water	
Balance, triple beam or plastic-pan hand balance; trip balance	
Desiccators	
Melting-point apparatus	
Oil baths	
Manometer	
Polarimeter	
Ring stands, medium and large	
Rings, assorted	
Rubber stoppers	
Refractometer	
Stirrers, plain and mercury seal	
Stirring motor	
Suction pump	
Stopcocks	
Weights	1–500 g

III. LIST OF CHEMICALS AND REAGENTS

A complete list of the quantities of the materials and reagents needed for each experiment per student is available in mimeographed form and can be obtained by writing to the publisher for the *Instructor's Supplement*. The materials have been estimated for each part of every experiment per student for both macro and semimicro, so that the instructor will be able to select those parts of each experiment which best fit his needs. The *Instructor's Supplement* also lists the liquid and solid reagents and their preparation. The special reagents and solutions are listed below.

SPECIAL REAGENTS AND SOLUTIONS

Benedict's reagent. Dissolve 17.3 g of finely powdered copper sulfate in 100 ml of hot water. Cool and dilute to 150 ml. Dissolve separately 173 g of sodium citrate and 100 g of pure anhydrous sodium carbonate in 600 ml of water. Heat to effect solution; cool; then add the copper sulfate solution and dilute to 1000 ml.

Fehling's solution. Solution (I). Dissolve 69.2 g of copper sulfate ($CuSO_4 \cdot 5\ H_2O$) in water and dilute it to a liter. Solution (II). Dissolve 346 g of Rochelle salts ($KNaC_4H_4O_6 \cdot 4\ H_2O$) and 250 g of sodium hydroxide in water and dilute to a liter.

3,5-Dinitrobenzoyl chloride. Place in an eight-inch tube 2 g of 3,5-dinitrobenzoic acid and 4 g of phosphorus pentachloride. Heat in the hood with a small smoky flame for five minutes. In the beginning the tube is heated to start the reaction and thereupon the flame is removed until the reaction has subsided. Then the flame is adjusted so that the vapors condense at about the middle of the tube. Allow to cool for one minute and pour carefully into a small evaporating dish. Cool and transfer the solid to a paper drying disc or to several filter-paper circles. Press with the spatula so as to force the phosphorus oxychloride into the absorbent medium. After ten minutes transfer the crude 3,5-dinitrobenzoyl chloride into a small bottle or tube. The crude material is satisfactory for the preparation of derivatives of the lower hydroxy compounds.

Indicators.

(1) *Universal, or long-range, indicators.* Several long-range indicators are commercially available. The one developed by the author is prepared by the Synthetical Laboratories, Chicago, Illinois, and is sold under the trade name of *Sylco Universal Indicator* through laboratory supply dealers. Price: $5.00 per liter; Color charts 30 cents each. The color chart has fifteen colors correspond-

ing to *p*H 1–13. The *Gramery Universal Indicator* is prepared by Fisher Scientific Company, Pittsburgh, Pennsylvania, and Eimer and Amend, New York City. Price: $8.00 per liter, with one color chart included. The chart has twelve colors corresponding to *p*H 4–10. The *Harleco Universal Indicator* is prepared by the Hartman-Ledon Company, Philadelphia, Pennsylvania. Price: $9.00 per liter; color charts: 25 cents each. The color chart has one blended color scale corresponding to *p*H 1–13.

(2) *Sulfonphthalein indicators.* Place 0.4 g of the sulfonphthalein indicator in a 250 ml flask and add 12 ml of 0.1 *N* sodium hydroxide solution and 50 ml of water. Warm until the dye is completely dissolved. Dilute to 200 ml and filter into a bottle. Add 100 ml of water through the filter to wash the adhering dye, and then make up the solution to a volume of one liter by adding 700 ml of water. Since excess of alkali was used to effect solution, standardize the indicator solution as follows: Add one drop at a time of 0.1 *N* acid and shake; compare the color of the foam with the color chart of sulfonphthalein indicators which appears in W. M. Clark's *The Determination of Hydrogen Ions.* (A separate color chart can be obtained from Williams and Wilkins, Baltimore, Maryland; price: $1.00.) When the color of the foam corresponds to the color of the midpoint indicated in the chart by an arrow, the indicator is ready for use. If the midpoint is passed, add dropwise 0.1 *N* solution of sodium hydroxide. It is preferable to store the indicator solution in Pyrex bottles (rubber-stoppered). Storage in soft glass changes the *p*H. The standardization described is accurate for most purposes where indicator solutions are used by students. If greater accuracy is required, the solution may be standardized by a glass or quinhydrone electrode.

(3) *Indicator for titrations.* Phenolphthalein, methyl red, and *o*-cresolphthalein are dissolved in 90 per cent methanol. The useful concentration is 0.5 to 1.0 g per liter.

Millon's reagent. Place 20 g of mercury in a beaker under a well-ventilated hood. Add 30 ml of concentrated nitric acid. When the reaction is complete, add 65 ml of water. It is best to make the solution in small amounts.

Nessler's reagent. Dissolve 22.5 g of iodine in 20 ml of water containing 30 g of potassium iodide. Place in an Erlenmeyer flask, add 30 g of mercury, stopper, and shake well with cooling until the color of iodine is discharged. Set aside for a few days and then filter.

Phenylhydrazine reagent. The reagent may be prepared either from the base or from the hydrochloride. The former is more expensive. Dissolve 50 ml of phenylhydrazine base in 500 ml of 10 per cent acetic acid. Add 0.5 g of charcoal and 0.5 g of Super-cel, and filter into a dark bottle.

Alternate method: Dissolve 50 g of phenylhydrazine hydrochloride in 500 ml of water. Warm if necessary, and then cool. The salt should be almost pure white; otherwise, it should be recrystallized. Add 90 g of powdered sodium acetate ($Na_2C_2H_3O_2 \cdot 3\,H_2O$) and shake until it is dissolved. Add 0.5 g of charcoal and 0.5 g of Super-cel, shake, and filter.

Caution: The base is highly poisonous; wash at once any liquid which has come in contact with the skin first with 2 per cent acetic acid solution and then with soap and water.

Sodium acetate anhydrous. For amounts of 100 g and more use the method described for zinc chloride on page 133. For amounts of 10–25 g proceed as follows: Wear goggles and canvas or rubber gloves. Place 15–35 g of the trihydrate ($Na_2C_2H_3O_2 \cdot 3\,H_2O$) in a small iron or porcelain dish and heat first with a very small and later a very strong flame. The salt first melts, then solidifies again. Hold the dish with tongs and stir by means of a glass rod so that as the salt melts again there is no superheating and decomposition. When the salt has entirely melted for the second time, remove the flame and continue the stirring until the melt solidifies. Transfer while warm into a mortar and pulverize. Place in a bottle at once.

Sodium hypochlorite solution. To one liter of water add 100 g of "high-test" calcium hypochlorite ("H.T.H."), shake for a few minutes, and allow to stand for an hour. Add 100 g of solid sodium carbonate (commercial soda ash), shake, cork, and allow to stand. The supernatant liquid may be withdrawn and used directly, or the entire mixture may be filtered from the precipitated calcium carbonate. The resulting solution contains about 7 per cent available chlorine. A 5 per cent solution of sodium hypochlorite is commercially available under the trade name of *Chlorox.*

Schiff's fuchsin aldehyde reagent. Dissolve 1 g of fuchsin (*p*-rosaniline hydrochloride) in 200 ml of water, with gentle warming. Cool and saturate with sulfur dioxide. Allow to stand for several hours. Add 1 g of decolorizing carbon, shake, filter, and dilute with water to 1 liter.

Tollen's reagent (ammoniacal solution of silver oxide). To be prepared as needed. See directions on pages 192–193.

Zinc chloride anhydrous. For direction see page 133.

Iodine solution. Dissolve 10 g of potassium iodide in about 100 ml of distilled water. To this add 1.3 g well-powdered resublimed iodine and stir until completely dissolved; then dilute to one liter. This solution is about 0.01 N and is used to test for starch.

Phloroglucinol reagent. Dissolve 2 g of phloroglucinol in 50 ml of water and add 50 ml of concentrated hydrochloric acid.

IV. CALIBRATION OF THERMOMETERS

As mentioned on pages 50–51, the calibration of thermometers is most easily accomplished by comparing them side by side with another thermometer already calibrated by the Bureau of Standards, and by taking three or four readings over the entire scale. In the absence of a standardized thermometer, the calibration has to be accomplished through comparison with known boiling or melting points of pure substances. Table 6 lists compounds recommended for such a purpose. For the beginner, however, two or three compounds are sufficient. The zero point is best determined by using an intimate mixture of pure distilled water and pure ice made from distilled water, and immersing the thermometer tube in it for about five minutes. The best method is to pour 20–25 ml of pure water into an eight-inch tube and to freeze it partially by immersion in an ice-salt mixture. While the water is freezing, it is stirred with a clean glass rod until a thick slush is obtained. The tube containing the slush is removed from the ice-salt mixture and the thermometer is then immersed in the slush until the zero point is just covered. The thermometer is used to stir the slush gently for 2–3 minutes. After the temperature has become constant, several readings are taken and averaged to establish the zero point.

For determination of the 100° point, 15 ml of pure distilled water is placed in an eight-inch tube with two clean boiling stones. The thermometer is suspended within the tube from a wire held by a clamp so that the bulb of the thermometer is 30 mm above the surface of the liquid. By means of a burner the lower end of the tube is heated until the liquid boils briskly. This is continued until steam issues from the mouth of the tube. When the temperature reading has become nearly constant, several readings are taken at short intervals. The barometric pressure and the length of the mercury column extending above the mouth of the tube are noted. By means of a second thermometer, the temperature at the midpoint of the exposed part is ascertained, and the proper stem correction is computed in accordance with the directions given on pages 50–51. The barometric and stem corrections are added to the observed temperature, and this gives the 100° point.

Bromobenzene and naphthalene may be used to determine the points 156° and 218°, respectively. About 10 g of the substance used is placed in the tube with two boiling stones. The thermometer is inserted through a two-hole cork and adjusted as before. A tube 8 mm in diameter and 400–500 mm in length is inserted through the other hole to serve as an air condenser. After the substance boils and gentle refluxing has begun, readings are taken at short intervals, and the same procedure is followed as before.

The determinations arrived at in this manner are employed in making corrections. If the variation is less than 0.5° it may be neglected, as the accuracy of ordinary thermometer scales is limited to this difference. If, however, the variation exceeds 0.5°, it must be taken into account, and the necessary correction is added or subtracted from the observed temperature. In this case it is assumed that the bore of the capillary is uniform throughout. For example, assume that the zero point is found to be +0.7°, while the 100° point shows no variation. It is obvious that the reading at any intermediate temperature will vary from that observed by a proportionate amount. Thus, if the temperature recorded by the thermometer is 30°, the correction is $-0.7° \times \frac{(100\text{-}30)°}{100} = -0.49°$, and the true reading is $30° - 0.5° = 29.5°$.

Table 6

REFERENCE COMPOUNDS FOR CALIBRATION OF THERMOMETERS

SUBSTANCE	FIXED POINT °C.
Water (ice)	0° melting point
Chloroform	61.3° boiling point
Naphthalene	80.8° melting point
Water	100.0° boiling point
Benzoic acid	121.7° melting point
Bromobenzene	156.2° boiling point
Salicylic acid	159.8° melting point
Naphthalene	218.0° boiling point

V. FREEZING MIXTURES

In laboratory work it is often necessary to obtain lower temperatures than that of the room. In such cases various mixtures of ice and salts are used to lower the temperature. The most common is an intimate mixture of commercial sodium chloride and finely chopped ice. There is a definite limit to the depression of temperature that can be obtained with each of the mixtures given in Table 7.

Table 7

FREEZING MIXTURES

MIXTURE	TEMPERATURE ATTAINED BY MIXTURE, °C.
Ammonium chloride 30 g Water at 13° 100 ml	−5
Sodium thiosulfate 110 g Water at 11° 100 ml	−8
Ammonium nitrate 60 g Water 13° 100 ml	−13
Sodium chloride 33 g Ice (chopped) 100 g	−21
Calcium chloride ($CaCl_2 \cdot 6H_2O$) 100 g Ice (chopped) 80 g	−40
Calcium chloride ($CaCl_2 \cdot 6H_2O$) 100 g Ice (chopped) 70 g	−54
Alcohol and solid carbon dioxide	−72
Chloroform and solid carbon dioxide	−77
Acetone and solid carbon dioxide	−77

VI. DRYING AGENTS FOR ORGANIC LIQUIDS

Drying agents are used to remove small amounts of water from organic compounds. The desirable features which are to be considered in selecting a drying agent are: (1) it should not react or combine with the compound to be dried; (2) it should not catalyze polymerizations or condensation reactions; (3) it should have a high drying power; (4) it should be economical (if the initial cost is high, it should be possible to regenerate it by dehydration). Table 8 lists a number of drying agents.

Table 8

COMMON DRYING AGENTS FOR ORGANIC COMPOUNDS

Anhydrous Substance	Applicable to	Not Applicable to	Drying Power	Relative Efficiency	Price[a] per lb. in 1942
Calcium chloride	Hydrocarbons, halides, ethers, esters	Hydroxy and amino compounds	High below 30°	Medium	$0.40
Calcium sulfate ("Drierite")	All compounds	None	Low	Good	0.75
Magnesium sulfate	All compounds	None	High	Good	1.05
Potassium carbonate	Amines, alcohols, ketones	Acids	Medium	Medium	0.75
Potassium hydroxide	Amines, hydrazines, saturated hydrocarbons	Most compounds	High	Good	0.65[b]
Phosphorus pentoxide	Halides, hydrocarbons, nitriles	Most compounds	High	Excellent	1.10
Sodium hydroxide	Amines, hydrazines, saturated hydrocarbons	Most compounds	High	Excellent	0.50[b] 0.25[c]
Sodium metal[d]	Ethers, saturated hydrocarbons	Most compounds	High	Excellent	0.85

[a] Prices are approximate, and subject to variations.
[b] Pellets.
[c] Flake—commercial grade.
[d] Danger is involved in its use.

VII. CLEANING SOLUTIONS

Chromic acid cleaning mixture. Dissolve 10 g of sodium dichromate in 10 ml of water in a 400 ml beaker. Add slowly with careful stirring 200 ml of concentrated sulfuric acid. The temperature will rise to nearly 80°. Allow the mixture to cool to about 40° and place in a dry glass-stoppered bottle. Care should be exercised in making and handling this solution.

Trisodium phosphate solution. Glassware which does not contain tars may be cleaned with a 15 per cent solution of trisodium phosphate. A warm solution with the aid of an abrasive powder, such as pumice, is safer to handle and cleans as well as or better than chromic acid solutions.

VIII. PREPARATION OF PIPETTES AND PIPETTE DROPPERS

For semimicro work a number of small pipettes and pipette droppers are used. Pipette droppers having a glass tube 80–90 mm in length and 6 mm in diameter (1–2 mm at the point) are commercially available. Pipettes and pipette droppers of greater length and smaller capillary diameter are prepared as needed.

Pipettes for semimicro separation of immiscible liquids. In conjunction with the use of the separatory tube for separating two immiscible liquids, a pipette with a long capillary thread is very useful for removing the last few drops. In the separation of organic liquids from water or in the extraction of acqueous liquids from ether it is extremely difficult to remove every drop of water. Droplets of water adhere to the sides of the tube or separatory funnel, or remain suspended in the organic liquid, and on standing accumulate and form a thin layer. This can be removed with a pipette having a capillary thread 60–80 mm in length and 0.05–08 mm in diameter at the end of the capillary. A rubber bulb fitted to the wide end of the tube completes the capillary pipette.

To prepare a pipette, clean thoroughly with soap and water a piece of soft glass tubing 200 mm in length and 6–8 mm in diameter. Rinse well first with tap water and then with distilled water. Allow it to dry. Use either a good Bunsen flame or, if not familiar with elementary manipulations, use a burner provided with a wing top. Grasp the ends of the glass tubing with both hands and rotate it between the thumb and index finger over the flame. When the glass has softened enough to bend easily, remove from the flame and draw gently and steadily lengthwise until the length has doubled. Hold in place until the glass has hardened and then lay it carefully on an asbestos mat. The capillary is then cut in about the middle. The wide end of the pipette is heated until it is fire polished. If the glass tubing used is of 6-mm bore, the wide end is flanged in order to form a tight fit with the rubber bulb. To flange the end, heat it in the flame until the tube has softened; then press firmly against an asbestos pad. The operation is repeated until a flange 7–8 mm in diameter is formed.

Pipette droppers. Pipette droppers of various sizes are made by a method similar to that described for the capillary pipette. A piece of glass tubing 160 mm in length and 6 mm in diameter is heated over the flame and then pulled very slowly until the length of the tube has increased to 180–190 mm. The tube is held in place until cold and then the drawn part is cut into two equal lengths. The capillary end is heated carefully in the flame to smooth the glass, and the wide end is flanged as before. It is suggested that several of these droppers be made since the rubber bulb may be changed from one dropper to another.

IX. PREPARATION AND SEALING OF A BOMB TUBE

Pyrex combustion tubes are available for macro, semimicro, and micro work. So-called "bomb" tubes with one end closed and with a ready-made constriction for heating under pressure may be obtained in several sizes. For macro work a tube having an outside diameter of 22 mm and a length of 600–700 mm is used. For semimicro work the dimensions of the tube are 10 × 200 mm or 20 × 250 mm.

If the temperature at which the bomb tube is to be heated does not exceed 100°, an ordinary ignition tube 20 × 150 mm (Pyrex glass No. 172) may be used and the constriction made as follows. Hold the closed end of the tube with the left hand and heat the open end over a small smoky flame of the blast lamp. Rotate the tube and, after it has been heated for a minute or two, increase the size of the flame and turn on the air or oxygen until a good blue flame has been obtained. Grasp with the right hand a glass rod about 150 mm long and heat it in the zone of the flame opposite the region in which the tube is heated. When the glass in both tube and rod is near the fusion point press the rod lightly against the inside wall of the tube. Adjust the flame quickly to a narrow point and heat the junction until the glass is fused and a good seal is obtained. Shut off the air and heat the tube over the smoky flame for a few minutes. Then align tube and rod. Increase the flame and heat the tube about 30 mm below the seal. As the glass softens, the wall of the tube grows thicker in the region heated by the intense flame. Holding the tube straight in the left hand at an angle of 45°, rotate it continuously with the right hand. When the inside diameter of the tube has been reduced to about half, withdraw the tube to a short distance above the flame and draw the end out cautiously until the constricted part has attained a length of about 20–25 mm and a diameter of about 8 mm. Shut off the air and heat the constricted portion over the smoky flame for several minutes. The tube should then be allowed to cool to room temperature.

The bomb tube is charged with the material to be heated under pressure. The tube should be no more than half full and preferably no more than one-third full. The tube is immersed upright in an ice-salt mixture and cooled for 10–15 minutes. Heat by means of a small smoky flame while the tube is kept in the ice bath. Open the air and adjust the burner to produce a hot flame. Hold the tube in the left hand by means of asbestos paper, and the rod with the right hand, and rotate the tube, keeping the constricted portion in the hot part of the flame. When the glass has softened, begin to draw it out slowly. Finally remove the tube from the flame and, holding it vertically, draw out slowly the thickened part to form a capillary. Adjust the flame quickly to a narrow point and direct it against the capillary, holding the tube slightly inclined. Seal off the tube by cautiously pulling apart the upper portion of the tube. Shut off the air at once and direct the smoky flame against the capillary. It is best to clamp the tube and allow a small smoky flame to play upon the capillary for 5–10 minutes. The tube is allowed to cool and is then heated, in the bomb furnace. Directions for opening the tube are given on page 321.

X. DENSITIES AND PERCENTAGE COMPOSITIONS OF VARIOUS SOLUTIONS

Table 9

DENSITY AND PERCENTAGE COMPOSITION OF AQUEOUS ETHYL ALCOHOL SOLUTIONS

Per cent alcohol by volume	Density at 20°/4° C	Per cent alcohol by weight	Grams of alcohol per 100 ml	Per cent alcohol by volume	Density at 20°/4° C	Per cent alcohol by weight	Grams of alcohol per 100 ml
1	.99849	.79	.79	65	.9021	57.20	51.60
2	.99701	1.59	1.59	70	.8900	62.45	55.60
3	.99557	2.39	2.38	75	.8773	67.88	59.54
4	.99417	3.20	3.18	80	.8639	73.50	63.51
5	.99281	4.00	3.97	85	.8496	79.40	67.48
10	.98660	8.04	7.93	90	.8339	85.70	71.45
15	.98114	12.13	11.90	91	.8306	87.00	72.24
20	.97608	16.26	15.87	92	.8272	88.30	73.04
25	.97097	20.43	19.84	93	.8236	89.60	73.83
30	.96541	24.66	23.81	94	.8199	91.00	74.63
35	.95910	28.96	27.78	95	.8161	92.41	75.42
40	.95185	33.35	31.74	96	.8121	93.81	76.21
45	.94364	37.84	35.71	97	.8079	95.35	77.00
50	.9344	42.48	39.70	98	.8035	96.85	77.80
55	.9244	47.25	43.65	99	.7989	98.37	78.60
60	.9136	52.80	47.64	100	.7939	100.00	79.39

Table 10

DENSITY AND PERCENTAGE COMPOSITION OF AQUEOUS METHYL ALCOHOL SOLUTIONS

Per cent CH_3OH by weight	Density 15°/4° C	Per cent CH_3OH by volume	Per cent CH_3OH by weight	Density 15°/4° C	Per cent CH_3OH by volume	Per cent CH_3OH by weight	Density 15°/4° C	Per cent CH_3OH by volume
1	.99727	1.25	40	.93720	47.11	93	.81568	95.33
2	.99543	2.50	50	.91852	57.71	94	.81285	96.02
3	.99370	3.75	60	.89781	67.69	95	.80999	96.70
4	.99198	4.99	70	.87507	76.98	96	.80713	97.37
5	.99029	6.22	80	.85048	85.50	97	.80428	98.04
10	.98241	12.35	90	.82396	93.19	98	.80143	98.70
20	.96814	24.33	91	.82124	93.92	99	.79859	99.35
30	.95366	35.95	92	.81849	94.63	100	.79577	100.00

Table 11

DENSITY AND PERCENTAGE COMPOSITION OF AQUEOUS SOLUTIONS OF SODIUM SALTS IN COMMON USE

Sodium Carbonate			Sodium Chloride			Sodium Nitrite		
Per cent Na_2CO_3 by weight	Density	Grams per 100 ml	Per cent NaCl by weight	Density	Grams per 100 ml	Per cent $NaNO_2$ by weight	Density	Grams per 100 ml
1	1.0086	1.009	1	1.0053	1.005	1	1.0058	1.006
2	1.0190	2.038	2	1.0125	2.025	2	1.0125	2.025
4	1.0398	4.159	4	1.0268	4.107	4	1.0260	4.104
6	1.0606	6.364	6	1.0413	6.248	6	1.0397	6.238
8	1.0816	8.653	8	1.0559	8.447	8	1.0535	8.428
10	1.1029	11.03	10	1.0707	10.71	10	1.0675	10.68
12	1.1244	13.49	12	1.0857	13.03	12	1.0816	12.98
14	1.1463	16.05	14	1.1009	15.41	14	1.0959	15.34
16	1.1682	18.50	16	1.1162	17.86	16	1.1103	17.76
18	1.1805	21.33	18	1.1319	20.37	18	1.1248	20.25
20	1.2132	24.26	20	1.1478	22.96	20	1.1394	22.79

Table 12

DENSITY AND PERCENTAGE COMPOSITION OF COMMON ACIDS

Hydrochloric Acid

Per cent HCl by weight	Density 20°/4° C	Grams HCl per 100 ml	Per cent HCl by weight	Density 20°/4° C	Grams HCl per 100 ml	Per cent HCl by weight	Density 20°/4° C	Grams HCl per 100 ml
1	1.003	1.01	14	1.067	14.95	28	1.139	31.90
2	1.008	2.01	16	1.077	17.24	30	1.149	34.48
4	1.008	4.07	18	1.088	19.58	32	1.159	37.10
6	1.028	6.16	20	1.098	21.96	34	1.169	39.75
8	1.037	8.30	22	1.108	24.38	36	1.179	42.44
10	1.047	10.47	24	1.118	26.85	38	1.188	45.10
12	1.057	12.69	26	1.129	29.35	40	1.198	47.92

Nitric Acid

Per cent HNO_3 by weight	Density 20°/4° C	Grams HNO_3 per 100 ml	Per cent HNO_3 by weight	Density 20°/4° C	Grams HNO_3 per 100 ml	Per cent HNO_3 by weight	Density 20°/4° C	Grams HNO_3 per 100 ml
1	1.0036	1.004	25	1.1469	28.67	65	1.3913	90.43
2	1.0091	2.018	30	1.1800	35.40	70	1.4134	98.94
3	1.0146	3.044	35	1.2140	42.49	75	1.4337	107.5
4	1.0201	4.080	40	1.2463	49.85	80	1.4521	116.2
5	1.0256	5.128	45	1.2783	57.52	85	1.4686	124.8
10	1.0543	10.54	50	1.3100	65.50	90	1.4826	133.4
15	1.0842	16.26	55	1.3393	73.66	95	1.4932	141.9
20	1.1150	22.30	60	1.3667	82.00	100	1.5129	151.3

SULFURIC ACID

Per cent H_2SO_4 by weight	Density 20°/4° C	Grams H_2SO_4 per 100 ml	Per cent H_2SO_4 by weight	Density 20°/4° C	Grams H_2SO_4 per 100 ml	Per cent H_2SO_4 by weight	Density 20°/4° C	Grams H_2SO_4 per 100 ml
1	1.0051	1.005	25	1.1783	29.46	65	1.5533	101.0
2	1.0118	2.024	30	1.2185	36.56	70	1.6105	112.7
3	1.0184	3.055	35	1.2599	44.10	75	1.6692	125.2
4	1.0250	4.100	40	1.3028	52.11	80	1.7272	138.2
5	1.0317	5.159	45	1.3476	60.64	85	1.7786	151.2
10	1.0661	10.66	50	1.3951	69.76	90	1.8144	163.3
15	1.1020	16.53	55	1.4453	79.49	95	1.8337	174.2
20	1.1394	22.79	60	1.4983	89.90	100	1.8305	183.1

Table 12—Continued

ACETIC ACID

Per cent CH_3COOH	Density 20°/4° C	Grams per 100 ml	Per cent CH_3COOH	Density 20°/4° C	Grams per 100 ml	Per cent CH_3COOH	Density 20°/4° C	Grams per 100 ml
1	.9996	.9996	10	1.0125	10.13	60	1.0642	63.85
2	1.0012	2.002	20	1.0263	20.53	70	1.0685	74.80
3	1.0025	3.008	30	1.0384	31.15	80	1.0700	85.60
4	1.0040	4.006	40	1.0488	41.95	90	1.0661	95.95
5	1.0055	5.028	50	1.0575	52.88	100	1.0498	105.0

Formic Acid

Per cent HCOOH	Density 20°/4° C	Grams per 100 ml	Per cent HCOOH	Density 20°/4° C	Grams per 100 ml	Per cent HCOOH	Density 20°/4° C	Grams per 100 ml
1	1.0019	1.002	10	1.0246	10.25	60	1.1424	68.54
2	1.0044	2.009	20	1.0488	20.98	70	1.1655	81.59
3	1.0070	3.021	30	1.0729	32.19	80	1.1860	94.88
4	1.0093	4.037	40	1.0963	43.85	90	1.2044	108.4
5	1.0115	5.058	50	1.1207	56.04	100	1.2212	122.1

Hydrobromic Acid

Per cent HBr	Density 20°/4° C	Grams per 100 ml	Per cent HBr	Density 20°/4° C	Grams per 100 ml	Per cent HBr	Density 20°/4° C	Grams per 100 ml
10	1.0723	10.7	30	1.2580	37.7	50	1.5173	75.8
20	1.1579	23.2	40	1.3772	56.1	60	1.6787	100.7

Phosphoric Acid

Per cent H_3PO_4	Density 20°/4° C	Grams per 100 ml	Per cent H_3PO_4	Density 20°/4° C	Grams per 100 ml	Per cent H_3PO_4	Density 20°/4° C	Grams per 100 ml
10	1.0632	10.5	60	1.426	85.5	90	1.746	157.1
30	1.1805	35.4	70	1.526	106.8	100	1.870	187
50	1.335	66.7	80	1.633	130.6			

XI. VAPOR PRESSURES OF VARIOUS SUBSTANCES AT TEMPERATURES OF 10° TO 140° C.

(in millimeters of mercury)

SUBSTANCE[a]	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	120°	140°
Water	9.2	17.5	31.8	55.3	92.5	149.3	233.7	355.1	526.7	760	1489	2711
Ethyl alcohol	23.6	43.9	78.8	135.3	222.2	352.7	542.5	812.6	1180	1710	3200	5690
Methyl alcohol	54.7	96.0	160.0	260.5	406	625	930	1340	1900	2640	4750	8100
Ether	272	442	647	921	1280	1720	2280	3000	3800	4850		
Benzene	45.4	74.7	118	181	269	388	547	753	1016	1344	2238	3520
Acetone	115.6	184.8	283	421	612	861	1190	1611	2142	2797	4547	6974
Acetic acid	—	11.7	30.6	35	56	89	136	202	294	417	794	1414
Chloroform	100	159	246	366	527	739	1019	1403	—	2429	3926	6000
Carbon tetrachloride	56	91	143	216	317	451	622	843	1122	1463	2400	3700
Aniline	—	—	—	—	2.4	5.7	10.6	18	29.2	45.7	96.6	204
Benzoyl chloride	—	—	—	1.1	2.4	4.8	8.2	13.6	21.8	33.9	75.1	152
n-Butyl alcohol	—	4.4	9.5	18.6	33.7	59.2	112.3					
Cyclohexane	—	47	76.9	131.6	181.7	269	384	540.6	741.3	992	1304	2152
n-Hexane	76.8	122	189	281	408	576	796	1062	1407	1836	2982	4606
Naphthalene (solid)	0.02	0.05	0.13	0.32	0.81	1.83	3.9	7.4[b]	12.6	18.5	40	87.4
n-Octane	5.6	10.4	18.4	30.8	49.3	77.5	118	175	253	354	646	1114
Toluene	—	—	37	59	93	139	203	289	404	557	(100°) 760	
o-Xylene	6.4	10	16	24	36	52	76	109	153	213	294	690
Bromobenzene	—	—	5.7	10	16.9	27.6	43.5	68.2	97.7	141	275	496

[a] The first eight compounds listed are common solvents.
[b] Liquid.

XII. REFERENCE BOOKS FOR BEGINNERS IN PRACTICAL ORGANIC CHEMISTRY AND LABORATORY METHODS

Organic Syntheses by Henry Gilman, collective volume I (New York: John Wiley, 1940).

Organic Syntheses (New York: John Wiley) annual volumes XI–XXII.

Systematic Organic Chemistry by William M. Cumming, I Vance Hopper, and T. Sherlock Wheeler, 3rd edition (New York: D. Van Nostrand, 1937).

Practical Organic Chemistry by Frederick G. Mann and Bernard C. Saunders, 2nd edition (New York: Longmans, Green, 1938).

Practical Organic Chemistry by Julius B. Cohen, 3rd edition (New York: Macmillan, 1924).

Laboratory Methods of Organic Chemistry by L. Gattermann, translated from the 24th German edition (New York: Macmillan, 1941).

Experiments in Organic Chemistry by Louis F. Fieser, 2nd edition (Boston: D. C. Heath, 1941).

Elementary Laboratory Experiments in Organic Chemistry by Roger Adams and John R. Johnson, 3rd edition (New York: Macmillan, 1940).

Laboratory Practice of Organic Chemistry by G. Ross Robertson (New York: Macmillan, 1937).

Practice of Organic Chemistry by Homer Adkins, S. M. McElvain, and M. W. Klein, 3rd edition (New York: McGraw-Hill, 1940).

An Introduction to the Preparation and Identification of Organic Compounds by Robert D. Coghill and Julian M. Sturtevant (New York: McGraw-Hill, 1936).

Identification of Pure Organic Compounds by Ernest H. Huntress and Samuel P. Mulliken (New York: John Wiley, 1941).

The Systematic Identification of Organic Compounds by Ralph L. Shriner and Reynold C. Fuson (New York: John Wiley, 1935).

Qualitative Organic Chemistry by Neil Campbell (New York: D. Van Nostrand, 1939).

Laboratory Technique in Organic Chemistry by Avery A. Morton (New York: McGraw-Hill, 1938).

Micromethods of Quantitative Organic Analysis by Joseph B. Niederl and Victor Niederl, 2nd edition (New York: John Wiley, 1942).

Introduction to the Microtechnique of Inorganic Chemistry by A. A. Benedetti-Pichler (New York: John Wiley, 1942).

XIII. WRITE-UP OF A TYPICAL EXPERIMENT

A. PAGE FROM A STUDENT'S NOTEBOOK[1]

October 19, 1942. Richard Anderson

Experiment 19(B) <u>Preparation of n-Butyl Bromide (M)</u>

<u>Object:</u> To illustrate the preparation of an alkyl halide through the reaction of an alcohol with a Halogen acid.

Equation: $CH_3CH_2CH_2CH_2OH + NaBr + H_2SO_4 \rightarrow CH_3CH_2CH_2CH_2Br + NaHSO_4 + H_2O$

Moles	0.5	0.63	0.95	0.5
Grams	37 (46 ml)	65.2	93 (50 ml)	68.5
B.P.	117°	—	290°	101°
sp.g./20°	0.810	—	1.84	1.299

Apparatus

1 Flask. 500 ml
1 condenser
Ring Stand
Clamps Burner
sep.-funnel
Dist flask 125 ml.
Graduate
Funnel
6 ft. 6 mm Glass tubing
2 Rec. flasks 125 ml.
Thermometer.

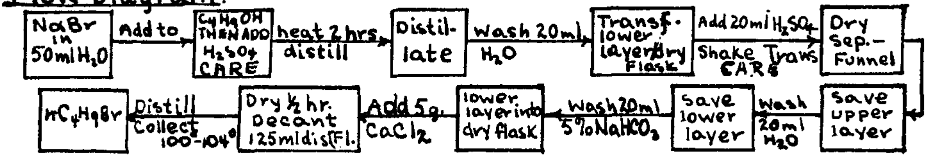
chemicals

46 ml $n\text{-}C_4H_9OH$
66 g NaBr
70 ml conc H_2SO_4
5 g Anhyd. $CaCl_2$
20 ml. $NaHCO_3$ 5%

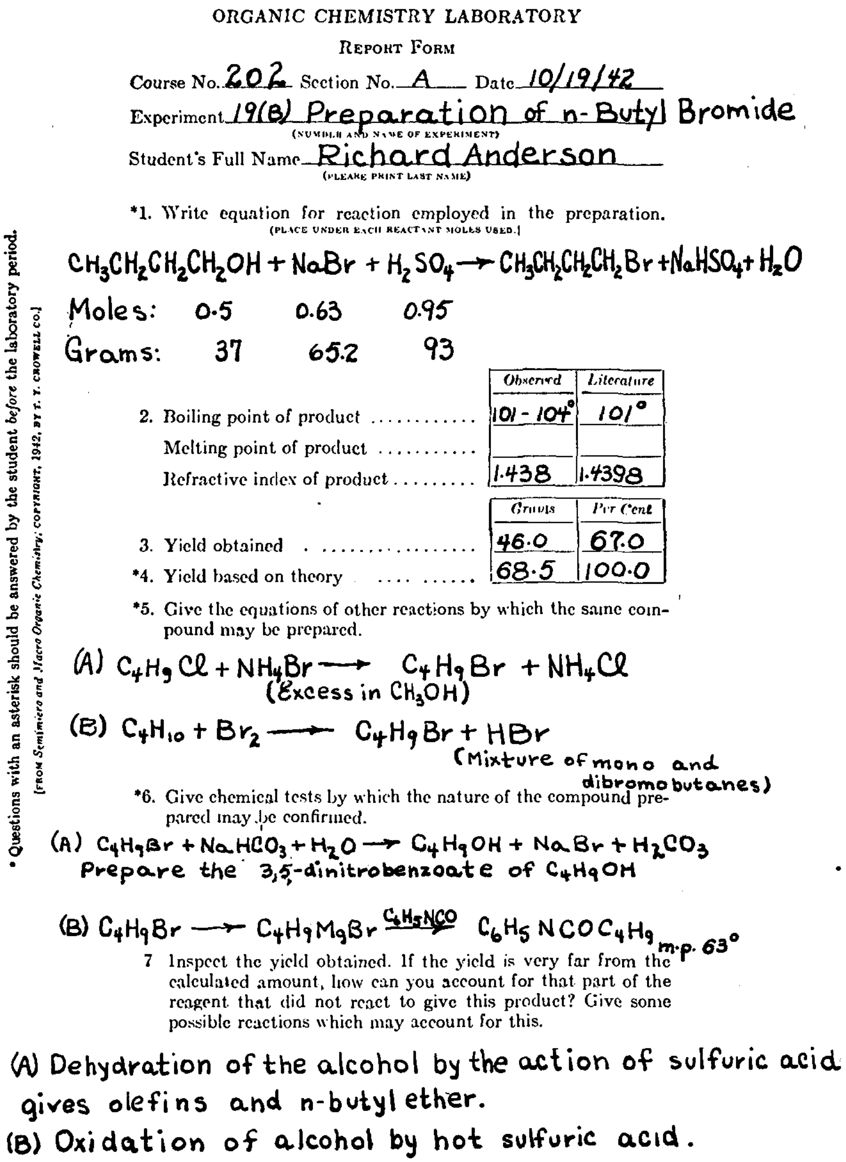
<u>Qualitative Tests:</u>

1. Hydrolyze to C_4H_9OH and prepare 3,5-dinitrobenzoate.
2. Prepare $C_4H_9MgBr \xrightarrow{C_6H_5N{=}CO} C_6H_5NHCOC_4H_9$ anilide m.p. 63°

<u>Flow Diagram:</u>



<u>Laboratory Entries:</u> The method followed is outlined in the above flow diagram. Sulfuric acid added acts as a catalyst and reacts with the sodium bromide to form hydrobromic acid. The distillate consisted of: water, n-butyl bromide, butenes, unchanged alcohol, sulfur dioxide and hydrogen bromide. Washing with water removed the greater part of the last three. Washing with conc. H_2SO_4 removed the olefins and remainder of alcohol. Traces of acids were removed by washing with water and dilute solution of sodium bicarbonate. The halide was dried and distilled. The yield was 46 g. (67% of theory). The refractive index of the compound prepared was found to be 1.438.



ORGANIC CHEMISTRY LABORATORY

REPORT FORM

Course No. 202 Section No. A Date 10/19/42

Experiment 19(B) Preparation of n-Butyl Bromide
(NUMBER AND NAME OF EXPERIMENT)

Student's Full Name Richard Anderson
(PLEASE PRINT LAST NAME)

*1. Write equation for reaction employed in the preparation.
(PLACE UNDER EACH REACTANT MOLES USED.)

$CH_3CH_2CH_2CH_2OH + NaBr + H_2SO_4 \rightarrow CH_3CH_2CH_2CH_2Br + NaHSO_4 + H_2O$

Moles:	0.5	0.63	0.95
Grams:	37	65.2	93

	Observed	Literature
2. Boiling point of product	101 - 104°	101°
Melting point of product		
Refractive index of product	1.438	1.4398

	Grams	Per Cent
3. Yield obtained	46.0	67.0
*4. Yield based on theory	68.5	100.0

*5. Give the equations of other reactions by which the same compound may be prepared.

(A) $C_4H_9Cl + NH_4Br \rightarrow C_4H_9Br + NH_4Cl$
(Excess in CH_3OH)

(B) $C_4H_{10} + Br_2 \rightarrow C_4H_9Br + HBr$
(Mixture of mono and dibromobutanes)

*6. Give chemical tests by which the nature of the compound prepared may be confirmed.

(A) $C_4H_9Br + NaHCO_3 + H_2O \rightarrow C_4H_9OH + NaBr + H_2CO_3$
Prepare the 3,5-dinitrobenzoate of C_4H_9OH

(B) $C_4H_9Br \rightarrow C_4H_9MgBr \xrightarrow{C_6H_5NCO} C_6H_5NCOC_4H_9$ m.p. 63°

7 Inspect the yield obtained. If the yield is very far from the calculated amount, how can you account for that part of the reagent that did not react to give this product? Give some possible reactions which may account for this.

(A) Dehydration of the alcohol by the action of sulfuric acid gives olefins and n-butyl ether.

(B) Oxidation of alcohol by hot sulfuric acid.

• Questions with an asterisk should be answered by the student *before* the laboratory period.

[FROM *Semimicro and Macro Organic Chemistry*; COPYRIGHT, 1942, BY T. Y. CROWELL CO.]

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