PRACTICAL APPLIED ELECTRICITY

MORETON

Practical Applied

ELECTRICITY

A BOOK IN PLAIN ENGLISH FOR THE PRACTICAL MAN. THEORY, PRACTICAL APPLICATIONS AND EXAMPLES

By

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PREFACE TO THE THIRD EDITION

In bringing out the third edition of Practical Applied Electricity, the body of the book, with the exception of a few minor changes, remains the same as in the second edition. Several pages of material, giving a summary of the more common direct- and alternating-current relations, have been added at the back of the book.

This book is intended primarily for those persons who are desirous of obtaining a practical knowledge of the subject of Electricity, but are unable to take a complete course in Electrical Engineering. It is the opinion of the author that such persons should have a thorough understanding of the fundamental principles of the subject, in order that they may easily understand the applications in practice. Numerous examples are solved throughout the book, which serve to illustrate the practical application of certain laws and principles and give the reader an opportunity to more readily grasp their true significance.

The text is based, to a certain extent, upon a series of lectures given in the evening classes in the Department of Electrical Engineering at Armour Institute of Technology. The arrangement is not the one usually followed, and to some it may not appear to be logical; but it is one the author has found very satisfactory.

Although the book was not originally intended to be used as a text-book, it is, however, especially adapted for use in the practical courses given in the various High and Manual Training Schools, and at the same time gives a substantial groundwork for the more advanced college and university courses.

The author wishes to express his thanks to the various manufacturing companies who have been very kind in supplying material and cuts, and to Professor E. H. Freeman, head of the Department of Electrical Engineering of Armour Institute of Technology, for a number of valuable suggestions.

DAVID PENN MORETON

ARMOUR INSTITUTE OF TECHNOLOGY

DEDICATED

TO MY

FATHER AND MOTHER

CHARLES BROWN MORETON

AND

SALLIE PENN MORETON

IN

APPRECIATION OF THEIR UNTIRING EFFORTS WHILE I WAS RECEIVING MY EARLY EDUCATION

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PRACTICAL APPLIED ELECTRICITY

CHAPTER I

THE ELECTRICAL CIRCUIT AND ELECTRICAL UNITS

1. **Electricity.**—There are certain phenomena of nature that are taking place about us every day which we call electrical, and to that which produces these phenomena we give the name **electricity.** The exact nature of electricity is not known, yet the laws governing its action, under various conditions, are well understood, just as the laws of gravitation are known, although we cannot define the constitution of gravity. Electricity is neither a gas nor a liquid; its behavior sometimes is similar to that of a fluid so that it is said to flow through a wire. This expression of flowing does not really mean there is an actual movement in the wire, similar to the flow of water in a pipe, when it possesses electrical properties,. but is simply a convenient expression for the phenomena involved. According to the modern electron theory of electricity, there is a movement of some kind taking place in the circuit, but the real nature of this movement is not as yet very well understood. A great many electrical problems can be easily understood by comparing them to a similar hydraulic problem, where the relation of the various quantities and the results are apparent under given conditions, and on account of the similarity of the two, the hydraulic analogy will often be used to illustrate what actually takes place in the electrical circuit.

2. **Electrical Circuit.**—The electrical circuit is the path in which the electricity moves. The properties of electrical circuits and the electrical quantities associated with them make an appropriate beginning for the study of the subject of electrical engineering, for electrical energy is in almost all

practical applications utilized in circuits. These circuits are of various forms and extent, and are made for many different purposes, but all possess to a greater or less extent the same properties and involve the same electrical quantities. Suppose, for example, a door bell that is operated from two

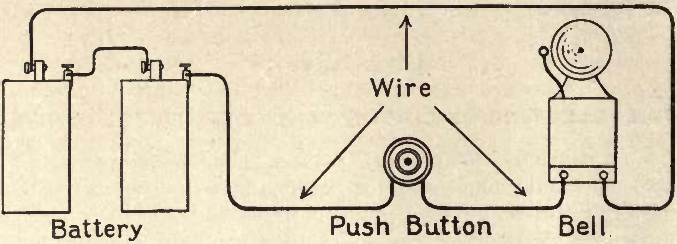


Fig. 1

or three dry cells, as shown in Fig. 1. This combination forms an electrical circuit, typical of all electrical circuits. It contains a source of electrical energy (the battery), an energy transforming device (the bell), and the necessary connecting materials (wire and push button). It is closed upon itself and like the circumference of a circle has neither beginning nor end. (A table of symbols commonly used in representing the different pieces of electrical apparatus is given in Chapter 20.)

3. **Hydraulic Analogy of the Electrical Circuit.**—Before considering the relation of the various electrical quantities associated with the electric circuit it would, no doubt, be best to make a brief study of a simple hydraulic problem, similar to the electrical circuit, and the relation of the various quantities involved. It must be clearly understood that the similarity between the water and the electrical circuits is in regard to action only, and does not in any way imply an identity between electricity and water. A simple hydraulic circuit is shown in Fig. 2, where (P) is a pump that supplies water, under a constant pressure, to the pipe (T). The water is conducted through the pipe (T) to the tank (K), the amount of water flowing through the pipe being regulated by the valve (V). The pipe (T) is composed of a number of different pieces of pipe, differing in area of

cross-section, length, and condition of their inner surface, some being rough and some smooth. Pressure gauges (G_1, G_2, etc.) are placed along the pipes at certain intervals, as shown in the figure, to indicate the pressure in the pipe at different points. Assume, first, that the valve (V) is closed; no water will then be flowing through the pipe and all of the various pressure gauges will indicate the same pressure in the pipe. Assume, as a second condition, that the valve (V) is partly opened; there will be a flow of water in the pipe, and the pressure gauges will indicate a different pressure, their indications decreasing as you pass along the pipe, starting from the end attached to the pump. Opening the

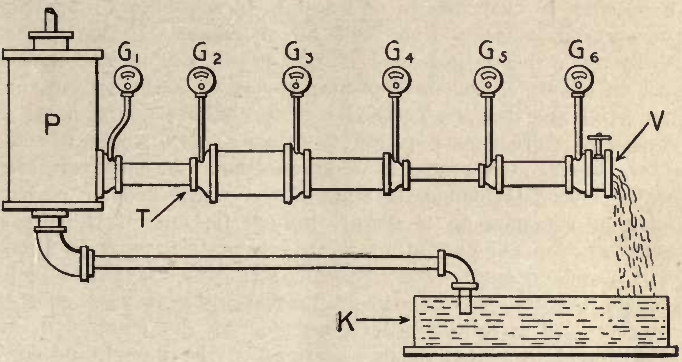


Fig. 2

valve still more will increase the flow of water and also the difference in indications of the various gauges. If the gauge (G_6) at the end of the pipe indicates zero pressure, it is apparent that the total pressure supplied by the pump has all been used in forcing the water through the pipe. If, on the other hand, the last gauge indicates a certain pressure, then the total pressure supplied by the pump has not all been used and there still remains a certain amount, neglecting that pressure required to force the water through the valve (V), that could be used in driving a water wheel, placed in such a position that the water could strike against the buckets on the wheel and cause it to rotate. The difference in pressure indicated by any two gauges is a measure of the pressure required to cause the water to flow between the two points where the gauges are connected to the pipe. If it were possible to have a pipe that would offer no opposition to the passage of the water through it, there would be no difference in the indications of the various gauges and the water would flow from the end of the pipe under the same pressure as that produced by the pump. Anything that increases the opposition to the flow of the water will increase the value of the pressure required to cause a certain quantity to pass through the section of pipe, between the pressure gauges, whose indications are being noted. Or, if the same pressure is maintained over a given section and its opposition to the passage of water is increased, the quantity passing in a given time will be decreased; similarly the quantity will be increased if the opposition is decreased. As an example, suppose a water motor is connected in the pipe (T) and it is perfectly free to turn, there will then be a very small pressure required to cause a certain quantity to flow through the motor in a given time. If, however, the water motor is loaded, it will offer a much greater resistance to the passage of water through it; and, if the pressure remains constant, the quantity passing in a given time will be decreased. The rate of flow can be maintained constant when the opposition increases by increasing the pressure. The total pressure supplied by the pump will be distributed over the various sections of the pipe in proportion to their opposition. The opposition offered by the pipe can be called its **resistance** and it will depend upon the area, length, nature of the inner surface, and any obstruction that might be in the pipe, such as sand, gravel, or sieves. The quantity of water passing a given point in a pipe in a unit of time, usually one second, is called the **current.** These three quantities, **pressure, current,** and **resistance,** are related to each other in a very simple way, as can be seen from the above problem, and this relation, expressed in the form of an equation is:

$$\text{Current} = \frac{\text{Pressure}}{\text{Resistance}} \qquad (1)$$

It must be remembered that this equation does not hold in its strictest sense for the hydraulic problem, but will serve to illustrate the relation between the electrical quantities that are to be discussed in one of the following sections.

4. Electrical Circuit Compared with Hydraulic Circuit.—In the electrical circuit, as indicated in Fig. 3, there is a source of electrical pressure, the battery, that corresponds to the pump in the hydraulic analogy. The wire by means of which the electricity is conducted corresponds in the hydraulic analogy to the pipe through which the water flows,

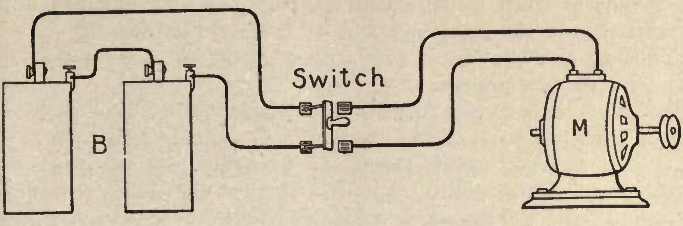


Fig. 3

while the electric motor (M), in Fig. 3, corresponds to the water motor referred to in the example under section (3). If all the electrical pressure is consumed in causing a given quantity of electricity to flow through the wire in a given time, there will be no pressure available to operate the electrical motor or any other electrical device, just as there would be no pressure available to operate the water motor in the hydraulic problem when all the pressure was used in causing the water to flow through the pipe. The difference in electrical pressure between any two points on the wire is a measure of the pressure required to cause a given quantity of electricity to pass from one of the points to the other in a given time. This difference in pressure will depend upon the opposition offered by the circuit between the two points and the quantity passing between them in a given time. With an increase in the opposition offered by the circuit there must be an increase in pressure to maintain a constant flow. If, on the other hand, the pressure remains constant and the opposition to the flow increases or decreases, there will be a decrease or increase in the quantity of electricity passing a certain point in the circuit in a given time.

5. **Electrical Quantities.**—There are three electrical quantities associated with the electrical circuit that correspond to those given for the hydraulic analogy. These quantities are the **current** of electricity, the **electromotive force** which causes the current, and the **resistance** which hinders the free flow of the electricity.

6. **Current of Electricity.**—The rate at which the movement, or flow, of electricity takes place is the current—for a uniform movement it is the amount of electricity flowing per unit of time—usually the second. The unit quantity of electricity is the **coulomb,** and if the rate of flow is such that one coulomb flows per second, there is said to be a current of one **ampere.**

At any instant the current is the same at all parts of a circuit having no branches, and it is the same for all points in each branch, where there are branches. A mistake is often made in thinking that the current is used up—that there is practically no current returning to the source of the electrical energy. Such a condition is not true. The current in the return conductor to the battery or dynamo is exactly the same as the current in the conductor carrying the electricity from the battery or dynamo. The current that leaves a motor, lamp, or bell is no different in value from that which enters them. It is the energy of the electricity that is used up, just as it is the energy possessed by the water that is imparted to the water wheel and causes it to rotate without the water itself being consumed. The symbol used in representing the current is the letter (I).

7. **Resistance.**—Resistance is that property possessed by substances which opposes the free flow of electricity, but does in no way tend to cause a flow in the opposite direction to that in which the electricity actually moves.

All substances resist the movement of electricity through them, but the resistance offered by some is very much greater than that offered by others, and as a result all materials may be grouped under one of two heads, namely, conductors and insulators.

Conductors are those substances offering relatively low resistance.

Insulators are those substances offering a high resistance as compared to conductors.

There is no such thing as a perfect conductor or a perfect insulator, but conductors and insulators are merely relative terms and define the degree to which a substance conducts. Metals have by far the least resistance of any substances and are used in electrical circuits where a minimum resistance is desired. The most common insulators in use are porcelain, glass, mica, stoneware, slate, marble, rubber, oils, paraffin, shellac, paper, silk, cotton, etc.

The unit in which resistance is measured is the **ohm,** and it is represented by the symbol (R).

8. **Electromotive Force.**—As every part of the circuit offers resistance to the flow of electricity, there must be some force, or pressure, to overcome this resistance and maintain the current. This is the **electromotive force** or electricity moving force. Electromotive force, or e.m.f., as it is abbreviated, can be generated in a number of different ways; perhaps the two most common are the chemical production in a primary cell and the mechanical generation by the process of electro-magnetic induction in a generator. Electromotive force does not create electricity, but simply imparts energy to it, as a mechanical force may produce motion in a body and as a result convey energy to the body. An electromotive force may exist without producing a current, just as a mechanical force may exist without producing motion. The unit in which electromotive force is measured is the **volt.**

9. **Electromotive Force and Potential Difference.**—The electromotive force in any circuit is the total generated electrical pressure acting in the circuit, while the potential difference is the difference in electrical pressure between any two points in the circuit. The electricity in its passage around the circuit loses some of its energy; hence, between any two points in the circuit there will be a difference in energy or potential possessed by the electricity. In overcoming the resistance of the wire between the points (A) and (B), Fig. 4, the electricity will lose some of its energy and will, therefore, have less potential at (B) than at (A), or, in other words, there is a difference in potential between (A) and (B). This difference in potential in the electrical circuit

is analogous to the difference in pressure between two points on the pipe in the hydraulic circuit. This potential difference, or p.d., as it is abbreviated, is due to the current through the resistance, for when the current stops, the difference in potential will no longer exist. The potential difference is measured in the same unit as the electromotive force, the **volt.** The sum of all the potential differences in any electrical circuit is numerically equal to the effective e.m.f. acting in the circuit. If two points can then be located on a circuit so that all the p.d.'s around the circuit will be between them, the potential difference between the points and the e.m.f. acting in the circuit will be numerically equal.

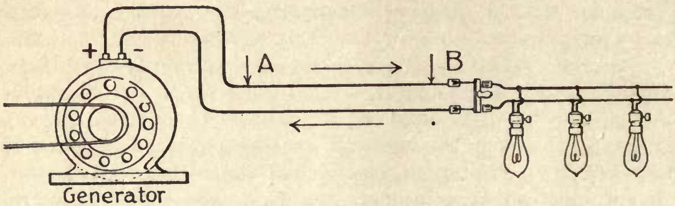


Fig. 4

10. **Ohm's Law.**—Current, electromotive force, and resistance are always present in an active circuit and there is a simple, but very important, relation connecting them. This relation was first discovered by Dr. G. S. Ohm in 1827 and has, as a result, been called **Ohm's Law.** Dr. Ohm discovered by experiment that the difference of potential, represented by the symbol (E), between any two points on a conductor, is, all other conditions remaining constant, strictly proportional to the current (I), or

$$E = \text{Constant} \times I \qquad (2)$$

By measuring (E) in volts and (I) in amperes, the constant in the above equation is numerically equal to the resistance, between the points, in ohms. The expression can then be reduced to the form

$$\text{Volts} = \text{Resistance} \times \text{Amperes}$$

$$E = RI \qquad \mathbf{(3)}$$

or, as it is usually written,

Amperes = Volts ÷ Ohms

$$I = \frac{E}{R} \qquad (4)$$

and as a third form,

Ohms = Volts ÷ Amperes

$$R = \frac{E}{I} \qquad (5)$$

The above relations hold true for all or any part of a circuit composed of metals and electrolytes, but it does not seem to be true for gases, under certain conditions, nor for insulators.

Example.—The total resistance of a certain circuit is 55 ohms. What current will a pressure of 110 volts produce in the circuit?

Solution.—The value of the current is given in terms of the pressure and the resistance in equation (4) and by a direct substitution in this equation we have

$$I = \frac{110}{55} = 2$$

Ans. 2 amperes.

Example.—A current of 10 amperes is produced in a circuit whose resistance is 12½ ohms. What pressure is required?

Solution.—The electrical pressure is given in terms of the resistance and the current in equation (3) and by a direct substitution in this equation we have

$$E = 12\tfrac{1}{2} \times 10 = 125$$

Ans. 125 volts.

11. Coulomb, Ampere, Ohm, and Volt.—The International Electrical Congress that met in Chicago in 1893 officially passed upon the following values for the **coulomb, ampere, ohm,** and **volt,** and they are known as the **practical** units.

(a) In defining the **coulomb** advantage is taken of the fact that electricity in passing through a solution of silver nitrate deposits silver on one of the conductors immersed in the solution and the amount deposited is proportional to the quantity of electricity that passed through the solution. (See chapter on "Instruments.") The coulomb will deposit, under standard conditions, .001 118 of a gram of silver.

(b) Since the current is the rate of flow of electricity, then the **ampere** is the unit rate of flow, or one coulomb per second, and its value is, therefore, that current which will deposit silver at the rate of .001 118 of a gram per second. When smaller currents are to be measured, the **milliampere,** or one-thousandth of an ampere, and the **microampere,** or one-millionth of an ampere, are frequently used.

(c) **The International ohm,** as nearly as known, is the resistance of a uniform column of pure mercury 106.3 centimeters long and 14.4521 grams in mass, at the temperature of melting ice. This makes the cross-section one square millimeter. The **microhm** is one-millionth of an ohm and the **megohm** is one million ohms. These units are very frequently used in the measurement of very small or very large resistances.

(d) The **volt,** the unit of electromotive force or potential difference, is that e.m.f. or p.d. which, when applied to a conductor having a resistance of one ohm, will produce in it a current of one ampere. One volt equals the $1000/1434$ part of the e.m.f. of a Clark Standard Cell at 15 degrees centigrade. A smaller unit, called the **millivolt,** or one-thousandth of a volt, is often used in measuring small e.m.f.'s and p.d.'s. Another unit, called the **kilovolt,** has a value of one thousand volts.

PROBLEMS ON OHM'S LAW

(1) The difference in potential between the terminals of a generator is 110 volts. If the generator is causing a current of 12 amperes in the circuit to which it is connected, what is the resistance of the circuit?

Ans. 9.17 ohms.

(2) What e.m.f. must a dynamo generate to supply an electroplating current of 20 amperes through a circuit whose total resistance is .2 ohms? Ans. 4 volts.

(3) An electric-car heater is supplied with a p.d. of 500

volts from the trolley. What must its resistance be in order that the current may not exceed 8 amperes?

Ans. 62.5 ohms.

(4) The difference in potential between the terminals of an incandescent lamp is 110 volts when there is a direct current of .5 ampere through the lamp. What is the resistance of the lamp? Ans. 220 ohms.

(5) The field circuit of a dynamo takes a current of 1.5 amperes from a 110-volt circuit. What is the resistance of the field winding? Ans. 73⅓ ohms.

(6) A certain bell requires a p.d. at its terminals of 8 volts to operate it. The bell has a resistance of 50 ohms. What current is required to operate the bell?

Ans. .16 ampere.

(7) An e.m.f. of 5 volts is connected to a line and bell having a combined resistance of 12½ ohms. What current is there through the bell? Ans. .4 ampere.

(8) A lamp has a hot resistance of 55 ohms and requires a current of 1 ampere to cause it to light up to full candle-power. What p.d. must exist between the terminals of the lamp when it burns at full candle-power?

Ans. 55 volts.

12. Electrical Force.—Force is defined as that which tends to produce motion, or a change of motion; thus a force must always be applied to a body to cause it to move, and a force must be again applied to cause the body to come to rest. It must be remembered that a force does not always produce motion, but only tends to produce it, as when you push on a brick wall you apply muscular force, but there is no motion. There are a number of different kinds of force: Gravitational force, as a result of which all bodies fall from a higher to a lower level: mechanical force, which is produced by the expansion of the steam in the engine cylinder, and may be used in driving a generator; and electrical force is that force which produces or tends to produce a movement of electricity. It is commonly produced in the primary battery or by an electrical generator.

13. Electrical Work or Energy.—When a force overcomes a certain resistance, work is done; or work is the result of a force acting through a certain distance. Force may exist without any work being done. Thus, a generator may be operating and generating an electrical force, but it is not sufficient to overcome the resistance between the terminals of the machine, therefore, no current is produced and the generator is not doing any work. If, however, a conductor be connected to the terminals of the generator, a current will be produced and as a result the generator will do work. The electrical work done by the dynamo will show itself as heat and the wire will become heated as a result. Energy is the ability to do work. Electrical energy, then, is the capacity or ability to do electrical work. Energy is measured in the same unit as work and it is numerically equal to the work done. Thus the energy possessed by a certain quantity of electricity, with respect to its energy at some other electrical level, is equal to the work done on or by the quantity in moving from the first to the second electrical level. When a quantity moves from a higher to a lower level, it gives up energy or does work; when it is moved from a lower to a higher electrical level, work is performed and the energy of the quantity of electricity is increased.

14.—The Joule.—The joule, the unit of electrical work or energy, is the amount of work performed in raising one coulomb of electricity through a difference in electrical pressure of one volt. Work is independent of the time. In other words, it will require the same amount of work to raise a certain weight a given height in one hour as would be required to raise it the same height in one minute. The name for the mechanical unit of work is a compound word in which one of the parts is a force unit and the other part is a distance unit. The unit commonly used is the **foot-pound,** the pound being the unit of force and the foot the unit of distance. The electrical work performed in an electrical circuit is equal to

$$\text{Joules} = \text{Volts} \times \text{Amperes} \times \text{Time (in seconds)} \quad (6)$$

Amperes times time is equal to the quantity of electricity moved, so that the right-hand portion of the above equation is the product of a certain quantity and the difference in electrical pressure through which it is moved.

15. **Electrical Power.**—Power is the rate of doing work, or the rate at which energy is expended. The unit of electrical power is a unit of electrical work performed in a unit of time, or a joule per second, and it is called the **watt,** represented by the symbol (W).

$$\text{Electrical Power} = \frac{\text{Electrical Work}}{\text{Time}} \qquad (7)$$

Substituting the value of the electrical work given in equation (6) in equation (7), we have

$$\text{Electrical Power} = \frac{\text{Volts} \times \text{Amperes} \times \text{Time}}{\text{Time}}$$

$$= \text{Volts} \times \text{Amperes, or} \qquad (8)$$

$$W = EI \qquad (9)$$

One watt, therefore, equals one volt multiplied by one ampere, or any product of volts and amperes whose result is unity. Equation (9) may be written

$$I = \frac{W}{E} \qquad (10)$$

or

$$E = \frac{W}{I} \qquad (11)$$

Example.—A 220-volt generator supplies 20 amperes to a motor. How many watts does the motor consume?

Solution.—Substituting directly in equation (9) we have

$$W = 220 \times 20 = 4400$$

Ans. 4400 watts.

Example.—An arc lamp requires 880 watts from a 110-volt circuit to operate it. What current does the lamp take?

Solution.—Substituting in equation (10) we have

$$I = \frac{880}{110} = 8$$

Ans. 8 amperes.

16. Mechanical Horse-Power.—If a body weighing 33000 pounds be raised one foot in one minute, there is a rate of working, or expenditure of energy, equivalent to one **horse-power** (abbreviated **h.p.**). The horse-power any machine is developing is equal to the foot-pounds of work done per minute divided by 33 000, or the foot-pounds of work done per second divided by 550.

17. Relation between the Watt and the Foot-Pound.—Dr. Joule discovered experimentally that

$$\text{One watt} = .7375 \text{ foot-pound per second} \qquad (12)$$

or

$$\text{One foot-pound per second} = 1.356 \text{ watts} \qquad (13)$$

18. Electrical Horse-Power.—Since the mechanical horse-power is 550 foot-pounds per second, an equivalent rate of doing work would be

$$\frac{550}{.7375} = 746 \text{ watts} = 1 \text{ electrical horse-power} \qquad (14)$$

Then to change from mechanical horse-power to the electrical units, multiply by 746, or

$$\text{Watts} = \text{h.p.} \times 746 \qquad (15)$$

To determine the horse-power a generator is developing, determine its output in watts and divide by 746, or

$$\text{h.p.} = \frac{E \times I}{746} = \frac{\text{watts}}{746} \qquad (16)$$

19. Kilowatt.—The kilowatt (abbreviated k.w.) is a larger unit of electrical power than the horse-power. It is equal to 1000 watts or about 1⅓ horse-power.

20. Larger Units of Energy.—The joule is a very small unit of electrical energy or work, and as a result larger units are usually used in practice. The **watt-hour** is one watt expended for one hour. The **kilowatt-hour** is equal to 1000 watts expended for one hour. The watt-hour is equivalent to 3600 watt-seconds or 60 watt-minutes.

$$\text{Watt-hours} = \text{watts} \times \text{hours} \tag{17}$$

$$\text{Kilowatt-hours} = \text{k.w.} \times \text{hours} \tag{18}$$

$$\text{Horse-power hour} = \text{h.p.} \times \text{hours} \tag{19}$$

The dials of the integrating wattmeters used by central station companies usually record the energy supplied to the consumer for lighting or power purposes in watt-hours or kilowatt-hours.

Example.—Ten incandescent lamps take a current of 2½ amperes from a 220-volt circuit. What will it cost to operate these lamps for five hours if the power company charges 14 cents per kilowatt-hour?

Solution.—Substituting in equation (9), we can determine the power taken by the lamps in watts:

$$\text{Power} = 220 \times 2\tfrac{1}{2} = 550 \text{ watts}$$

Now by substituting in equation (17), we can determine the energy consumed in watt-hours:

$$\text{Energy} = 550 \times 5 = 2750 \text{ watt-hours}$$

One kilowatt-hour is equivalent to 1000 watt-hours, hence 2750 watt-hours are equal to 2.75 kilowatt-hours. The total cost then would be

$$2.75 \times 14 = 38\tfrac{1}{2}$$

Ans. 38½ cents.

21. Units.—Units are of two kinds—**fundamental** and **derived.** The fundamental units are the ones from which all others are derived and in terms of which all physical measurements may be made. They are fundamental in the sense that no one is derived from the others. The derived units are all those that are dependent for their definition upon the fundamental ones.

The three fundamental units in use are those of **length, mass,** and **time.** Of these the only unfamiliar one may be that of mass, which means the quantity of matter in a body. From these three fundamental units are derived all others in use, such, for example, as those of force, work, and energy already mentioned, and all of the electrical units.

22. **Systems of Units.**—Unfortunately there are two systems of units in use in this country. One is the ordinary commercial, or **English System,** and the other the universal scientific, or **Metric System.** In each of these systems we have the three fundamental units and also a set of derived units. It is quite essential that you know something of the metric system, since all the electrical units are based upon it, and a great many dimensions will be given in units that belong to this system. Table No. I will show the most common units in the two systems.

The English System is sometimes spoken of as the **foot-pound-second (f.p.s.)** system, because of the three fundamental units upon which it is based. Similarly the Metric System is frequently spoken of as the **centimeter-gram-second (c.g.s.)** system.

The relation between the units of the two systems is given in Table A, Chapter 20.

TABLE NO. I

RELATION OF UNITS IN ENGLISH AND METRIC SYSTEMS

SYSTEM	UNITS		
	LENGTH	MASS	TIME
English or (F. P. S.)	Yard (yd.) Foot (ft.)	Pound (lb.) Ounce (oz.)	Second (sec.)
Metric or (C. G. S.)	Meter (m.) Centimeter (cm.)	Kilogram (kg.) Gram (g.)	Second (sec.)

PROBLEMS ON POWER AND ENERGY CALCULATIONS

(1) If 4000 watts are expended in a circuit, how many horse-power are being developed?

Ans. 5.36+ horse-power.

(2) If 20 horse-power of mechanical energy were converted into electrical energy, how many watts would be developed?
Ans. 14 920 watts.

(3) One hundred and twenty-five horse-power expended continuously for one hour will produce how many kilowatt-hours? Ans. 93.25 k.w.-hours.

(4) How many watts are expended in a 110-volt, 16-candle-power lamp that requires a current of .5 ampere?
Ans. 55 watts.

(5) How many horse-power will be absorbed by a circuit of series arc lamps taking 9.6 amperes, the line pressure being 2000 volts Ans. 25.73 + horse-power.

(6) A motor takes a current of 5 amperes from a 110-volt circuit. What will it cost to operate this motor for 10 hours, if the central station company charges 12 cents per kilowatt-hour? Ans. 66 cents.

CHAPTER II

CALCULATION OF RESISTANCE

23. Resistance.—Resistance has been defined as a property of materials which opposes the free flow of electricity through them. The value of the resistance of any conductor in ohms will, however, depend upon the dimensions, temperature, and the kind of material of which it is composed.

24. Conductance.—The inverse of resistance is known as the conductance of a conductor. That is, if a conductor has a resistance of (R) ohms, its conductance is equal to $(1 \div R)$. The unit in which the conductance is measured is the **mho,** and it is the conductance offered by a column of pure mercury 106.3 cm. long and 14.4521 grams in mass at the temperature of melting ice. This unit is little used in practice except in the calculation of the resistance of a divided circuit, which will be taken up later.

25. Resistance Varies Directly as the Length of a Conductor.—The resistance of a conductor is directly proportional to its length, the temperature and cross-section of the conductor remaining constant. That is, the resistance increases at the same rate the length of the conductor increases, just as the resistance of a pipe to the flow of water increases as the length of the pipe is increased, all other conditions remaining constant. Hence, if the length of a conductor is increased to four times its original value, the resistance will be four times as much; or if the length is divided into four equal parts, the resistance of each part will be one-fourth of the total resistance.

Example.—The resistance of a piece of wire fifteen feet long is 5 ohms. What is the resistance of 1000 feet of the same kind of wire?

Solution.—Since the resistance of a conductor is directly proportional to its length, we can determine the resistance of one foot of the wire, knowing the resistance of five feet, by dividing 5 by 15:

$$5 \div 15 = \frac{1}{3}$$

The resistance of one foot, then, is ⅓ ohm, and the resistance of 1000 feet would be 1000 times as much, or

$$1000 \times \frac{1}{3} = 333\frac{1}{3}$$

Ans. 333⅓ ohms.

Example.—The resistance of a certain conductor thirty feet long is 30 ohms. What is the resistance of three inches of the conductor?

Solution.—The length of the conductor in inches is equal to the number of inches per foot (12) multiplied by the number of feet:

$$12 \times 30 = 360$$

Since the length is 360 inches and the resistance is 30 ohms, the resistance per inch can be obtained by dividing 30 by 360:

$$30 \div 360 = \frac{1}{12}$$

The resistance of one inch is then $\frac{1}{12}$ ohm and the resistance of three inches will be three times one-twelfth:

$$3 \times \frac{1}{12} = \frac{3}{12} = \frac{1}{4}$$

Ans. ¼ ohm.

26. Resistance Varies Inversely as the Cross-Section of a Conductor.—The resistance of a conductor is inversely proportional to the cross-section, the temperature and length of the conductor remaining constant. That is, the resistance decreases at the same rate the area of the cross-section increases, all other quantities remaining constant. Hence, if the area of a conductor is reduced to one-fourth its original value, the resistance will be four times as much, or if its area is increased to four times its previous value the resistance will be decreased to one-fourth its original value.

Example.—A conductor $\frac{1}{100}$ square inch in area has a resistance of .075 ohm per foot. What is the resistance of a conductor of the same material $\frac{1}{25}$ of a square inch in area and one foot long?

Solution.—Since the resistance varies inversely as the relation between the areas, and the relation between the areas in this case is

$$\frac{1}{25} \div \frac{1}{100} = 4$$

the resistance of the conductor of larger cross-section will be ¼ the resistance of the conductor of smaller cross-section.

$$\frac{1}{4} \text{ of } .075 = .018\,75$$

Ans. .018 75 ohm.

27. Area of Circular Conductors.—Most all conductors have a circular cross-section; and it is necessary to know how to calculate their areas in terms of their diameters or radii in order to determine the relation between their resistances. The area of any circle is obtained by multiplying the radius by itself and this product by a constant called Pi. The value of this constant is 3.1416, and it is the number of times the diameter must be used in order to reach around the circle. It is represented by the Greek symbol (π). Hence, the area of any circle can be obtained by using the equation

$$\text{Area} = r^2 \times \pi \qquad (20)$$

$$\text{Area} = \text{radius} \times \text{radius} \times \text{pi}$$

Since the diameter of a circle is equal to twice the radius, this equation may be rewritten in terms of the diameter,

$$\text{Area} = \left(\frac{d}{2}\right)^2 \times \pi$$

$$\text{Area} = \frac{\pi}{4} \times d^2$$

$$\text{Area} = .7854\ d^2 \qquad (21)$$

From the above equation it is seen that the area of one circle bears the same relation to the area of another as exists between their respective diameters squared. That is, if two circles have diameters 3 and 5, the relation between their areas will be the relation between $(3)^2$ and $(5)^2$, or 9 and 25. The circle of smaller diameter will have 9/25 the area of the circle of larger diameter.

Example.—The resistance of a wire .1 inch in diameter and

10 feet long is 10 ohms. What is the resistance of a wire of the same material and same length .3 inch in diameter?

Solution.—The ratio of the areas of the two wires will be the ratio between $.1^2$ and $.3^2$ which is .01 and .09. The larger wire will have 9 times the area of the smaller wire and since the resistance varies inversely as the area it will have one-ninth the resistance.

$$\frac{1}{9} \text{ of } 10 = \frac{10}{9} = 1\frac{1}{9}$$

Ans. $1\frac{1}{9}$ ohms.

28. Resistance Changes with Temperature.—A change in the temperature of all substances will cause a change in their resistance. In the majority of cases an increase in temperature means an increase in resistance. Carbon is the best example of substances whose resistance decreases with an increase in temperature. The resistance of the carbon filament of an incandescent lamp is about twice as great when the lamp is cold as when it is lighted. The change in resistance due to a change in temperature is quite different for different materials, and it is also slightly different for the same materials at different temperatures. Alloys, such as manganin, have a very small chance in resistance due to a change in temperature, and standard resistances are, as a rule, made from such alloys, as it is desired to have their resistance remain as near constant as possible.

29. Temperature Coefficient.—The temperature coefficient of a material is defined as the change in resistance per ohm due to a change in temperature of one degree. The resistance at 0° centigrade or 32° Fahrenheit is usually taken as the standard resistance, which we will call R_0. Now, let the resistance at some higher temperature (t) be measured and call it R_t. Then $R_0 - R_t$ is the change in resistance for a change in temperature of (t) degrees, and $\frac{R_t - R_0}{R_0}$ is the change in resistance per ohm for the given change in temperature (t). The change in resistance for each ohm due to a change in temperature of one degree is

$$\frac{R_t - R_o}{R_o t} = a \qquad (22)$$

in which (a) is the temperature coefficient. When the resistance increases with an increase in temperature, as in the case of metals, then R_t is greater than R_o and (a) is positive; if R_t decreases with a rise of temperature, as in the case of carbon, then (a) is negative. The above expression for the temperature coefficient can be changed to the form

$$R_t = R_o\ (1 + at) \qquad (23)$$

This equation gives the value of the resistance (R_t) at any temperature (t) in terms of the resistance (R_o) the temperature coefficient (a), and the change in temperature (t).

30. Values of Temperature Coefficients.—Table No. II gives the value of the temperature coefficient for a number of materials when the temperature change is expressed in centigrade (a_c) and Fahrenheit (a_f) degrees.

TABLE NO. II

TEMPERATURE COEFFICIENTS

Material	a_c	a_f
Aluminum	0.004 35	0.002 417
Carbon	0.000 3	0.000 17
Copper	0.004 20	0.002 33
Iron	0.004 53	0.002 52
Lead (pure)	0.004 11	0.002 2
Mercury	0.000 88	0.000 49
Nickel	0.006 22	0.003 45
Platinum	0.002 47	0.001 37
Silver	0.003 77	0.002 1
Tin	0.004 2	0.002 3
Zinc (pure)	0.004	0.002 2

The relation between the two coefficients as given in the table is the same as that between the centigrade and the Fahrenheit degree; that is $a_f = 5/9\ a_c$.

Table B, Chapter 20, gives the relation between the centigrade and Fahrenheit thermometer scales.

The above values of the temperature coefficients are based upon a change in resistance, due to a change in temperature from 0° centigrade or 32° Fahrenheit. If the original temperature of the conductor is not 0° centigrade or 32° Fahrenheit, the value of the temperature coefficient will not be the same as that given in Table No. II. There will be a different value obtained for (a) for each different initial temperature. Table No. III gives the change in the value of (a) for copper for initial temperatures from 0° to 50° centigrade.

TABLE NO. III

VALUES OF THE TEMPERATURE COEFFICIENT OF COPPER AT DIFFERENT INITIAL TEMPERATURES CENTIGRADE

Initial temperature deg. Cent.	Temp. coefficient per deg. Cent.	Initial temperature deg. Cent.	Temp. coefficient per deg. Cent.
0	.004 200	26	.003 786
1	.004 182	27	.003 772
2	.004 165	28	.003 758
3	.004 148	29	.003 744
4	.004 131	30	.003 730
5	.004 114	31	.003 716
6	.004 097	32	.003 702
7	.004 080	33	.003 689
8	.004 063	34	.003 675
9	.004 047	35	.003 662
10	.004 031	36	.003 648
11	.004 015	37	.003 635
12	.003 999	38	.003 622
13	.003 983	39	.003 609
14	.003 967	40	.003 596
15	.003 951	41	.003 583
16	.003 936	42	.003 570
17	.003 920	43	.003 557
18	.003 905	44	.003 545
19	.003 890	45	.003 532
20	.003 875	46	.003 520
21	.003 860	47	.003 508
22	.003 845	48	.003 495
23	.003 830	49	.003 483
24	.003 815	50	.003 471
25	.003 801		

31. Calculation of Resistance Due to Change in Temperature.—When the resistance of a conductor at a given temperature is known, which we will assume is 0° centigrade, its resistance at some other temperature may be calculated by the use of the temperature coefficient. If it is desired to calculate the resistance of a conductor at a higher temperature than that at which it was measured, proceed as follows: Multiply the temperature coefficient by the change in temperature and the product will be the change in resistance of each ohm for the given change in temperature; multiplying this product by the original resistance in ohms gives the total change in resistance of the conductor. This increase in resistance must now be added to the original value and the result is the resistance at the second temperature.

The method just given for calculating the resistance with a change in temperature can be expressed by the following equation:

$$R_t = R_0 + R_0 at \qquad (24)$$

or, it is usually written

$$R_t = R_o \ (1 + at) \qquad (25)$$

In the above equation (R_t) is the resistance at the second temperature, (R_0) the resistance at the first temperature, (0° centigrade), (a) the temperature coefficient, and (t) the number of degrees above or below freezing (0° centigrade or 32° Fahrenheit).

The value of (a) to use in the equation will depend upon whether the change in temperature (t) is to be measured on the centigrade or on the Fahrenheit scale.

By an inspection of equation (25) it is apparent that if the resistance of a conductor at a higher temperature is known, the resistance at a lower temperature can be calculated from the equation

$$R_o = \frac{R_t}{1 + at} \qquad (26)$$

When the resistance of a conductor at two different temperatures is known, the change in temperature can be calculated from the equation

$$t = \frac{R_t - R_o}{R_o a} \qquad (27)$$

Practical use is made of this equation in what is known as the resistance thermometer, where the change in resistance of a coil of wire is measured and the change in temperature calculated. (R_o) is then the resistance of the coil at a known temperature (T_o), and (R_t) is the resistance of the coil at some other temperature (T_1). (T_1) is then equal to

$$T_1 = T_o + t \qquad (28)$$

If there is an increase in resistance, (t) is positive and if there is a decrease, (t) is negative. Hence (T_1) will be greater or less than (T_o) depending upon the sign of (t).

Example.—The resistance of a certain copper conductor is 15 ohms at 0° centigrade. What is its resistance at 50° centigrade?

Solution.—The temperature coefficient for copper, when the temperature is measured on the centigrade scale, is, from Table No. II, found to be .0042. Substituting the values for (R_0), (a), and (t) in equation (25), we have

$$R_t = 15\ (1 + .0042 \times 50) = 18.15$$

Ans. 18.15 ohms.

Example.—The resistance of a silver wire is 25 ohms at 45° Fahrenheit. What resistance will it have at 32° Fahrenheit?

Solution.—The temperature coefficient for silver is found from Table No. II to be .0021. Substituting the values for (a), (t), which is (45 — 32 = 13), and (R_t) in equation (26), we have

$$R_o = \frac{25}{1 + 13 \times .0021} = \frac{25}{1.0273} = 24.33$$

Ans. 24.33 ohms.

Example.—A certain platinum coil that is used as a resistance thermometer has a resistance of 100 ohms at 0° centigrade. What is the temperature of the coil when its resistance is 115 ohms?

Solution.—The temperature coefficient for platinum is found from Table No. III to be .00247. Substituting the values of the resistance and (a) in equation (27), we have

$$t = \frac{115 - 100}{100 \times .002\,47} = \frac{15}{.247} = 60.73\text{—}$$

Since the original temperature (T_o) of the coil or the one at which (R_0) was determined was 0° centigrade, the final temperature (T_1) can be determined by substituting the values of (T_0) and (t) in equation (28), which gives

$$T_1 = 0 + 60.73 = 60.73\text{—}$$

Ans. 60.73— degrees centigrade

All of the above calculations are based on an initial temperature of 0° centigrade or 32° Fahrenheit. It is often the case that the resistance of a conductor is known at some temperature other than freezing, and it is desired to know its resistance at some other temperature. Thus, the resistance of a certain coil of wire may be known at 20° centigrade and it is desired to know its resistance at 60° centigrade. In this case the resistance of the coil at 0° centigrade should be determined first, by the use of equation (26), and the value of (R_0), thus determined, together with the value of (a) and (t) substituted in equation (25), which will give the value of the resistance at the second temperature. The above operations can be combined, which will give the equation

$$R_{t+t_1} = \frac{R_t}{(1 + at)} (1 + at_1) \qquad (29)$$

In the above equation (t_1) is the final temperature and (t) is the initial temperature, above or below freezing; (R_t) the original resistance; (R_{t+t_1}) the final resistance; and (a) the temperature coefficient. If the temperatures are measured on the Fahrenheit scale, the values of (t) and (t_1) should be measured above or below 32° depending upon whether the temperature be above or below freezing.

Example.—A coil of platinum wire has a resistance of 100 ohms at 45° Fahrenheit. What will the resistance of this coil be at 75° Fahrenheit?

Solution.—This problem can be solved by using equation (29). The value of (R_t) to substitute in the equation is 100; the value of (t) is (45 — 32), or 13; the value of (t_1) is (75 — 32), or 43; and the value of (a) is .001 37. Substituting the above values in the equation gives the value of (R_{t+t_1}), which is the value of the resistance of the coil at (t_1) degrees above freezing, or in this case 75° Fahrenheit:

$$R_{t+t_1} = \frac{100\,(1 + .001\,37 \times 43)}{(1 + .001\,37 \times 13)} = 104.03+$$

Ans. 104.03+ ohms.

The error introduced, if the calculation be made without reducing the resistance to zero, is not very large, depending upon the initial temperature, and in the majority of ordinary cases equation (25) can be used. When this equation is used (R_o) represents the initial resistance, which should be written (R_t); (R_t) represents the final resistance, which should be written (R_{t+t_1}); and (t) represents the change in temperature, which is equal to (t_1 — t). Equation (25) may then be rewritten as follows:

$$R_{t+t_1} = R_t\,[1 + a\,(t_1 - t)] \qquad (30)$$

Using this equation in calculating the resistance in the last problem gives

$$\begin{aligned} R_{t+t_1} &= 100\,[1 + .001\,37\,(75 - 43)] \\ &= 100\,(1 + .0411) \\ &= 104.11 \end{aligned}$$

Ans. 104.11 ohms.

Equation (29) must then be used when an accurate determination of the resistance is desired. Equation (29) can be rewritten so that the value of (t_1) can be calculated when the proper substitution is made:

$$t_1 = \frac{[R_{t+t_1}\,(1 + at)] - R_t}{a\,R_t} \qquad (31)$$

32. Relation of Resistance to Physical Dimensions.—From section (26) we know the resistance varies directly as the length, and from section (27) inversely as the area of the cross-section. These two relations may be combined with a constant, giving the following equation:

$$R = K \frac{l}{A} \qquad (32)$$

The above equation expresses three facts:

(a) The resistance (R) varies directly as the length (l) of the conductor.

(b) The resistance varies inversely as the cross-sectional area (A) of the conductor.

(c) The resistance depends upon the material of which the conductor is composed. The quality of any material as a conductor is expressed by the letter (K), which has a definite value for every substance.

33. **Meaning of K.**—The physical meaning of (K) in equation (32) may be readily determined by making (l) and (A) equal to unity. Then length (l) may be measured in any unit of length and the area (A) may be measured in any unit of area. (K), then, is the resistance of a conductor of unit length and unit cross-section, and there will be as many values of (K) as there are units in which we may measure (l) and (A). There are two values of (K) that are in common use and these only will be considered. They are the **specific resistance** and the **mil-foot resistance.**

34. **Specific Resistance.**—If the length of a conductor is one centimeter and its cross-section one square centimeter, then, by equation (32), we have $R = K$; that is, (K) is the resistance of a cubic centimeter of the material considered. If the length of the conductor is one inch and the area one square inch, then (K) is equal to the resistance of a cubic inch of the material. The resistance of a cubic centimeter or cubic inch of any material is called the **specific resistance** of the material, and it is usually expressed in microhms at 0° centigrade. (A microhm is the one-millionth part of one ohm.

35. **Circular Mil.**—In the majority of cases electrical conductors have a circular cross-section and when we calculate the cross-sectional area from the diameter, the awkward factor .7854, or ($\pi \div 4$), appears. To avoid this factor a more convenient practical unit of area has been adopted—the **circular mil (c.m.).** The circular mil is the area of a circle whose

diameter is one mil or .001 of an inch. The **square mil,** on the other hand, is the area of a square whose side is one mil. The advantage in the use of the circular mil is that when the diameter of the conductor is given in mils, its circular-mil area may be determined by squaring the diameter. Conversely, the diameter may be determined, when the circular-mil area is given, by taking the square root of the area. This gives the diameter in mils and from it the diameter in inches may be obtained by dividing by one thousand.

36. Mil-Foot Resistance.—The mil-foot resistance of a material is defined as being the resistance of a volume of the material one foot in length and having a uniform cross-section of one circular mil. Then if (l) is equal to one foot and (A) is equal to one circular mil, in equation (32) (K) will be equal to (R). The mil-foot resistance is really a particular value for the specific resistance, as it is the resistance of a certain volume.

Values of Specific and Mil-Foot Resistance.—The values of the specific resistances of some of the common materials are given in Table No. IV.

TABLE NO. IV

SPECIFIC RESISTANCE, PER CENT RELATIVE RESISTANCE AND CONDUCTANCE, OF DIFFERENT MATERIALS

Material	Measurements at 0° Centigrade			Relative Resistance %	Relative Conductivity %
	Microhms per cubic cm.	Microhms per cubic inch	Mil-foot res.		
Copper (Matthiessen's Standard)	1.594	.6276	9.54	100.0	100.0
Copper, annealed..	1.56	.614	9.35	97.5	102.6
Silver............	1.47	.579	8.82	92.5	108.2
Zinc (pure).......	5.75	2.26	34.5	362.	27.6
Iron (very pure)..	9.07	3.57	54.5	570.	17.6
Lead (pure).......	20.4	8.04	123.	1280.	7.82
Platinum (annealed).........	8.98	3.53	53.9	565.	17.17
Mercury:.........	94.3	37.1	566.	5930.	1.69
Gold (practically pure)...........	2.2	.865	13.2	138.	72.5
Aluminum (99% pure)...........	2. 6	1.01	15.4	161.	62.1

The above values are based upon Matthiessen's determination of what he thought to be the specific resistance of pure copper. The copper he used, however, contained considerable impurities and as a result the copper obtainable at the present time has a specific resistance less than that determined by Matthiessen in 1860.

37. Relative Conductivity.—The conductivity of a material is equal to the reciprocal of its specific resistance. The relative conductivity of any material would be the percentage relation between the conductivity of the material and the conductivity of copper, which is taken as the standard:

$$\% \text{ relative conductivity} = \frac{\text{Conductivity of material}}{\text{Conductivity of copper}} \times 100, \text{ or}$$

$$= \frac{\text{Specific resistance of copper}}{\text{Specific resistance of material}} \times 100 \qquad (33)$$

The value of the per cent relative conductivity of a number of different materials is given in Table No. IV.

38. Relative Resistance.—The relative resistance of a material in per cent is the relation between its specific resistance and the specific resistance of the standard, multiplied by 100:

$$\% \text{ relative resistance} = \frac{\text{Specific resistance of material}}{\text{Specific resistance of standard}} \times 100 \qquad (34)$$

The value of the per cent relative resistance of a number of different materials is given in Table No. IV.

39. Relation between Square and Circular-Mil Measure.—In the calculation of the resistance of electrical conductors it is often necessary to change from the square to the circular mil or vice versa. The relation of the area represented by one circular mil as compared to the area represented by one square mil can be easily shown by reference to Fig. 5. The small square in the figure represents an area corresponding to 100 square mils (these areas are greatly exaggerated in the figure). A circle drawn inside the square as shown will have an actual area less than the square. The area of the square in square mils is equal to the product of the two sides measured in mils, or it is the value of the side in mils squared. The circle has an area in square mils equal to the diameter squared times .7854, or the area of the circle is .7854 of the area of the square. Now the area of the circle in circular mils (by definition of the circular mil, Sec. 35) is equal to the diameter in mils squared $(d)^2$. The number of square mils enclosed by the circle will then be equal to .7854 of the number of circular mils enclosed by the circle, or the actual area corresponding to a circular mil is less than the area corresponding to one square mil. This results in there always being a greater number of circular mils in any area than there are square mils. To change from circular to square mils, multiply the area in circular mils by .7854 and the result is the area in square mils. Or, to change from square to circular mils, divide the area in square mils by .7854 and the quotient thus obtained will be the area in circular mils.

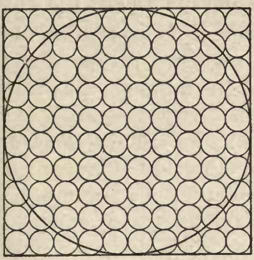


Fig. 5

Example.—The diameter of a circular copper conductor is 102.0 mils. Determine the area of the above conductor in both circular and square mils.

Solution.—The area of any circular conductor in circular mils is equal to the diameter of the conductor in mils, squared, or

$$\text{Circular-mil area} = d^2 = (102.0)^2 = 10\,404$$

Ans. 10 404 circular mils.

(2) The area of a circle in square measure is equal to .7854 times the diameter of the circular squared, or

$$\text{Square mil area} = .7854 \times d^2 = .7854 \times (102.0)^2 = 8171.3$$

Ans. 8171.3 square mils.

40. Calculation of Resistance from Dimensions and Specific Resistance.—The resistance of any conductor may be calculated by the use of equation (32) if the dimensions of the conductor and the value of (K) are known. The value of the constant (K) used in the equation will, of course, depend upon the units used in expressing the length and area of the conductor. When the length (l) of the conductor is expressed in feet and the area (A) in circular mils, the constant (K) corresponds to the mil-foot resistance of the material. The value of this constant for different materials can be obtained from Table No. II. The mil-foot resistance of commercial copper at 25° centigrade is approximately 10.8.

41. **Wire Gauges.**—For many purposes it is desirable to designate the size of a wire by gauge numbers rather than by a statement of their cross-section. A number of wire gauges have been originated by different manufacturers of wire, such as the B. & S. gauge, commonly called the American gauge, Brown and Sharpe Manufacturing Company, which is the one generally used in this country. In the measurement of iron and steel wire the "Birmingham wire gauge" (B. W. G.), or Stub gauge is usually used. There are a number of other gauges such as the Roebling, Edison, and New British standard, but these are not used very much. The diameters in mils of the different size wires is given in Table D, Chapter 20.

The B. & S. gauge is by far the most common wire gauge in use in this country and for that reason it will be used almost entirely in wiring calculations. Tables E and F, Chapter 20, give the properties of copper wire.

42. **How to Remember the Wire Table.**—The wire table has a few simple relations, such that if a few constants are carried in the memory, the whole table can be constructed mentally with approximate accuracy. The chief relations, without proof, may be enumerated below and verified from the table.

The following approximate relations should be remembered:

No. 10 B. & S. gauge wire is 100 mils in diameter, approximately; has an area of 10 000 c.m.; has a resistance of one ohm per thousand feet; and weighs 31.43 pounds per thousand feet, at 20°C. (68°F.). No. 5 wire weighs 100.2 pounds per 1000 feet. The following rules are approximately true for B. & S. gauge wire.

(a) A wire which is three sizes larger than another has half the resistance, twice the weight, and twice the area.

(b) A wire which is ten sizes larger than another has one-tenth the resistance, ten times the weight, and ten times the area.

(c) To find the resistance, divide the circular-mil area by 10; the result is the number of feet per ohm.

(d) To find the weight per thousand feet, divide the number of circular mils by 10 000 and multiply by the weight of No. 10 wire. Table C, Chapter 20, gives the equivalent cross-sections of different size wires.

PROBLEMS

(1) What is the circular-mil area of a wire ¼ inch in diameter?

Ans. 62 500 c.m.

(2) The circular-mil area of a wire is 4225. What is its diameter in inches?

Ans. .065 inch.

(3) A certain rectangular piece of copper is ¼ by ½ of an inch in cross-section. What is the area of this bar in square mils?

Ans. 125 000 sq. mils.

(4) What is the area of the rectangular piece of copper given in problem 3, in circular mils?

Ans. Approximately, 159 150 c.m.

(5) What would be the diameter of a circular conductor in mils that would have the same actual area as the rectangular piece of copper given in problem 3?

Ans. Approximately 399. mils.

CHAPTER III

SERIES AND DIVIDED CIRCUITS—MEASUREMENT OF RESISTANCE

43. Grouping of Conductors.—The resistance of a whole or a portion of a circuit will depend upon the manner in which the various parts constituting the circuit are connected. Two or more conductors may be combined in a number of ways, and the total resistance of the combination can be determined if the resistance of each part of the circuit and the manner in which the various parts are connected is known. The various ways in which conductors may be grouped are as follows:

(a) **Series grouping.**
(b) **Parallel or multiple grouping.**
(c) **Any combination of series and parallel.**

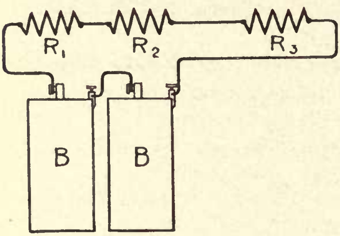


Fig. 6

44. Series Grouping.—When the conductors forming a circuit are so arranged that the current has a single path the conductors are said to be connected in series and such a circuit is called a series circuit. Fig. 6 shows three resistances (R_1), (R_2), and (R_3), connected in series to the terminals of the battery (B). The current has only one path from the positive to the negative terminal of the battery. These resistances may be of widely different values and composed of different materials, but the total resistance of the combination is equal to the sum of the resistances of the various parts.

Suppose the three resistances in Fig. 6 have values of 3, 4, and 5 ohms, then the total resistance of the circuit, neglecting the resistance of the connections and the internal resistance of the battery, will be $3 + 4 + 5 = 12$ ohms.

The above relation of the total resistance to the individual resistances can be shown by a hydraulic analogy. Suppose that in Fig. 7 (A), (B), and (C) are three pipes of different size and length and that they are joined end to end, or in

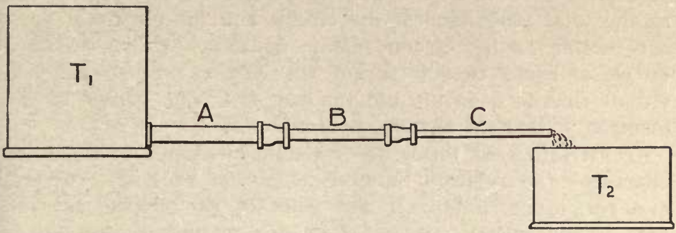


Fig. 7

series, and they are to be used in conducting water from the tank (T_1) to the tank (T_2). It is apparent that the total resistance offered by the three pipes connected in series is equal to the sum of their respective resistances.

45. **Facts Concerning Series Circuit.**—There are four facts concerning every series circuit:

(a) The current is uniform throughout the series circuit.

(b) The p.d.'s over any portions of the series circuit are proportional to the resistances of these portions.

(c) The total resistance is the sum of the individual resistances.

(d) The effective e.m.f. of the circuit is the algebraic sum of all the e.m.f.'s acting in the circuit.

46. **Uniformity of Current.**—Since there is but one path for the current, the conductors being all joined in series, there must be as much current at one end of the conductor as at the other. If this were not the case there would be an accumulation of electricity at certain points along the circuit, but careful experiments show no such accumulation. The flow of electricity can be compared to the flow of water or other incompressible fluid in a pipe, as shown in Fig. 7. If there is a certain quantity of liquid entering the end of the pipe, connected to the tank (T_1), in a certain time,

then that same quantity must pass by any cross-section of the pipe and the same quantity must flow out of the other end of the pipe in the same time. It is impossible for the liquid to accumulate at any point as it is incompressible.

An ammeter, which is an instrument used to measure the current, may then be connected at any point in a series circuit and there will be the same indication on its scale so long as the total resistance of the circuit and the electrical pressure acting on the circuit remain constant. It must always be remembered that it is not the current in an electrical circuit that is used up, but instead, it is the energy of the electricity that is always utilized.

47. Relation of P.D.'s to Resistance.—Ohm's Law, which expresses the relation between electrical pressure, current, and resistance, holds for any part of the circuit as well as for the whole circuit. Consider a uniform conductor

Fig. 8

(A, B, C, D), carrying a current of (I) amperes in the direction indicated by the arrow in Fig. 8. There must be a difference in pressure between the points, say (A) and (B), since there is a current between them and the point (A) is at a higher potential or pressure than the point B when the current exists in the direction indicated. Let the resistance between the points (A) and (B) be represented by (R_1) and the difference in pressure or drop in potential between the same two points be represented by (E_1). The current is then equal to (E_1) divided by (R_1), or

$$I = \frac{E_1}{R_1} \qquad (35)$$

If any other section of the conductor be taken, such as that between the points (C) and (D), and the drop in potential between the two points be represented by (E_2) and the resistance of the section by (R_2) we have

$$I = \frac{E_2}{R_2} \qquad (36)$$

The currents in the two sections are equal since they are in series and the right-hand portions of the above equations are equal, hence

$$\frac{E_1}{R_1} = \frac{E_2}{R_2} \qquad (37)$$

or the drop in potential is proportional to the resistance.

Example.—Two coils of 5 and 10 ohms are connected in series to a battery whose e.m.f. is 6 volts. What is the potential drop over each coil?

Solution.—From equation (37) we can determine the relation between (E_1) and (E_2), where they represent the drops in potential over the two coils, by substituting the values of (R_1) and (R_2) in the equation, which gives

$$\frac{E_1}{5} = \frac{E_2}{10}$$

$$5\ E_2 = 10\ E_1$$

$$E_2 = 2\ E_1$$

The p.d. (E_2) over the 10-ohm coil is then equal to twice the p.d. (E_1) over the 5-ohm coil. The 5-ohm coil will then have ⅓ of the total pressure over it and the 10-ohm coil will have ⅔. Since the total pressure is 6 volts, the drop over the 5-ohm coil will be

$$\tfrac{1}{3} \text{ of } 6 = 2$$

Ans. 2 volts.

and the p.d. over the 10-ohm coil will be

$$\tfrac{2}{3} \text{ of } 6 = 4$$

Ans. 4 volts.

48. Resistance of Series Circuit.—In a previous section the statement was made that the total resistance of the series circuit is equal to the sum of the various resistances composing the circuit. This statement is practically self-evident, but it may be shown to be true by an application of Ohm's Law.

If a number of resistances (R_1), (R_2), etc., are connected in series and there is a current of (I) amperes through them, we have, from equation (35),

$$E_1 = R_1I, \qquad E_2 = R_2I, \qquad \text{etc.,} \qquad (38)$$

where (E_1), (E_2), etc., represent the p.d.'s over the resistances (R_1), (R_2), etc.

Let (R) represent the total resistance and (E) the total pressure. Then

$$E = RI \qquad (39)$$

But we also know (E) is equal to the sum of all the p.d.'s, that is,

$$E = E_1 + E_2 + \text{etc.} \qquad (40)$$

Hence

$$RI = R_1I + R_2I + \text{etc.} \qquad (41)$$

or

$$R = R_1 + R_2 + \text{etc.} \qquad (42)$$

The above equation states that the resistance of several conductors joined in series is the sum of their individual resistances.

Example.—Three resistance coils of 5, 6, and 7 ohms, respectively, are connected in series and the combination connected to a battery whose e.m.f. is 9 volts. What is the value of the current in the coils?

Solution.—The total resistance (R) is equal to the sum of the several resistances, or

$$R = 5 + 6 + 7 = 18 \text{ ohms}$$

The current then is equal to (E) divided by (R), or

$$I = \frac{9}{18} = \frac{1}{2}$$

Ans. ½ ampere.

If there are (n) equal resistances of (r) ohm each connected in series, the total resistance (R) is

$$R = nr \qquad (43)$$

An example of this would be a number of lamps connected in series and the combination then connected to the mains. If there are 5 incandescent lamps connected in series each having a resistance of 220 ohms, the combination will have a resistance of 5×220, or 1100 ohms.

49. Effective E.M.F. in a Circuit.—The effective e.m.f. in a circuit is the e.m.f. that is really effective in causing the current. Several sources of e.m.f. may be joined in series, but the effective e.m.f. would not necessarily be equal to the sum of their values because some of the e.m.f.'s might act in the opposite direction to others. If all the e.m.f.'s in the circuit tend to send a current in the same direction then the value of the effective e.m.f. is the sum of all the e.m.f.'s acting. When they are not all acting in the same direction, the effective e.m.f. is equal to the difference between the sum of the e.m.f.'s acting in one direction and the sum of the e.m.f.'s acting in the opposite direction, and its direction will be that of the larger sum. An example of the above would be a battery composed of a number of cells all connected in series but the e.m.f. of some of the cells acting in the opposite direction to the remainder. The effective e.m.f. is a maximum when all the e.m.f.'s in the circuit are acting in the same direction.

50. Parallel or Multiple Grouping.—When the conductors forming a circuit are so connected that there are as many paths for the current as there are conductors, the conductors are said to be connected in parallel or multiple, and such a circuit is called a divided circuit. Fig. 9 shows three coils (R_1), (R_2), and (R_3) connected in parallel and the combination connected to the battery (B). In a circuit such as that shown in Fig. 9, it is apparent that the current cannot be the same in all parts of the circuit, since it divides at the point (A) between the branches, part existing in each branch. The part of the total current that is in each branch will depend upon the relation between the resistance of that particular branch to the resistance of the other branches.

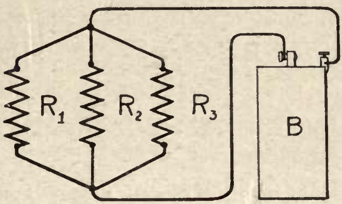


Fig. 9

The total resistance is not equal to the sum of the several resistances, as in the series circuit, but it will be less than the resistance of the branch having the smallest resistance. A simple hydraulic analogy, as shown in Fig. 10, will serve to verify the above statements. Three pipes, (P_1), (P_2), and (P_3) are used in conducting water from a tank (T_1)

to another tank (T_2), as shown in the figure. If the pressure in the tank (T_1) is maintained constant, the pressure acting on the three pipes will remain constant and it will be the same for each pipe, neglecting the difference in their level. The same pressure is acting on each of the resistances in Fig. 9, neglecting the resistance of the connecting leads. Let this pressure be represented by (E). The current in each of the resistances will be equal to the presure over the branch, which in this case is (E), divided by the resistance of the branch. The current supplied by the battery is equal to the sum of the currents in the various branches, just as the total quantity of water flowing from the tank (T_1), Fig. 10, in a given time, is equal to the sum of the quantities flowing in the three pipes in the same time. Representing the currents in the several branches by (I_1), (I_2), and (I_3), and the total current by (I) we have the relation

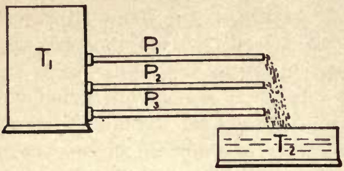


Fig. 10

$$I = I_1 + I_2 + I_3 \quad (44)$$

$$I_1 = \frac{E}{R_1} \qquad I_2 = \frac{E}{R_2} \qquad I_3 = \frac{E}{R_3} \quad (45)$$

The total current (I) is equal to the electrical pressure (E) acting on the combination divided by the total resistance (R) which we want to determine, or

$$I = \frac{E}{R} \quad (46)$$

Substituting the values of the various currents in equation (44), we have

$$\frac{E}{R} = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3} \quad (47)$$

Dividing both sides of the equation by (E), we have

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \qquad (48)$$

The above equation states that the total conductance of a number of resistances in parallel is equal to the sum of the respective conductances regardless of the number connected. This equation can be reduced to the form

$$R = \frac{R_1R_2R_3}{R_1R_2 + R_2R_3 + R_1R_3} \qquad (49)$$

When there are only two resistances connected in parallel, the combined resistance can be calculated by the use of the equation

$$R = \frac{R_1R_2}{R_1 + R_2} \qquad (50)$$

If the resistances (R_1) and (R_2) are equal, the combined resistance is equal to one-half of the resistance of either of them. Or, in general, if (n) equal resistances of (r) ohms each are connected in parallel, the combined resistance (R) is

$$R = \frac{r}{n} \qquad (51)$$

Example.—Eight incandescent lamps, each having a resistance of 220 ohms, are connected in parallel across a 110-volt circuit. What is the total current taken by the lamps?

Solution.—The total resistance of the eight lamps would be equal to the resistance of one of them divided by the number of lamps connected in parallel, or

$$R = \frac{r}{n} = \frac{220}{8} = 27\tfrac{1}{2} \text{ ohms}$$

The current taken by the lamps is equal to the applied voltage divided by the resistance, or

$$I = \frac{E}{R} = \frac{110}{27\tfrac{1}{2}} = 4$$

Ans. 4 amperes.

Example.—Two resistances of 3 and 5 ohms, respectively, are connected in parallel. What is their combined resistance?

Solution.—The combined resistance can be determined by substituting directly in equation (50), which gives

$$R = \frac{3 \times 5}{3 + 5} = \frac{15}{8} = 1\tfrac{7}{8}$$

Ans. $1\tfrac{7}{8}$ ohms.

51. Series and Parallel Combinations.—A number of resistances may be connected in such a way that some of them are in parallel with others, or some of them may be in series with others, or a combination of series and parallel connections may be formed. Six resistance coils are shown connected together in Fig. 11. This is a parallel combination of three different resistances, the first of which consists of the resistances (R_4) and (R_5) in series; the second consists of (R_1), (R_2), and (R_3) in series; and the third consists of the single resistance (R_6). To find the total resistance of the circuit determine the resistance of each path separately and combine their resistances by the use of equation (49).

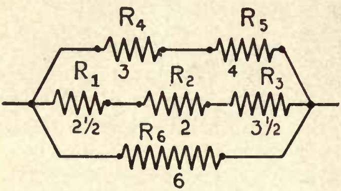


Fig. 11

Several such groups of resistances may be connected in series and the total resistance would be the sum of the resistances of the several groups.

Example.—The six coils shown connected in Fig. 11 have the resistances marked on them in the figure. What is the total resistance?

Solution.—The resistance of the upper branch, call it (B_1), is equal to the sum of the resistances (R_4) and (R_5), these being connected in series, or

$$B_1 = 3 + 4 = 7 \text{ ohms}$$

Similarly the resistance of the middle branch (B_2) is

$$B_2 = 2\tfrac{1}{2} + 2 + 3\tfrac{1}{2} = 8 \text{ ohms}$$

and the resistance of the lower branch (B_3) is 6 ohms. Substituting these values for the resistances of the various branches in equation (49), we obtain

$$R = \frac{7 \times 8 \times 6}{7 \times 8 + 7 \times 6 + 8 \times 6} = \frac{336}{146} = 2.301$$

Ans. 2.301 ohms.

PROBLEMS ON SERIES AND DIVIDED CIRCUITS

(1) Five similar incandescent lamps are connected in series across 550-volt mains, and there is a current of .5 ampere through them. What is the combined resistance of the five lamps and the resistance of each?

Ans. Combined resistance, 1100 ohms.
Resistance of each lamp, 220 ohms.

(2) An adjustable resistance is connected in series with the field winding of a dynamo, which has a resistance of 40 ohms, and a current of 2 amperes exists in the circuit when the impressed voltage is 110 volts. What is the total resistance of the circuit, and how many ohms resistance is there in the circuit due to the adjustable resistance?

Ans. Total resistance, 55 ohms.
Adjustable resistance, 15 ohms.

(3) There is a current of 50 amperes in a circuit when the impressed voltage is 200 volts. What resistance should be added in series with the circuit in order that the current be reduced to 40 amperes?

Ans. 1 ohm.

(4) What resistance should be connected in parallel with the circuit in problem 3 when the current is 50 amperes in order that the total current may be 80 amperes?

Ans. 6⅔ ohms.

(5) Three resistances of 5, 6, and 7 ohms, respectively, are connected in parallel. What is their combined resistance?

Ans. 1.96 ohms.

(6) If 12 similar incandescent lamps connected in parellel have a combined resistance of 18⅓ ohms, what is the resistance of each lamp?

Ans. 220 ohms.

(7) Two resistances of 4 and 12 ohms, respectively, are connected in parallel and the combination connected in series with a 7-ohm coil. What is the current through each resistance when a pressure of 50 volts is impressed upon the circuit?

Ans. Current in 7-ohm coil, 5 amperes.
Current in 12-ohm coil, 1¼ amperes.
Current in 4-ohm coil, 3¾ amperes.

(8) What is the drop in potential over each resistance in the above problem? What resistance should be introduced in the circuit, and how, to make the value of the current 2.5 amperes?

Ans. Drop over 7-ohm coil, 35 volts.
Drop over 4-ohm coil, 15 volts.
Drop over 12-ohm coil, 15 volts.
Connect 10 ohms in series.

52. Measurement of Resistance.—Practically all the methods employed in measuring resistance depend upon some application of Ohm's law. The method to be used in any case will depend upon the kind of resistance to be measured, that is, whether it is capable of carrying a large or small current; the accessibility of the resistance; the value of the resistance to be measured; and the accuracy desired. The different methods described in the following sections are, perhaps, the most common ones employed in practice.

53. Drop in Potential Method.—Since Ohm's Law holds true for any part of an electrical circuit, it follows that the value of a certain resistance can be determined by measuring the drop in potential across the resistance when the current through the resistance is known. A voltmeter for measuring the drop in potential, an ammeter for measuring the current, and some source of energy such as a battery or generator are required in measuring resistance by this method. The resistance (R) to be measured is connected in series with the ammeter (A), and the combination then connected to the source of energy such as a battery (B), indicated in Fig. 12. The drop in potential across the resistance can be determined by means of the voltmeter (V), which should be connected to the terminals of the resistance, as shown in the figure. The value of the resistance can be determined by substituting the ammeter and voltmeter readings in equation (5), which states that the resistance is equal to the difference in electrical pressure divided by the current. This is a very simple and convenient method and will give quite accur-

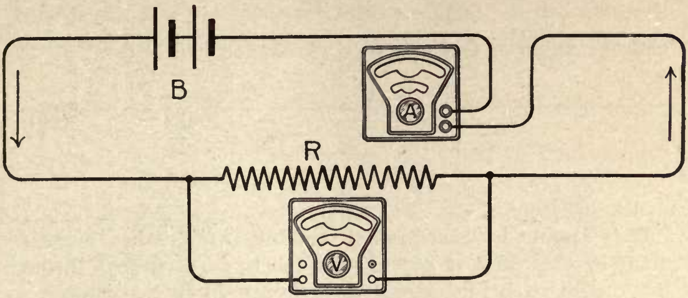


Fig. 12

ate results when proper care is exercised in reading the instruments. The method is best suited for the measurement of low resistances capable of carrying rather large currents, for the following reason: The current in the resistance to be measured is not equal to that indicated on the ammeter because there is a certain current through the voltmeter. The current through the voltmeter will, however, be small in comparison to that through the unknown resistance, if the resistance of the voltmeter is large in comparison to the unknown, the currents in the two branches of a divided circuit being to each other inversely as the resistances of the respective branches. This error can be avoided by subtracting from the value of the current indicated on the ammeter the value of the current through the voltmeter, which gives the true value of the current through the resistance to be measured. The current through the voltmeter is equal to its indication in volts divided by its own resistance, or

$$I_v = \frac{E}{R_v} \qquad (52)$$

The resistance of the voltmeter is usually given on the lid of the containing case. If not, it can be determined by means of a resistance bridge. The current I_r through the resistance then is

$$I_r = I_a - I_v \text{ or} \tag{53}$$

$$I_r = I_a - \frac{E}{R_v} \tag{54}$$

and the value of the unknown resistance will be

$$R = \frac{E}{I_r} = \frac{E}{I_a - \dfrac{E}{R_v}} = \frac{E}{I_a R_v - E} R_v \tag{55}$$

Care should be exercised in making a resistance measurement by this method not to pass too large a current through the object to be measured as you are likely to change its resistance due to a change in temperature resulting from the excessive current. The greater the current, however, without undue heating of the conductor, the greater the voltmeter reading and, as a usual thing, the greater the accuracy. When very low resistances are to be measured, a low-reading voltmeter or, better still, a millivoltmeter should be used.

Example.—The current through a rail joint is 300 amperes and the drop in potential across the joint and bonds is 18 millivolts or .018 volt. What is the resistance in ohms and microhms?

Solution.—By substituting in equation (5) we have

$$R = \frac{.018}{300} = .000\,06$$

Ans. .000 06 ohm.

$$0.000\,06 \times 1\,000\,000 = 60$$

Ans. 60 microhms.

Example.—The current through a spool of wire is .5 ampere and the drop in potential across the spool as indicated on a (0-15) voltmeter, having a resistance of 1500 ohms, is 12 volts. What is the resistance of the wire?

Solution.—Substituting in equation (55) we have

$$R = \frac{12}{.5 \times 1500 - 12} \times 1500 = 24.39$$

Ans. 24.39 ohms.

54 Measurement of Resistance by Comparison.—This method requires no ammeter and the value of the unknown resistance (X) is determined in terms of a known resistance

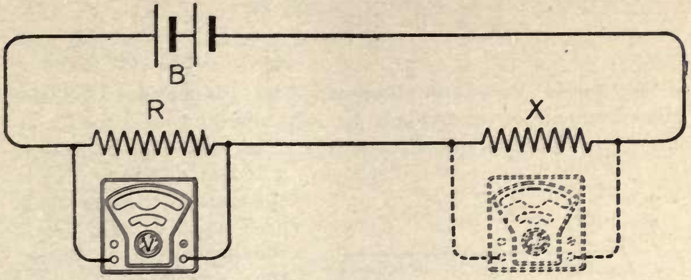


Fig. 13

(R) connected in series with it, as shown in Fig. 13. The drop in potential over the known and unknown resistances is measured when they are both carrying the same current. The proper connections of the voltmeter for making these measurements is shown in the figure by the full and dotted lines. Since the drop in potential across any part of a circuit bears the same relation to the drop across any other part of the same circuit as exists between the resistances of the two parts, we have the simple relation

$$\frac{\text{Drop in potential over X}}{\text{Drop in potential over R}} = \frac{\text{Resistance of X}}{\text{Resistance of R}} \qquad (56)$$

or

$$\text{the unknown resistance } X = \frac{\text{Resistance of R} \times \text{p. d. over X}}{\text{p. d. over R}} \qquad (57)$$

Example.—A known resistance (R) of 10 ohms was connected in series with an unknown resistance (X), as shown in Fig. 13. The drop in potential over (R) was 5 volts and the drop over X was 10 volts. What was the resistance of (X)?

Solution.—Since the drop over the resistance (X) was twice that over the standard, the resistance of (X) must be twice that of the standard, or

$$X = 2 \times 10 = 20$$

Ans. 20 ohms.

Substituting in equation (57) we have

$$X = \frac{10 \times 10}{5} = 20$$

Ans. 20 ohms.

55. Series Voltmeter Method.—The connections for the measurement of resistance by this method are made as shown in Fig. 14. The terminals (T_1) and (T_2) represent a source of e.m.f.; (X) is the resistance to be measured and (V) is a direct reading voltmeter. When the voltmeter is connected as shown by the dotted line, the resistance (X) is not in series with it between the terminals (T_1) and (T_2) and the voltmeter indicates the total pressure between the two terminals. When, however, the resistance (X) is connected in series with the voltmeter by opening the switch (S), the indication of the voltmeter is no longer the total pressure between the terminals (T_1) and (T_2) but it simply indicates the difference in pressure between its own terminals. The drop in potential over the voltmeter (E_v) or its own indication subtracted from the total pressure between (T_1) and (T_2), which we will call (E), will give the value of the drop (E_x) over the resistance (X).

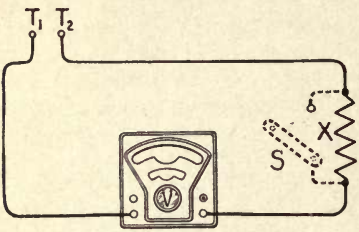


Fig. 14

$$E_x = E - E_v \tag{58}$$

It is assumed, of course, that the difference in pressure between (T_1) and (T_2) remains constant. If this is not the case a second voltmeter should be used, it being connected across the source of supply, and the value of its indication should be noted at the same time the voltmeter in series with the resistance is read. The current through the voltmeter and the resistance (X) is the same, since they are in series. The current through the voltmeter at any time is equal to the voltmeter reading divided by its own resistance, or

$$I_v = \frac{E_v}{R_v} \qquad (59)$$

The value of the resistance (X) can now be calculated, since the current through it and the drop in potential across it are known. Substituting in equation (5) the values of the p.d. and the current given in equations (58) and (59), gives

$$R = \frac{E - E_v}{\frac{E_v}{R_v}} = \frac{E - E_v}{E_v} \times R_v \qquad (60)$$

The above equation gives the value of the resistance in terms of the total pressure (E), the voltmeter reading (E_v) when it is in series with the resistance, and the resistance (R_v) of the voltmeter.

This method is, in general, serviceable for the measurement of high resistances, such as the insulation of electric light and power wires that are installed, insulation of trolley lines, dynamos, transformers, etc.

The scheme of connections for the measurement of the resistance of the insulation of a lighting circuit is shown in Fig. 15. A small generator (G) capable of supplying an e.m.f. of about 500 volts is usually used as a source of pressure for testing. The generator may be engine- or motor-driven. One terminal of the generator is connected directly to the conduit or ground and the other terminal is connected to the wire whose insulation resistance is to be determined, with the voltmeter in circuit. The total pressure generated by the machine (G) will be distributed over the resistance between the wire and the conduit, or ground, and the voltmeter. The voltmeter will read the drop (E_v) across itself. A second voltmeter (V_g) is shown connected across the terminals of the generator, and this voltmeter will read the total pressure (E). The value of the insulation resistance

(X) can now be calculated by substituting the values of the readings of the two voltmeters in equation (60) together with the resistance of the voltmeter (V_x) and solving the equation. Insulation resistance is usually given as so many megohms.

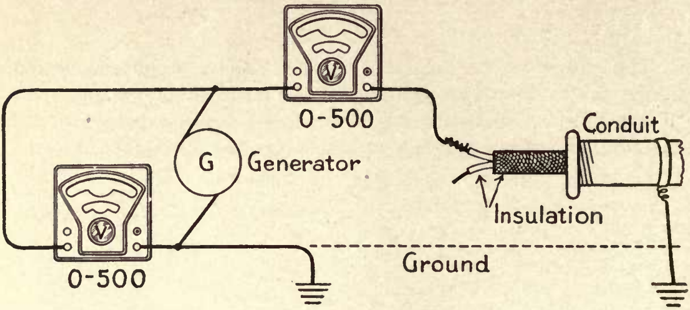


Fig. 15

Example.—Connections were made, as shown in Fig. 15, for testing the insulation resistance of a certain electric light system. The resistance of the voltmeter (V_x) connected in series with the resistance to be measured was 50 000 ohms. The voltmeter (V_g) read 500 volts and (V_x) 10 volts. What was the insulation resistance in megohms?

Solution.—Substituting the voltmeter readings and the resistance R_v in equation (60) gives

$$R = \frac{500 - 10}{10} \times 50\,000 = 2\,250\,000$$

$$2\,250\,000 \div 1\,000\,000 = 2.25$$

Ans. 2.25 megohms.

56. Direct-Deflection Method.—A galvanometer (G) is connected in series with the resistance to be measured and the two then connected to a source of e.m.f., as shown in Fig. 16. The indication produced on the galvanometer when the circuit is closed should be noted. The unknown resistance is then replaced by a known resistance and the circuit again closed and the deflection again noted. The current in the circuit for the two cases can be determined from the deflections of the galvanometer. Let (R_g) represent the resistance of the galvanometer, (E) the battery pressure, (R) the known resistance, (X) the unknown resistance, (I_r) the current through the known resistance, and (I_x) the current through the unknown resistance, then

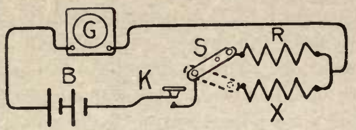


Fig. 16

$$I_x = \frac{E}{R_g + X} \qquad (61)$$

and

$$I_r = \frac{E}{R_g + R} \qquad (62)$$

Since the same pressure is acting on the circuit in both cases, and knowing the current in a circuit will vary inversely as the resistance, the relation may be written

$$\frac{I_x}{I_r} = \frac{R_g + R}{R_g + X} \qquad (63)$$

Calculating the value of (X) from the above equation we have

$$X = \frac{I_r\,(R_g + R)}{I_x} - R_g \qquad (64)$$

The resistance of the galvanometer is usually very small in comparison to the resistance being measured so that it may be neglected in the above equation, which gives

$$X = \frac{I_r}{I_x} \times R \qquad (65)$$

as the resistance of the unknown in terms of the current in the two cases and the value of the known resistance (R).

This method is used in determining the insulation of coils of wire, etc. The wire whose insulation is to be measured is immersed in a salty solution (it being a better conductor than ordinary water), with at least three feet of the wire out of the solution at each end. One terminal of the testing circuit is connected to the wire itself and the other terminal to a metallic plate placed in the solution. The resistance between the wire and the solution is then measured, giving the insulation resistance for the length of wire immersed in the solution.

The insulation resistance of a wire varies inversely as its length, because with an increase in length there is more surface exposed, resulting in a greater leakage and less resistance.

57. Principle of the Slide-Wire Wheatstone Bridge.—Two resistances, which may be equal or unequal, are shown connected in parallel between the points (A) and (B), Fig. 17, and the combination is connected to a source of e.m.f., such

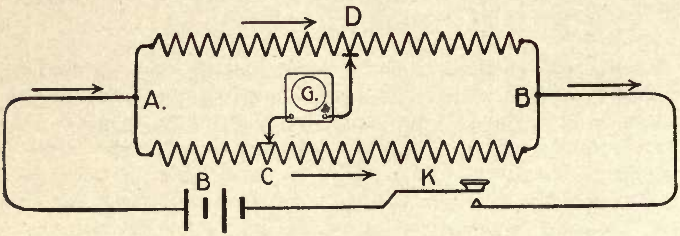


Fig. 17

as the battery (B). The drop in potential across the two branches of the divided circuit is the same regardless of the relation of the two resistances. If the resistance in each branch is the same, then the drop over a certain resistance in one branch is equal to the drop over the same resistance in the other branch. When the resistances of the two branches are not equal, the above relation does not hold true, but there are points on the two branches that have the same potential with respect to (A) or (B). Select some point, such as (C) on the lower branch, that will always have a potential less than the point (A) and higher than the point (B) when the current is in the direction indicated by the arrows. There is a point on the upper branch whose potential is equal to that of (C) and this point can be located by means of a galvanometer as follows: Connect one terminal of the galvanometer to the point (C) and slide the other terminal along the upper branch until a point is found which results in no deflection of the galvanometer when the circuit is closed. This point, which is marked (D) in the figure, is at the same potential as the point (C), since there is no current between them, there being no deflection produced on the galvanometer.

When the point (D) has been located, the drop in potential across (A C) is equal to the drop across (A D), and the drop across (C B) is equal to the drop across (D B). The resistance (A C) bears the same relation to (A D), after a balance is obtained, as the resistance (C B) bears to (D B). This statement may be put into the form of a simple equation, thus

$$\frac{\text{Resistance (A D)}}{\text{Resistance (A C)}} = \frac{\text{Resistance (D B)}}{\text{Resistance (C B)}} \qquad (66)$$

For example, suppose the resistance (A C) and the total resistance of the upper branch are known and the resistance (C B) is unknown. A balance is obtained, as previously described, and, from the position of the point (D) on the upper branch, the values of the resistances (A D) and (D B) may be determined, the combined resistance of the two being known. The above equation can then be changed to the form

$$\text{Resistance (C B)} = \frac{\text{Res. (D B)}}{\text{Res. (A D)}} \times \text{Res. (A C)} \qquad (67)$$

By substituting the value of the three resistances (A C), (D B), and (A D) in the above equation, the value of the resistance (C B) may be determined. This type of bridge is called a **slide-wire** pattern because the upper branch is usually a piece of resistance wire stretched between the points (A) and (B). The wire is stretched over a board divided into equal parts and the relation between the two resistances (A D) and (D B) can be determined in terms of their respective lengths, the resistance of the wire varying directly as the length. The two resistances (A D) and (D B) are called the

ratio-arms, since their relation to each other gives the ratio between the known and the unknown resistances.

58. Commercial Wheatstone Bridge.—The form of Wheatstone bridge described in the previous section is not used to any great extent in practice, as its operation is usually too tedious, and for this reason it is confined almost entirely to laboratory work. The principle of the commercial bridge is the same as that of the slide-wire bridge, differing only in construction and operation. A diagram of a simple form of

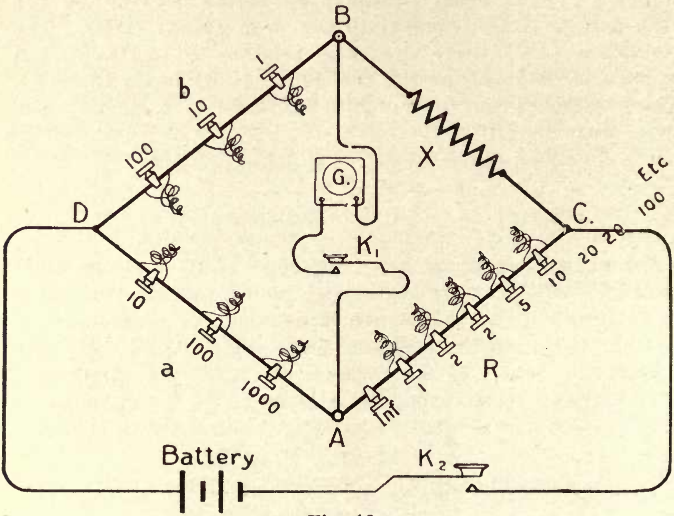


Fig. 18

bridge is shown in Fig. 18. The letters in the figure correspond to those in Fig. 17. The resistances (D B) and (D A) are the ratio arms, consisting of three coils each, having the resistances marked in the figure. The resistance (A C), called the **rheostat** of the bridge, consists of a number of coils ranging in value from a very low resistance to several hundred ohms, depending upon the range of the bridge. The various resistance coils that form the different arms of the bridge can be cut in or out of circuit by means of metallic plugs that connect massive brass or copper strips on top of the bridge. When a certain plug is removed the resistance coil that was shorted by the plug is connected in the circuit. The unknown resistance (X) is connected between the points (B) and (C). When a balance is obtained on the galvanometer, the following relation exists between the various arms of the bridge

$$\frac{a}{b} = \frac{R}{X} \qquad (68)$$

or

$$X = \frac{b}{a} R \qquad (69)$$

In making a measurement with this form of bridge the relation between the ratio arms (a) and (b) remains constant after they are adjusted to a certain value, and a balance is obtained by changing the value of the resistance in the rheostat (R). If (a) and (b) are made equal, then the resistance in (R), when a balance is obtained, is equal to the resistance of the unknown (X). When it is desired to measure a resistance larger than the value of (R), make the ratio arm

Fig. 19

(b) greater than (a); and to measure a resistance smaller than (R), make (b) less than (a). In the first case the resistance (R) is multiplied by a certain number, which is the quotient of (b ÷ a), and will always be greater than unity to obtain the value of (X); and in the second case (R) will be multiplied by a number less than unity. The galvonometer and the battery connections may be interchanged without interfering with the operation of the bridge.

There are a large number of different forms of bridges on the market at the present time. Some of them have the galvanometer, battery, and contact keys all mounted in the same box with the resistances, and the only connection that must be made is to the resistance to be measured. Fig. 19 shows a good form of portable Wheatstone bridge.

59. The Ohmmeter.—An Ohmmeter is an instrument for measuring automatically the resistance of a circuit connected to its terminals, by noting the position of a pointer on a dial that is marked to read directly in ohms. The principle of the **Evershed** instrument is as follows: The deflecting system consists of a set of coils (BB_1), as shown in Fig. 20, rigidly fastened together, which move about a center (O) in the magnetic field of strong permanent magnets (MM). The nature of this construction brings the instrument into the class of moving-coil permanent-magnet instruments, the advantages of which for reliability, accuracy under all conditions of use, and promptness in taking deflection, are quite

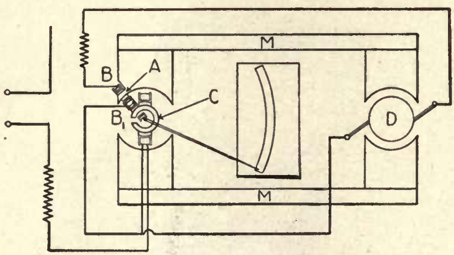


Fig. 20

numerous. Springs are not used for the control of the moving system, so that when not in use the needle may stand at any point along the scale.

If the generator is set in motion and no resistance is connected between the external terminals, current exists only in the coils (BB_1), which move at once to such location that (B) is clear of the horn on the pole piece and (B_1) is central over the air gap in the (O) shaped centrally placed hollow iron cylinder. The needle then stands over *Inf.* on the scale, showing an infinite resistance between the terminals. If a measurable resistance is connected between the terminals, a current exists in the stationary coil and, due to the thrust experienced by it in the magnetic field, the needle moves along the scale, and a direct reading of the amount of resistance so connected is made.

The hand dynamo (D) operates in the field of the same permanent magnets. The armature is wound so that a rated e.m.f. of 125, 250, 500, or even 1000 volts are generated for some 100 r.p.m. of the crank. The design of this machine is the result of a large amount of research by Mr. Evershed, in his desire to make a rugged, reliable, light-weight generator which would require slight propelling force to drive it. Instruments of this kind are usually used in measuring very high resistances, such as insulation resistances, etc.

CHAPTER IV

PRIMARY BATTERIES

60. The Voltaic Cell.—If two unlike metals are immersed in a solution, which is capable of acting upon one of them more than upon the other, there will be a current of electricity between them when they are connected by a wire. Such a combination constitutes a **voltaic cell.** This cell was first discovered by an Italian physicist, Volta, in 1800, and was named after him. It is, however, often called a **galvanic cell,** after Galvani, who was Volta's contemporary.

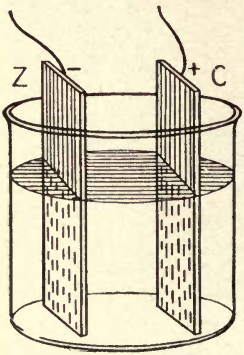


Fig. 21

61. Simple Voltaic Cell. — Two pieces of metal, such as copper and zinc, immersed in a solution that contains a little sulphuric acid, or other oxidizing acid, forms a simple voltaic cell. Such a cell is shown in Fig. 21. This cell is capable of furnishing a continuous flow of electricity through a wire whose ends are brought into contact with the strips of copper and zinc. When the electricity flows, the zinc is wasted away, its consumption furnishing the energy required to drive the current through the cell and the connecting wire. The cell might be thought of then as a chemical furnace in which the fuel is zinc. The copper strip from which the flow starts in passing through the external circuit is called the **positive pole** of the battery, and the zinc strip is called the **negative pole.** These poles are usually designated by the plus (+) and negative (—) signs.

It is the difference in electrical pressure between the positive and the negative poles of the battery that causes a current in the circuit when the poles are connected.

62. **Voltaic Battery.**—If a number of voltaic cells are joined in series—the zinc plate of one joined to the copper plate of the next, and so on—a greater difference in electrical pressure will be produced between the copper pole at one end and the zinc pole at the other end. When the poles forming the terminals of such a series are joined, there will be a more powerful current than one cell would cause. [It is assumed that the resistance of the circuit connecting the two poles or terminals is practically the same as the resistance of the circuit connecting the terminals of a single cell.] Such a grouping of voltaic cells is called a **voltaic battery.** Four single cells (C_1), (C_2), (C_3), and (C_4), are shown connected in series in Fig. 22. The cells may be combined in other ways and these

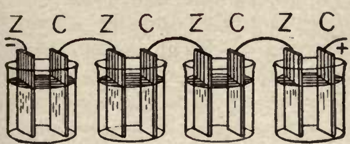


Fig. 22

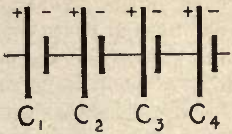


Fig. 23

methods will be taken up later. It is customary to represent a single cell by two parallel lines, as shown in Fig. 23, instead of drawing a picture of the cell each time you want to show it in a diagram. The long line corresponds to the plus (+), or positive, terminal, and the short line corresponds to the minus (—), or negative, terminal.

63. **Chemical Action in a Battery.**—A continuous potential difference is maintained between the zinc and copper in a simple voltaic cell chiefly by the action of the exciting liquid, say sulphuric acid, upon the zinc. Sulphuric acid is a complex substance in which every molecule is made up of a group of atoms, 2 of hydrogen, 1 of sulphur, and 4 of oxygen; or in symbols H_2SO_4. The SO_4 part of the acid has a very strong affinity for the zinc, and attacks it, when the plates are connected, producing a current, and forms zinc sulphate $ZnSO_4$, which is dissolved in the water. There will be two parts of

hydrogen gas liberated for every portion of the SO_4 part of the sulphuric acid that unites with the zinc. The zinc thus replaces the hydrogen in the acid, when the cell is being used, setting the hydrogen free. This chemical reaction is expressed in the equation

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

Zinc and sulphuric acid produce zinc sulphate and hydrogen.

This chemical action continues as long as the battery is supplying a current, the zinc gradually wasting away and the power of the acid to attack the zinc gradually becoming exhausted. Electrical energy is thus supplied to the external circuit by the combination of zinc and acid inside the cell.

64. **Local Action.**—When the circuit of a battery is not closed, the current cannot exist, and there should be no chemical action as long as the battery is producing no current. Ordinary commercial zinc, however, contains many impurities, such as tin, arsenic, iron, lead, carbon, etc., and these numerous foreign particles form local voltaic cells on the surface of the zinc inside the cell, with the result that the zinc is being continuously eaten away whether the cell is supplying current to an external circuit or at rest. These small cells weaken the current the main cell is capable of supplying under proper conditions. Often local action is caused by a difference in density of the liquid at different parts of the cell. This causes the zinc at the top of the cell to waste away and it may be entirely eaten off.

65. **Amalgamation.**—To do away with this local action, and thus abolish the wasting of the zinc while the battery is at rest, it is usual to **amalgamate** the surface of the zinc plates with mercury. The surface to be amalgamated should be thoroughly cleaned by dipping it into acid and then a few drops of mercury should be rubbed into the surface. The mercury unites with the zinc at the surface forming pasty amalgam. The foreign particles do not dissolve in the mercury, but float to the surface, and they are carried away by the hydrogen bubbles. As the zinc in the pasty amalgam dissolves into the acid, the film of mercury unites with fresh portions of zinc, and a clean, bright surface is always presented to the liquid.

66. **Polarization.**—When there is a current through a cell, the hydrogen that is liberated from the acid appears upon

the surface of the copper, and the copper plate becomes practically a hydrogen plate. If a cell were made having a hydrogen and zinc plate, there would be a current from the hydrogen to the zinc inside the cell and from the zinc to the hydrogen outside the cell. The hydrogen collecting on the copper plate tends to send a current through the cell opposite to that produced by the copper and zinc current. This results in the current supplied by the battery decreasing as the hydrogen on the copper plate increases, or the plate becomes more nearly covered with the hydrogen gas. A cell that has become weakened in this way is said to be polarized, and the phenomenon is called **polarization.** Hence, polarization is an evil, and if it could be overcome by preventing the hydrogen bubbles collecting on the copper plate, the cell would be capable of supplying a current of almost constant strength as long as zinc remained to be acted upon and the acid was not exhausted. Various attempts to prevent polarization have given rise to many different types of cells on the market at the present time.

67. Prevention of Polarization.—Various remedies have been practiced to reduce or prevent the polarization of cells. These may be classed as **mechanical, chemical,** and **electrochemical.**

(a) Mechanical Means.—If the hydrogen bubbles be simply brushed away from the surface of the positive pole, the resistance they cause will be diminished. If air be blown into the acid solution through a tube, or if the liquid be agitated or kept in constant circulation by syphons, the resistance is also diminished. If the surface be rough or covered with points, the bubbles collect more freely at the points and are quickly carried up to the surface and got rid of. This remedy is used in the Smee cell, which consists of a zinc and a platinized silver plate dipping into dilute sulphuric acid; the silver plate, having its surface thus covered with a rough coat of finely divided platinum, gives up the hydrogen bubbles freely, nevertheless in a battery of Smee Cells the current falls off greatly after a few minutes.

(b) Chemical Means.—If a strongly oxidizing substance be placed in the solution it will combine with the hydrogen and thus will prevent both the increase in internal resistance and the opposing electromotive force. Such substances are bichromate of potash, nitric acid, and bleaching powder (so-called chloride of lime). These substances, however, would attack the copper in the zinc-copper cell. Hence, they can only be used in a zinc-carbon or zinc-platinum cell.

(c) **Electro-chemical Means.**—It is possible by employing double cells to so arrange matters that some solid metal, such as copper, shall be liberated, instead of hydrogen bubbles, at the point where the current leaves the liquid. This electro-chemical exchange entirely obviates polarization.

68. **Internal Resistance.**—The resistance offered by a cell to a current through it from one plate to the other is called its **internal resistance.** The value of the internal resistance of any cell will depend upon the area of the two plates, the distance between the two plates, the specific resistance of the liquid, and the degree of polarization. As the polarization of a cell increases, the internal resistance increases, since the effective area of the plates exposed to the action of the liquid is decreased due to the accumulation of the hydrogen gas. This increase in internal resistance of a cell causes the difference in potential between its terminals to decrease, as a larger part of the electromotive force of the cell is required to force the current through its own resistance and the available electrical pressure is decreased.

69. **Factors Determining the Electromotive Force of a Cell.**—When two plates of the same material, such as zinc, are immersed in an acid solution and are connected by a wire, there will be no current in the wire, because there is a tendency to opposite currents and these two tendencies neutralize each other. In other words, the difference in electrical potential between one zinc plate and the solution is the same as that between the other zinc plate and the solution, and these two potentials are opposite in direction—when the two plates are connected by a conductor—which results in no current through the circuit when it is closed. The essential parts of any cell, therefore, are two dissimilar materials immersed in a solution, one of which is more readily acted upon by the solution than the other. The greater this difference in intensity in chemical action, the greater the difference in potential between the terminals of the cell.

Copper, platinum, silver, and zinc are the only metals that have been mentioned up to the present time, but other metals may be used, and since the intensity of chemical action will be different for different metals, there will be combinations that will produce better results than others. For example, a cell composed of zinc and tin would not produce as large an electromotive force as one composed of zinc and copper the same size, because there is a greater difference of electrical potential between the zinc and the copper than there is between the zinc and the tin.

The solution used in the cell also determines the value of the difference in potential between any combination of plates. There will be a different value for the potential difference between any two plates when they are immersed in different liquids.

When the same kinds of metals and solution are used, the potential difference between the plates will be the same, regardless of the areas of the plates. A small battery will have the same electromotive force as a large one composed of the same materials.

In the following list, the substances are arranged in order depending upon the degree of chemical action when placed in dilute sulphuric acid: Zinc, Iron, Tin, Lead, Copper, Silver, Platinum, and Carbon.

70. Classification of Cells.—(a) If a cell is capable of producing a current directly from the consumption in it of some substance, such as zinc, it is a **primary cell.** If, however, a current must first be sent through the cell to bring it to such a condition that it is capable of producing a current, it is called a **secondary, or storage, cell.** The fundamental distinction then between a primary and a secondary, or storage, cell is that, with the latter type the chemical changes are reversible, while with the former type this is not practical even when possible. The discussion of the storage cell will be taken up in a later chapter.

(b) Cells are also classified into **closed-** and **open-circuit** types, depending upon whether they are or are not capable of furnishing a current continuously. This classification is entirely dependent upon the polarization—the cell which does not polarize being able to maintain its current until its chemical substances are exhausted.

The Grenet and the Leclanche are perhaps the best examples of the open-circuit cells, while the Daniell, the Lalande, and the Fuller are good examples of the closed-circuit cell.

(c) All cells must be made up of two substances immersed in a liquid, but in some cases there are different liquids separated by gravity or a porous cup. Cells may then be classified, as to their construction, into **single-fluid cells** and **double-fluid cells.** The Grenet, Leclanche, and Lalande are good examples of single-fluid cells, while the Bunsen, Fuller, Daniell, and Grove are perhaps the best examples of the double-fluid type.

71. **Forms of Primary Cells.**—The various cells given in Table No. V are the principal ones that are used to any extent and the construction of a few of these will be given in detail in the following sections.

TABLE NO. V

PRIMARY CELLS

Names of Cell	Negative Pole	Positive Pole	Solution	Depolarizing Agent	E.M.F. in Volts	Internal Resistance in Ohms
Smee......	Zinc	Platinized Silver	Solution of Sulphuric Acid	None	.65	0.5
Grenet....	Zinc	Graphite (Carbon)	Solution of Sulphuric Acid	Potassium Bichromate	2.1	2 to .5
Leclanche.	Zinc	Graphite (Carbon)	Ammoni'm Chloride	Manganese Dioxide	.5 to 1.6	1.5
Daniell....	Zinc	Copper	Zinc Sulphate	Copper Sulphate	1.079	2 to 6
Lalande...	Zinc	Graphite (Carbon)	Caustic Potash or Potassium Hydrate	Cupric Oxide	0.8 to 0.9	1.3
Fuller.....	Zinc	Graphite (Carbon)	Sulphuric Acid	Potassium Bichromate	2.0	0.5 to 0.7
Bunsen....	Zinc	Graphite (Carbon)	Dilute Sulphuric Acid	Nitric Acid	1.8 to 1.98	.08 to .11
Grove......	Zinc	Platinum	Dilute Sulphuric Acid	Nitric Acid	1.96	.1 to .12
Clark Standard..	Zinc	Mercury	Zinc Sulphate	Mercurous Sulphate	1.434	.3 to .5
Weston....	Cadmium	Mercury	Cadmium Sulphate	Mercurous Sulphate	1.01830	

72. Chemicals Used in Cells and Their Symbols.—

Sulphuric Acid, H_2SO_4.
Chromic Acid, CrO_3.
Manganese Dioxide, MnO.
Zinc Chloride, $ZnCl_2$.
Lead Oxide, PbO.
Zinc Sulphate, $ZnSO_4$.
Nitric Acid, HNO_3.
Hydrochloric Acid, HCl.
Silver Chloride, AgCl.
Copper Oxide, CuO.
Lead Peroxide, PbO_2.
Sodium Chloride, NaCl.
Caustic Potash or Potassium Hydrate, KOH.
Copper Sulphate (blue vitriol), $CuSO_4$.
Zinc Sulphate (white vitriol), $ZnSO_4$.
Ammonium Chloride (sal-ammoniac), NH_4Cl.
Bichromate of Potassium, $K_2Cr_2O_7$.
Bichromate of Soda, $Na_2Cr_2O_7$.
Mercurous Sulphate, Hg_2SO_4.
Cadmium Sulphate, $CdSO_4$.

73. Mechanical Depolarization.—The Smee cell has been mentioned in section (67) as a good example of a mechanical means of preventing polarization. This cell was used commercially a number of years ago, but it was not very successful. A Smee cell is shown in Fig. 24.

There are a number of cells used for intermittent work, such as ringing door bells, that depend entirely upon the use of a large positive plate surface to lessen the rapidity of polarization. They consist usually of zinc and carbon plates immersed in a solution of sal ammoniac (ammonium chloride), see section (72). The carbons for such cells are made in almost endless variety and with very large surface.

74. Chemical Depolarization. — Bichromate Cells.—There are a number of different forms of bichromate cells, the principal ones of which are perhaps the Grenet and Fuller.

(a) Grenet Cell.—In this form a zinc plate is suspended by a rod between two carbon plates, see Fig. 25, so that it does not touch them, and when the cell is not in use the zinc can be removed from the solution by raising and fastening the rod by means of a set screw, as the acid acts on the zinc when the cell is not in use. Sulphuric acid and water is the solution used in this cell, to which is added potassium bichromate that acts as the depolarizer. The bichromate is rich in oxygen, which readily combines with the liberated hydrogen and thus prevents polarization. This

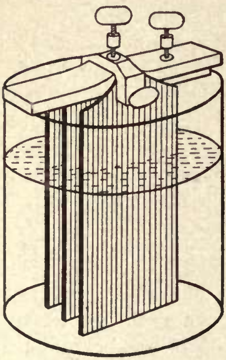


Fig. 24

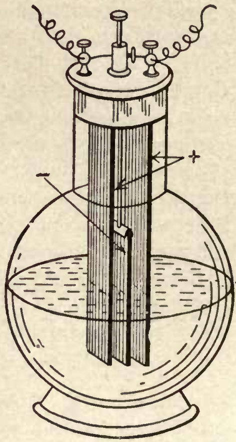


Fig. 25

cell gives a large e.m.f. and is capable of supplying a strong current for a short time, but the liquid soon becomes exhausted.

(b) **Fuller Cell.**—This form of bichromate cell is a double fluid type, and has the advantage over the Grenet type in that the zinc is always kept well amalgamated and it is not necessary to remove it from the solution. A pyramidal block of zinc is placed in a small porous cup, Fig. 26, and a small quantity of mercury poured in. The cup is then filled with a diluted solution of sulphuric acid and placed in a glass jar containing a solution of potassium bichromate and the carbon plate (P). A conductor, covered with a suitable insulation, is attached to the block of zinc and serves as one terminal of the cell. The zinc is well amalgamated by the mercury and there is practically no local action. The cell gives a large e.m.f. and may be used for open circuit or semi-closed circuit work.

75. Chemical Depolarization.—Leclanche.—This cell consists of a zinc plate in a solution of ammonium chloride and a carbon plate placed inside a porous cup which is packed full of manganese dioxide and powdered carbon. The action of the manganese dioxide on the hydrogen is not quick enough to prevent polarization entirely when large currents

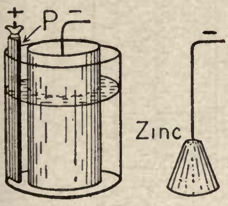


Fig. 26

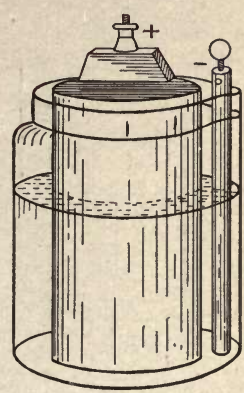


Fig. 27

are taken from the cell. The cell, however, will recover when allowed to stand on open circuit. A great advantage of this type of cell lies in the fact that the zinc is not acted on at all by the ammonium chloride when the cell is on open circuit, and as a result it can be left for almost an indefinite period when the circuit is open without deterioration. These cells are usually used for intermittent work, such as ringing door bells, and will supply quite a large current for a short time. Their e.m.f. is about 1.5 volts. Leclanche cells are called open-circuit cells on account of the very slight chemical action that takes place when the circuit is open. A Leclanche cell is shown in Fig. 27.

76. Electro-Chemical Depolarization.—Daniell Cells.—This type of cell consists of a zinc plate immersed in a solution of zinc sulphate and a copper plate immersed in a solution of copper sulphate. The two liquids may be kept apart either by gravity or by a porous earthen cup, as shown in Fig. 28. When the solutions are kept separated by gravity, the cell is called the **gravity,** or **crowfoot** type. A cross-section of a Daniell cell, in which the liquids are separated by a porous cup, is shown in Fig. 29. The gravity cell is

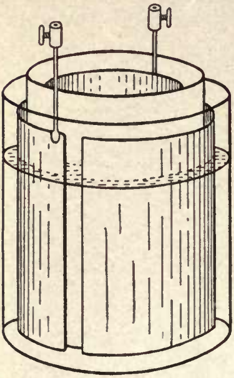


Fig. 28

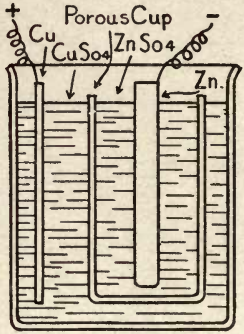


Fig. 29

shown in Fig. 30. The copper sulphate being the heavier of the two liquids remains at the bottom about the plate of copper, while the zinc sulphate remains at the top about the zinc plate. This cell will give a very constant e.m.f. of about 1.08 volts. It has a large internal resistance (two to six ohms) and as a result is not capable of supplying a very large current. The current supplied, however, is constant, and it will operate for a great length of time without renewal.

The Daniell cell is a closed-circuit cell and it should never be allowed to stand on open circuit, but a resistance (thirty to fifty ohms) should always be connected across its terminals.

77. Dry Cells.—The **dry cell** is a special form of the Leclanche cell first described. The cell is not altogether dry, since the zinc and carbon plates are placed in a moist paste which consists usually of ammonium chloride, one part; plaster of Paris, three parts; zinc chloride, one part;

zinc oxide, one part, and sawdust. These various materials composing the above mixture are thoroughly mixed and then moistened with a small quantity of water. The paste thus formed is packed around a carbon rod, placed inside a zinc cup lined with moistened blotting paper, and the cup is sealed with some kind of wax to prevent evaporation. There are a large number of different makes of dry cells on the market at the present time but the chemical action in each is practically the same. The dry cell is a very convenient form of cell and its operation is very satisfactory for work requiring an intermittent current. Fig. 31 shows a cross-section through a dry cell.

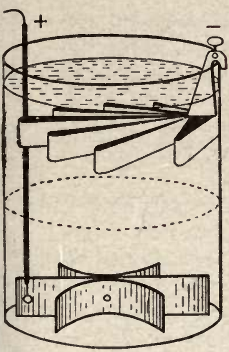


Fig. 30

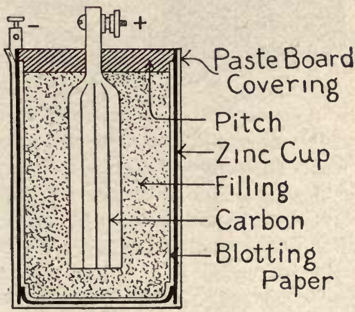


Fig. 31

78. Standard Cells.—A **standard cell** is one whose e.m.f. can be accurately calculated and will remain constant. The Clark Standard cell and the Weston cell are the two best examples of standard cells. The Clark cell has an e.m.f. of 1.434 volts at 15°C. and a correction must be made in this value when the cell is used at some other temperature.

The Weston normal cell has an e.m.f. of 1.01830 volts and there is practically no change in its e.m.f. due to a change in temperature. A Weston standard cell, as manufactured by the Weston Electrical Instrument Company, is shown in Fig. 32. The e.m.f. of different Weston cells is not exactly the same, but they are standardized in the factory and a certificate accompanies each cell. The average e.m.f. of a number of cells tested by the Bureau of Standards at Washington, D. C., was 1.01869 volts.

A great amount of care is exercised in assembling standard cells, to see that the materials used are the very best and that they are all constructed alike.

Fig. 32

79. Requirements of Good Cell.—A good cell should fulfill all, or the greater part, of the following conditions:

(a) Its electromotive force should be high and constant.

(b) Its internal resistance should be small.

(c) It should be capable of supplying a constant current, and, therefore, entirely free from polarization, and not liable to rapid exhaustion, requiring frequent renewals of the liquid or plates.

(d) It should be free from local action.

(e) It should be cheap and of durable materials which results in a low cost for renewals when they are required.

(f) It should be easily managed, and, if possible, should not emit corrosive fumes.

No particular cell fulfills all of the above conditions, however, and some cells are better for one purpose than others. Thus, for telegraph work over a long line, a cell of considerable internal resistance is no great disadvantage; while a large internal resistance is a great disadvantage when the cell is supplying current to a circuit of corresponding low resistance. An open-circuit cell would not operate satisfactorily in driving a small motor, but would be quite satisfactory for intermittent work; while the closed-circuit type would be very unsatisfactory for intermittent work.

80. Series Connection of Cells.—Any number of cells are said to be connected in series when the positive terminal of one is connected to the negative terminal of another, and so on. When all of the cells are connected, there remains a positive and a negative terminal which form the terminals of the battery. If (n) cells are connected in series, as shown in Fig. 33, and they each have an e.m.f. of (e) volts, the combination will have an e.m.f. of (ne) volts. The internal resistance of the battery will be equal to (nr) ohms where (r) is the internal resistance of each cell. If the external resistance or the resistance of the circuit to which the battery is connected is (R) ohms, then the current produced by the combination will be

$$I = \frac{ne}{R + nr} \qquad (70)$$

In the above equation (R + nr) represents the total resistance of the entire circuit and (ne) the total electromotive

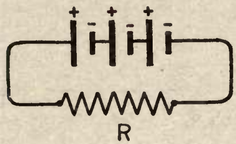


Fig. 33

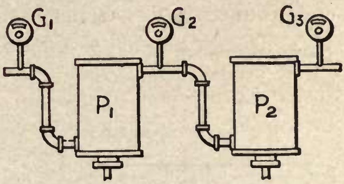


Fig. 34

force acting in the circuit. Fig. 33 shows three cells connected in series and the battery thus formed connected to a resistance (R).

Fig. 34 shows a hydraulic analogy similar to the connection of cells in series. The pumps (P_1) and (P_2) are so arranged that their pressures are added, the total pressure acting in the circuit being equal to the sum of the pressures produced by the respective pumps. If there is no water flowing and the gauge (G_1) reads zero, then (G_2) reads the pressure produced by the pump (P_1). The difference in the readings of (G_3) and (G_2) is the pressure produced by the pump (P_2). Hence (G_3) reads the total pressure produced by the two pumps combined when (G_1) reads zero and no water is flowing. When there is a flow of water, however, part of the pressure produced by the pumps is used in causing the water to pass through them or to overcome their internal resistance, and as a result the indication on (G_3) is reduced.

Example.—Six cells having an e.m.f. of 1.5 volts each and an internal resistance of .6 ohm each are connected in series with a resistance of 10 ohms. What is the current in the resistance when the circuit is closed?

Solution.—By a direct substitution in equation (70) we have

$$I = \frac{6 \times 1.5}{10 + (6 \times .6)} = \frac{9}{10 + 3.6} = \frac{9}{13.6} = 6.62—$$

Ans. 6.62 amperes.

81. Parallel Connection of Cells.—When (n) cells, all having the same e.m.f., are all connected in parallel, then the e.m.f. of the combination is only that of a single cell. The internal resistance of a battery formed of a number of cells connected in parallel is less than the internal resistance

Fig. 35

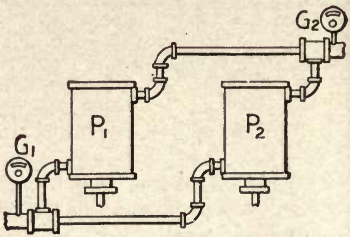


Fig. 36

of a single cell. If (r) is the internal resistance of each cell, and there are (n) cells in parallel, then the total internal resistance will be $\left(\frac{r}{n}\right)$. If the resistance of the external circuit is (R) ohms, then the current produced by the combination will be

$$I = \frac{e}{R + \frac{r}{n}} \qquad (71)$$

In the above equation $\left(R + \frac{r}{n}\right)$ is the total resistance of the entire circuit, and (e) is the electromotive force acting on this resistance.

Fig. 35 shows three cells connected in parallel and the battery thus formed connected to a resistance (R).

Fig. 36 shows a hydraulic analogy similar to the connection of cells in parallel. The pumps (P_1) and (P_2) are so connected that their pressures are not added, but the quantity of water supplied will be equal to that supplied by both pumps.

Example.—Six cells having an e.m.f. of 1.5 volts each and an internal resistance of .6 ohm each are connected in parallel, and the combination is then connected to a resistance of 10 ohms. What current exists in the resistance when the circuit is closed?

Solution.—By a direct substitution in equation (71) we have

$$I = \frac{1.5}{10 + \frac{.6}{6.}} = \frac{1.5}{10.1} = 0.148+$$

Ans. 0.148+ ampere.

82. Series and Parallel Combinations.—A very common grouping of cells is a combination of the series and the parallel groups. Suppose there are (P) groups of cells and each group consists of (S) cells in series. The total number of cells is then equal to (SP). The e.m.f. will be (Se) volts, the internal resistance of each set will be (Sr) ohms, and the internal resistance of the (P) sets combined will be $\left(\frac{Sr}{P}\right)$ ohms. If the external resistance is (R) ohms, then the total resistance will be $\left(R+\frac{Sr}{P}\right)$ ohms, and the current produced by the combination will be

$$I = \frac{Se}{R + \frac{Sr}{P}} = \frac{PSe}{PR + Sr} \qquad (72)$$

Fig. 37 shows a battery composed of three groups of cells and there are three cells connected in series in each group. The battery is connected to a resistance (R).

Example.—A battery is composed of nine cells connected, as shown in Fig. 37, to an external resistance of 10 ohms. The e.m.f. of each cell is 1.5 volts; each cell has an internal resistance of .5 ohm. What current will the battery supply when the circuit is closed?

Solution.—Substituting directly in equation (72), we have

$$I = \frac{3 \times 3 \times 1.5}{(3 \times 10) + (3 \times .5)} = \frac{13.5}{31.5} = 0.428+$$

Ans. 0.428+ ampere.

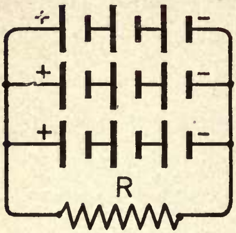


Fig. 37

83. Advantage of Series and Parallel Connections. — Cells are connected in parallel when it is desired to obtain a large current through a low external resistance. When the cells are so grouped they are equivalent to one large cell, and will have a very low internal resistance, and when connected to a low external resistance, as compared to the internal resistance, the current will be large. If the external resistance is large, the current will be small, as the electromotive force acting is small. The series connection is employed when the external resistance is the principal resistance to overcome and the maximum current strength is desired in the circuit.

PROBLEMS ON GROUPING OF CELLS

(1) How many cells should be connected in series to cause a current of 1.5 amperes in an external resistance of 8 ohms. The e.m.f. of each cell is 1.5 volts, and its internal resistance is .2 ohm.

Ans. 10 cells.

(2) How many cells must be connected in parallel to cause a current of 2 amperes in an external resistance of .6

ohm. The e.m.f. of each cell is 1.5 volts and its internal resistance is 1.2 ohms.

Ans. 8 cells.

(3) Ten cells, each having an e.m.f. of 2.2 volts and an internal resistance of .07 ohm, are connected in series to a circuit whose resistance is 4.3 ohms. What current exists in the circuit?

Ans. 4.4 amperes.

(4) Twenty storage cells are connected in series-multiple, there being five groups in parallel and four cells in series in each group. The e.m.f. of each cell is 2.2 volts and its internal resistance is .05 ohm. What current will the combination produce through an external resistance of .4 ohm?

Ans. 20 amperes.

(5) Five cells are connected in series. Each cell has an e.m.f. of 2 volts and an internal resistance of .2 ohm. What is the terminal voltage of the battery on open circuit and also when it is connected to an external resistance of 4 ohms?

Ans. Open-circuit voltage = 10 volts.
Closed-circuit voltage = 8 volts.

Note.—(There will be a drop in terminal voltage when the circuit is closed on account of the internal resistance.)

(6) Twenty cells, each having an e.m.f. of 2 volts and an internal resistance of .2 ohm, are to be connected so that they will give the maximum current through an external resistance of 1 ohm. What combination should be used?

Ans. Two groups, in parallel, each group having ten cells in series.

Note.—(The maximum current is obtained from any combination of cells when they are so connected that their combined internal resistance is equal to the external resistance to which they are connected).

Solution.—Let (S) equal the number of cells in series in any one group and then ($n \div S$) will equal the number of groups in parallel. Then in order that the maximum current be obtained from the battery

$$\frac{S \times r}{(n \div S)} \text{ must equal } 1.0$$

or

$$\frac{S \times .2}{\frac{20}{S}} = \frac{.2S^2}{20} = \frac{2S^2}{200} = \frac{S^2}{100} = 1.0$$

$$S^2 = 100$$
$$S = 10$$

(7) How many cells, each having an e.m.f. of 2.2 volts and an internal resistance of .005 ohm, must be connected in series in order that the terminal voltage may be at least 44 volts when the current through the battery is 40 amperes?

Ans. 22 cells.

(8) The terminal voltage of a battery drops from 1.8 volts on open circuit to 1.5 volts when there is a current of 6 amperes through the battery. What is the internal resistance of the battery?

Ans. .5 ohm.

CHAPTER V

MAGNETISM

84. The Magnet.—The name **magnet** was given by the ancients to certain black stones, found in various parts of the world, principally at Magnesia in Asia Minor, which possessed the property of attracting to them small pieces of iron or steel. This magic property, as they deemed it, made the magnet-stone famous; but it was not until about the twelfth century that such stones were discovered to have the still more remarkable property of pointing approximately north and south when freely suspended by a thread. This property of the magnet-stone led to its use in navigation, and from that time the magnet received the name of "lode-stone," or "leading stone." The natural magnet, or lodestone, is an ore of iron, and is called magnetite. Its chemical composition is Fe_3O_4. This is found in quite large quantities in Sweden, Spain, and Arkansas, U. S. A., and other parts of the world, but not always in the magnetic state.

85. Artificial Magnets.—If a piece of iron, or, better still, a piece of hard steel, be rubbed with a lodestone, it will be found to possess the properties or characteristic of the magnet, viz, it will attract light bits of iron; it will point approximately north and south if hung up by a thread; and it can be used to magnetize another piece of iron or steel. Magnets made in this manner are called **artificial magnets.**

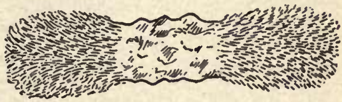


Fig. 38

Strong artificial magnets are not made from lodestone, as its magnetic force is not strong, but by methods as described under "Electromagnetism." Figs. 38 and 39 show, respectively, a natural and an artificial magnet, each of which has been dipped into iron filings; the filings are attracted and adhere in tufts at the ends.

86. Poles of a Magnet.—Certain parts of a magnet possess the property of attracting iron to a greater extent than do other parts. These parts are called the **poles** of the magnet. The poles of a bar magnet, for example, are usually situated at or near the ends of the bar, as shown in Fig. 38.

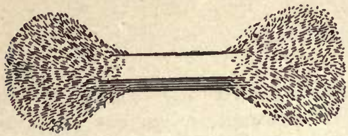


Fig. 39

87. Magnetic Needle.—The magnetic needle consists of a light needle cut out of steel, and fitted with a cap of glass, or agate, by means of which it can be supported on a sharp point, so as to turn with very little friction. This needle is made into a magnet by being rubbed on a magnet; and when placed on its support will turn into the north-and-south position, or, as we should say, will set itself in the "magnetic meridian." The end of the needle that points toward the north geographical pole is called the **North Pole,** and is usually marked with the letter N, while the other end is the **South Pole.**

By the term **polarity** is meant the nature of the magnetism at some particular point, that is, whether it is north or south-seeking magnetism. The compass sold by opticians consists of such a needle balanced above a card marked with the "points of the compass" and the whole placed in a suitable containing case. A common form of the magnetic needle is shown in Fig. 40.

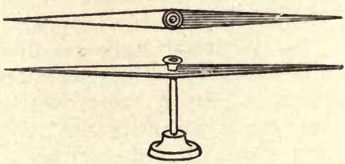


Fig. 40

88. Magnetic Attraction and Repulsion.—When the two poles of a magnet are presented in turn to the north-pointing pole of a magnetic needle, it will be observed that one pole of the magnet attracts it, while the other repels it. If the magnet is presented to the south-pointing pole of the magnetic needle, it will be repelled by one pole and attracted by the other. The same pole that attracts the north-pointing end of the magnetic needle repels the south-pointing end. As the needle and the magnet attract each other when unlike poles are presented, and repel each other when like poles are presented, it follows that like poles always repel each other and unlike poles always attract each other. Fig. 41 shows the results of presenting two like poles and Fig. 42 shows the result of presenting two unlike poles.

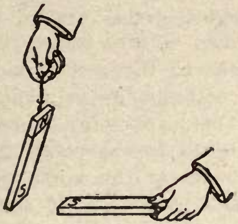


Fig. 41

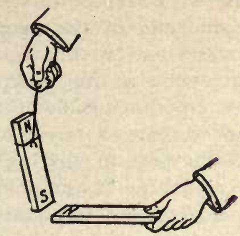


Fig. 42

Two equal and like poles are said to have unit **strength** when there is a force of repulsion between them of one dyne when placed one centimeter apart in air.

89. **Magnetizable Metals.**—The principal magnetic metals used in practice are steel and iron. There are other metals, such as nickel, cobalt, chromium, and cerium, that are attracted by a magnet, but very feebly. Of this last class cobalt and nickel are the best, but very inferior to iron or steel. All other substances, such as wood, lead, gold, copper, glass, platinum, etc., may be regarded as unmagnetizable, or nonmagnetic substances. Magnetic attraction or repulsion will, however, take place through these substances.

90. **Magnetic Force.**—The force with which a magnet attracts or repels another magnet, or any piece of iron or steel, is termed its magnetic force. The value of this magnetic force is not the same for all distances, the value being greater when the magnet is nearer, and less when the magnet is further off. The value of this force of attraction or repulsion decreases inversely as the square of the distance from the pole of the magnet. The force is mutual, that is, the

iron attracts the magnet just as much as the magnet attracts the iron.

91. Magnetic Lines of Force.—The magnetic force produced by a magnet emanates in all directions from the magnet. The direction of the magnetic force at any point near a magnet can be determined by means of a small compass needle suspended at the point in such a way that it is free to move in any direction. The direction at any other point can be determined by changing the position of the needle with respect to the magnet. Starting with the needle near one end of the magnet, it may be carried toward the other end and an imaginary line, drawn in such a way that its direction at any point corresponds to the direction assumed by the needle at that point, corresponds to what is termed a line of force, or it is the path taken by a north magnetic pole in moving from the north to the south pole of a magnet. These lines of force start at the north pole of a magnet and terminate at the south pole. Fig. 43 shows such a line.

92. Magnetic Field.—The region surrounding a magnet which is permeated by magnetic lines of force is called a

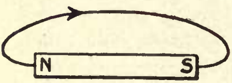


Fig. 43

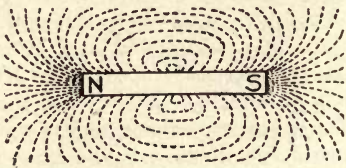


Fig. 44

magnetic field of force, or a **magnetic field.** The lines of force forming a magnetic field emanate from the N-pole of a magnet, pass through the medium surrounding the magnet, re-enter the S-pole and complete their path by passing from the S-pole to the N-Pole inside the magnet itself. The magnetic field surrounding a bar magnet is shown in Fig. 44. All magnetic lines form closed circuits and there must be two or more magnetic poles (always even) associated with each of these circuits except in the case of a ring magnetized by a current, which will be discussed later.

The region we speak of as a magnetic field is capable of acting upon magnets, magnetic materials, and conductors carrying a current of electricity. The lines of force forming any magnetic field are assumed to have two properties: First, they tend to contract in length; second, they repel each other. The attraction and repulsion of unlike and like poles can be accounted for by assuming the lines to possess the above properties.

93. **Making Magnetic Fields.**—A graphical representation of a magnetic field may be made by placing a piece of cardboard over the magnet or magnets whose field you want to produce, and sprinkle iron filings on the paper, tapping it gently at the same time. The iron filings are composed of a magnet material and arrange themselves in the direction of the lines of force or magnetic field, and as a result produce a graphical representation of the field. This representation of the field can be made permanent by using a piece of paper that has been dipped in paraffine instead of the cardboard.

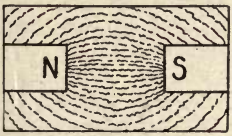


Fig. 45

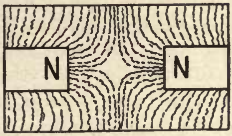


Fig. 46

The paraffine can be heated by means of a warm soldering iron, or other warm non-magnetic material, which permits the filings to imbed themselves in the wax and they will be held firmly in place when the paraffine has cooled.

The magnetic field that exists between unlike poles is shown in Fig. 45, and the field between like poles is shown in Fig. 46.

94. **Distortion of Magnetic Field.**—The direction of a magnetic field is influenced by the presence of magnetic material or magnets. When a magnetic material is placed in any magnetic field that exists in air, the form of the field will be changed because the material is a better conductor of magnetic lines than air and the lines of force crowd into the material. There will be a greater number of magnetic lines

in a given area in the iron than there is in a corresponding area in the air. A magnetic field that has been distorted, due to the presence of a piece of iron, is shown in Fig. 47. All materials that conduct magnetic lines better than air are called **paramagnetic,** and those that do not conduct as well as air are called **diamagnetic** substances.

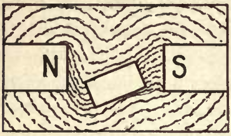


Fig. 47

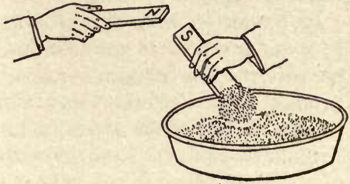


Fig. 48

95. **Magnetic Induction.**—Magnetism may be communicated to a piece of iron without actual contact with the magnet. If a short, thin, unmagnetized bar of iron be placed near some filings, and a magnet brought near to the bar, the presence of the magnet will **induce** magnetism in the bar, and it will now attract the iron filings, Fig. 48. The piece of iron thus magnetized has two poles, the pole nearest to the pole of the inducing magnet being of the opposite kind, while the pole at the farther end of the bar is of the same kind as the inducing pole. Magnetism can, however, only be induced in those bodies that are composed of magnetic materials. It is now apparent why a magnet should attract a piece of iron that has never been magnetized; it first magnetizes it by induction and then attracts it; as the nearest end will be a pole of opposite polarity, it will be attracted with a force exceeding that with which the more distant end is repelled.

96. **Retention of Magnetization.**—Not all of the magnetic substances can be used in making permanent magnets, as some of them do not retain their magnetism after being magnetized. The lodestone, steel, and nickel, retain permanently the greater part of the magnetism imparted to them. Cast iron and many impure qualities of wrought iron also retain magnetism imperfectly. Pure, soft iron is, however, only

temporarily magnetic. The above statements can be illustrated by the following experiment: Take several pieces of soft iron, or a few soft iron nails, and place one of them in contact with the pole of a permanent magnet, allowing it to hang downward from the magnet, as shown in Fig. 49. The piece of iron or nail is held to the magnet because it has become a temporary magnet, due to the process of magnetic induction. Another piece can be hung to the first, and another to the second, etc., until a chain of four or five pieces is formed. If now the steel magnet be removed from the first piece of iron, or nail, all the remaining pieces drop off and are no longer magnets. A similar chain formed of steel needles will act in the same way, but they will retain their magnetism permanently.

It is harder to get the magnetism into steel than into iron, and it is harder to get the magnetism out of steel than out of iron, because steel resists magnetization or demagnetization to a greater extent than soft iron. This power of resisting magnetization or demagnetization is called **hysteresis.**

97. Molecular Theory of Magnetism.—There are quite a number of experimental facts that lead to the conclusion that magnetism has something to do with the molecules of the

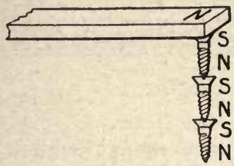


Fig. 49

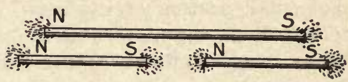


Fig. 50

substance, since any disturbance of the molecules causes a change in the degree of magnetization. If a test tube full of hard steel filings be magnetized, it will behave toward a compass needle or other magnet as though it were a solid bar magnet, but it will lose practically all of its magnetism as soon as the fillings are rearranged with respect to each other by giving the tube several good shakes. A needle that has been magnetized will lose its magnetism when heated. A magnet may be broken into any number of different pieces and there will appear at each break an N-pole and an S-pole, as shown in Fig. 50. The strength of the poles of any magnet will be greatly reduced by hammering, twisting, or bending it. A theory often used to explain certain magnetic phenomena is as follows: In an unmagnetized bar it is assumed that the molecules are each a tiny magnet, and that these molecules or magnets are arranged in no definite way, except that the opposite poles neutralize each other throughout the bar. The theoretical arrangement of the molecules in an unmagnetized bar is shown in Fig. 51. When the bar is brought into a magnetic field, the tiny magnets are turned, due to the action of the outside force, so that the N-poles tend to point in one direction and their S-poles in the other. The arrangement of the molecules after the bar has been magnetized is shown in Fig. 52. The opposite poles neutralize each other in the middle of the bar but there will be an N-pole found at one end and an S-pole at the other.

Fig. 51

The ease with which any material may be magnetized as compared to some other material will depend upon what might be termed the molecular friction of the material. Thus, the molecules in a bar of steel offer a greater resistance to a change in their position than do the molecules in cast iron. Steel, as a result, is harder to magnetize than cast iron, and it will also retain its magnetism after once magnetized better than cast iron for the same reason.

Fig. 52

98. Application of Permanent Magnets.—Permanent magnets are made to assume many different forms, depending upon the particular use to which they are to be placed. In the majority of cases the bar forming the magnet is bent into such a form that both poles will produce an effect instead of only one pole. Thus, instead of using a straight bar magnet in picking up a piece of iron, as shown in Fig. 53, the bar can be bent into a U-shape and both poles presented to the piece to be picked up as shown in Fig. 54. The effect of the two poles in the second case will, of course, be greater

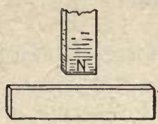


Fig. 53

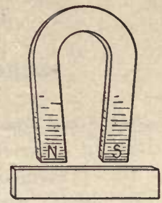


Fig. 54

than the single pole in the first. A magnet such as that shown in Fig. 54 is called a **horseshoe** magnet.

Permanent magnets are used for numerous different purposes, such as in telephone receivers, relays, ringers, measuring instruments, etc.

CHAPTER VI

ELECTROMAGNETISM

99. Magnet Field Around a Conductor Carrying a Current.—In 1819, Oersted discovered that a magnetic needle was disturbed by the presence of a conductor carrying a current, and that the needle always tended to set itself at right angles to the conductor. If a magnetic needle be placed below

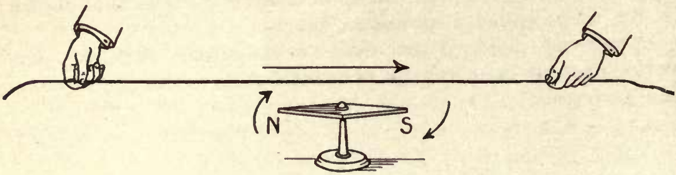


Fig. 55

a wire, as shown in Fig. 55, the current in the wire being from left to right, as indicated by the arrow, the needle will tend to move in the direction indicated by the curved arrows. If the current in the conductor be reversed, the direction of the magnetic needle will be reversed. It is thus seen that there is a magnetic field set up about a conductor carrying a current and that the direction of this magnetic field will depend upon the direction of the current in the conductor. Magnetism set up in this way by an electric current is called **electromagnetism.**

100. Direction of an Electromagnetic Field.—Remembering that the direction of a magnet field may be determined by placing a compass needle in the field and determining the direction in which the N-pole of the needle will point—this being taken as the positive direction—you can determine the direction of the magnetic field surrounding a conductor, produced by a current in the conductor. The small circle in Fig. 56 represents the cross-section of a conductor that can be imagined as passing through the paper. The direction of current in this conductor is away from the observer, and this fact is indicated by the plus sign (+) inside the circle. A compass needle placed below this conductor will set itself in such a position that the N-pole is toward the left and the S-pole is toward the right. If the compass needle be placed above the conductor, as shown in Fig. 57, the N-pole will point toward the right and the S-pole toward the

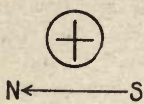


Fig. 56

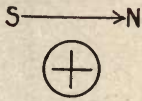


Fig. 57

left. When the current is reversed in direction, that is, the flow is toward the observer—which is indicated by the minus sign (—) inside of the circle—the positions assumed by the compass needle will be just the reverse of those shown in Figs. 56 and 57.

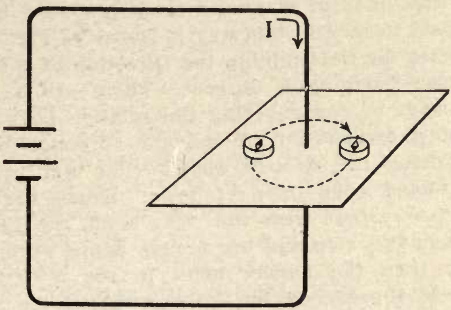


Fig. 58

If a conductor is passed through a small opening in the center of a piece of cardboard that is supported in a horizontal position, as shown in Fig. 58, and a current is passed through the conductor, the field may be explored by means of a small compass needle. When the current in the conductor is down through the cardboard, as indicated by the arrow (I) in the figure, the needle will assume a position at right angles to the conductor (neglecting the effect of the earth's magnetic field) and the N-pole will point, when you are looking down upon the cardboard, in the direction the hands of a clock move. The dotted line drawn on the surface of the cardboard indicates the path that an N-pole would move in, in passing around the conductor. The arrow on the dotted line indicates the direction in which the pole would move. If the current in the conductor were reversed, the direction of motion, or the direction of the field, would be reversed.

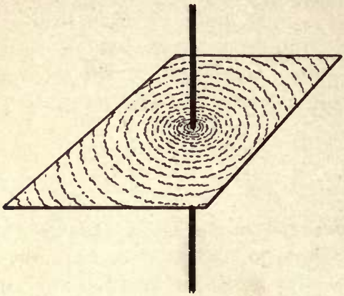


Fig. 59

Iron filings may be sprinkled on the cardboard and they will form concentric circles about the conductor which correspond to the lines of magnetic force produced by the current. A field formed in this way is shown in Fig. 59.

101. Rules for Determining the Direction of a Field About a Conductor Carrying a Current.—There are a number of different ways of remembering the relation between the direction of a magnetic field and the direction of the current producing it. A very simple rule that is known as the "right-hand rule" is as follows: Grasp the conductor carrying the current with the right hand, the thumb being placed along the wire and the fingers being wrapped around the wire; then the fingers point in the direction of the magnetic field produced by the current in the wire when the thumb points in the direction in which the current passes through the wire.

If a person looks along a conductor, carrying a current, in the direction of the current, the direction of the magnetic field surrounding the conductor will be clockwise.

Another rule known as the "right-hand screw rule" is as follows: Consider a right-handed screw which is being screwed into or out of a block, as shown in Fig. 60. If an electric current is supposed to exist through the screw in the direction in which the screw moves through the block, then the direction of the magnetic field will correspond to the direction in which the screw turns.

102. Strength of Magnetic Field.—The strength of any magnetic field is measured in terms of the number of lines of force per unit area, usually one square centimeter perpendicular to the direction of the field. The symbol used to indicate field strength is the letter (H). The properties of the magnetic field surrounding a conductor carrying a current are the same as those possessed by the magnetic field produced by a permanent magnet. The strength of a

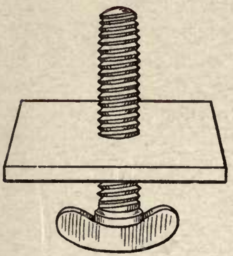


Fig. 60

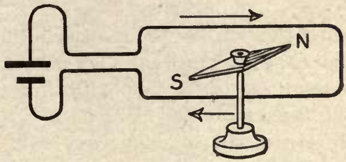


Fig. 61

magnetic field at a certain point, due to a current in a conductor or a permanent magnet, will depend directly upon the strength of the current in the conductor, or the strength of the permanent magnet, and inversely as the square of the average distance the point is from the conductor or permanent magnet.

103. Solenoid.—A little consideration will show that if a current be carried below a compass needle in one direction, and then back in the opposite direction above the needle by bending the wire around, as shown in Fig. 61, the forces exerted on the needle, due to the current in the upper and lower portions of the wire, will be in the same direction. If the needle is the same distance from each portion of the circuit the effect of the two parts will be just double that produced by either part acting alone. Hence, if the wire be coiled about the needle, each additional turn will produce an additional force tending to turn the needle from its normal position. The magnetic effect of any current can be greatly increased in this way.

A cross-section through a single turn of wire is shown in Fig. 62. The current is away from the observer in the upper part of the conductor, and toward the observer in the lower part, as indicated by the (+) and (—) signs. The direction of the magnetic field surrounding the upper cross-section will be clockwise, as indicated by the arrows on the curves drawn about it, while the direction of the field surrounding the lower cross-section will be counter clockwise, as indicated by the arrows, since the current is in the opposite direction in the lower cross-section of the conductor to what it is in the upper cross-section. It will be seen that the magnet field between the two cross-sections of the conductor or through the center of the turn is toward the left and it is the resultant of the two fields about the two cross-sections. The field is stronger between the two cross-sections than it is outside, which is indicated by a larger number of lines of force per unit of area, as shown in the figure.

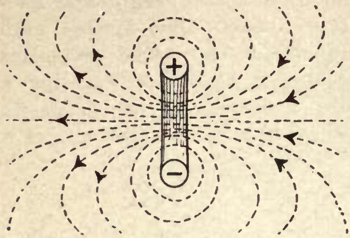


Fig. 62

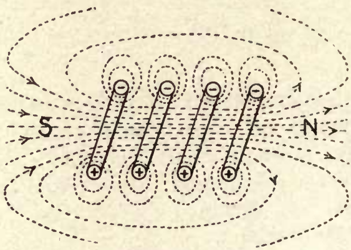


Fig. 63

Increasing the number of turns forming the coil will increase the strength of the magnetic field inside the coil, since the lines of force that surround each turn seem to join together and pass around the entire winding instead of passing around the respective conductors. A cross-section through a coil composed of several turns is shown in Fig. 63. A few of the lines encircle the different conductors, but the greater portion pass entirely through the center of the coil and around the total number of turns. Such coils are called **solenoids.**

104. Polarity of Solenoids.—A solenoid carrying a current exhibits all the magnetic effects that are shown by permanent magnets. If a solenoid that is carrying a current be suspended so that it is free to swing about a vertical axis, its own axis being horizontal, it will move into an approximately north and south position, exactly like a permanent magnet. A solenoid supported in this way is shown in Fig. 64. They attract and repel magnets, pieces of iron, and other solenoids. See Fig. 65.

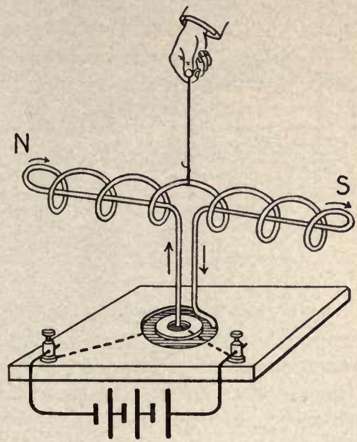


Fig. 64

The polarity of any solenoid may be determined, when the direction of the current is known, by a simple application of any one of the rules given in section (101). The lines of magnetic force inside the solenoid pass from the S-pole to the N-pole and outside the solenoid from the N-pole to the S-pole. Referring to Fig. 63, you see that the end of the solenoid toward the left will be the S-pole and the end toward the right, the N-pole.

A simple rule by which the polarity of a solenoid may be determined, if the direction of the current around the winding is known, is as follows: If you face one end of the solenoid and the current is around the winding in a clockwise direction, the end nearest you will be the S-pole and the other end will be the N-pole. If the direction of the current around the winding is counter clockwise, the end nearest you will be the N-pole and the other end, the S-pole.

Another simple rule is to grasp the solenoid with the right hand with the fingers pointing around the coil in the direction of the current, the thumb will then point toward the N-pole of the coil, as shown in Fig. 66.

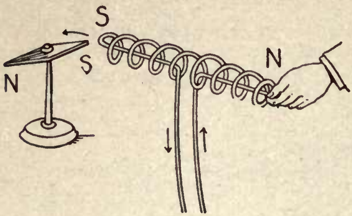


Fig. 65

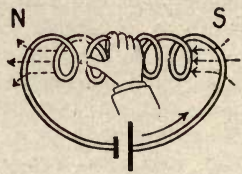


Fig. 66

105. The Toroid.—If a solenoid is bent around until its two ends meet, or if a winding is placed on a ring, the arrangement thus produced will be a **toroid.** By winding the various turns closely and uniformly over the entire periphery of the ring, the lines of force produced inside the ring by a current in the winding will form closed curves whose paths are entirely within the turns composing the winding; consequently, there are no external magnet poles. Such a coil is shown in Fig. 67.

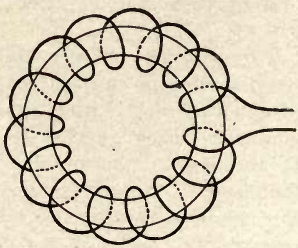


Fig. 67

106. Permeability. — The number of magnetic lines produced inside a solenoid, with an air core, can be greatly increased by introducing a piece of iron, even though the current in the winding of the solenoid remains constant. This is due to the fact that the iron is a better conductor of magnetic lines than air. The relation between the number of lines of force per unit area inside the solenoid after the iron has been introduced, designated by (β), to the number of lines per unit of area for an air core, which is the field strength, designated by (H), is called the **permeability,** designated by (μ).

$$\mu = \frac{\beta}{H} \qquad (73)$$

The permeability of a given sample of iron is not constant because the value of (β) does not increase at the same rate (H) increases. Curves showing the relation between the two quantities for wronght iron, cast iron, and cast steel

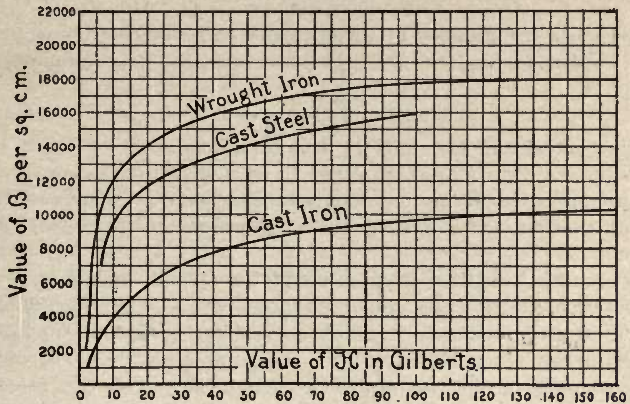


Fig. 68

are shown in Fig. 68. The permeability of these different kinds of iron can be determined for any value of (β) or (H) by dividing the value of (β) for any point on the curve by the corresponding value of (H).

The sharp bend in the curve is called the "knee" of the curve. The iron is very nearly saturated at this point because any further increase in (H) produces a small increase in (β) as compared to what a corresponding increase in (H) would do below the knee of the curve.

107. Magnetomotive Force. — The magnetomotive force (abbreviated m.m.f.) of a coil carrying a current is its total magnetizing power. When a current passes around a core several times, as shown in Fig. 69, the magnetizing power is proportional both to the strength of the current and the number of turns in the coil. The product of the current in the coil and the number of turns composing the coil is called the **ampere-turns.** The magnetizing power of the current is independent of the size of the wire, the area of the coils, or their shape, and remains the same whether the turns are close together or far apart. It has been found by experiment that one ampere turn sets up 1.2566 units of magnetic pressure. Hence, if (n) represents the number of turns in the coil and (I) represents the current in amperes through each turn, the magnetomotive force is

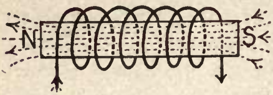


Fig. 69

$$\text{m.m.f.} = 1.2566 \times n \times I \qquad (74)$$

The **gilbert** is the unit in which magnetomotive force is measured. One gilbert is equal to (1 ÷ 1.2566) ampere-turn. **Magnetomotive force** or **magnetic pressure** corresponds to electromotive force and electrical pressure in the electrical circuit.

The m.m.f. acting in any magnetic circuit encounters a certain opposition to the production of a magnetic field, just as an electrical pressure encounters a certain opposition in the electrical circuit to the production of a current. The opposition in the magnetic circuit is called the **reluctance,** represented by ($\mathcal{R}$), of the circuit and its value will depend upon the materials composing the circuit and the dimensions of the circuit.

The total number of magnetic lines of force, called the **magnetic flux,** represented by (Φ), produced in any magnetic circuit will depend upon the m.m.f. acting on the circuit and the total reluctance of the circuit, just as the current in an electrical circuit depends upon the electrical pressure acting upon the resistance of the circuit. The unit of magnetic flux is the **maxwell,** and it is equal to one line of force.

The **gauss** is the unit of flux density, and it is equal to one line of force per unit of area.

$$\text{Number of lines} = \frac{\text{Magnetomotive force}}{\text{Reluctance}} \qquad (75)$$

$$\Phi = \frac{\text{m.m.f.}}{R} \qquad (76)$$

108. Reluctance.—The reluctance of any magnetic circuit depends upon the dimensions of the circuit and the kind of material composing the circuit. It varies directly as the length of the circuit and inversely as the area, all other conditions remaining constant. The reluctance of any given volume varies inversely as the permeability of the material filling the volume.

$$\text{Reluctance} = \frac{\text{Length in centimeters}}{\text{Permeability} \times \text{cross-section in sq. cm.}}$$

$$R = \frac{l}{\mu A} \qquad (77)$$

The unit in which reluctance is measured is called the **oersted** and it is equal to the reluctance of a cubic centimeter of air.

Reluctances can be added in the same way as resistances. If a magnetic circuit, such as that of the dynamo, is composed of a number of different kinds of materials, such as cast iron, wrought iron, air, etc., calculate the reluctance of each part by the above equation, and add these reluctances together to give the total reluctance of the entire magnetic circuit. The value of the permeability to use in the above equation will, of course, depend upon the number of magnetic lines the various parts of the circuit are to conduct per unit of area. The permeability of air is always unity.

Example.—An iron ring has a rectangular cross-section of four square centimeters and a mean length of 20.5 centimeters. A slot is cut in this ring .5 centimeters wide and the ring is wound with 1000 turns of wire. What current must there be in the winding in order that there will be 100 000 magnetic lines produced in the air gap? Take the permeability of the iron equal to 1000.

Solution.—The reluctance of the iron portion of the circuit can be determined by substituting in equation (77):

$$R = \frac{20}{1000 \times 4} = \frac{1}{200} \text{ oersted}$$

The reluctance of the air gap will be

$$R = \frac{.5}{1 \times 4} = 1/8 \text{ oersted}$$

Total reluctance is

$$\frac{1}{8} + \frac{1}{200} = \frac{13}{100} = .13 \text{ oersted}$$

Substituting the values of (R), (n), and (Φ) in equations (74) and (76) gives

$$100\,000 = \frac{1.2566 \times 1000 \times I}{.13}$$

$$1.2566 \times 1000 \times I = 13\,000$$

$$1\,256.6\ I = 13\,000$$

$$I = 10.34$$

Ans. 10.34 amperes.

Example.—The magnetic circuit, shown in Fig. 70, is rectangular in cross-section, the dimensions perpendicular to the paper being 3 centimeters. The permeability of the iron is 1000. The armature (A) is .5 centimeter from each magnet core. There are 500 turns in each coil and each turn is carrying a current of 10 amperes. What is the value of the total number of magnetic lines produced in the air gaps?

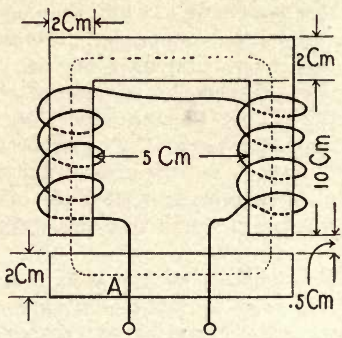


Fig. 70

Solution.—The total length of path in air is

$$2 \times .5 = 1 \text{ cm.}$$

The area of the magnetic circuit is the same throughout and is equal to

$$2 \times 3 = 6 \text{ sq. cm.}$$

The reluctance of the air gaps is equal to

$$\mathcal{R} = \frac{l}{\mu A} = \frac{1}{1 \times 6} = \frac{1}{6}$$

The length of the magnetic circuit in the iron is

$$(2 \times 5) + (2 \times 10) + 4 \left(\frac{\pi \times d}{4}\right) = 33.1416 \text{ cm.}$$

(Note—The circuit is taken as a curve about the corners.) The reluctance of the iron portion of the magnetic circuit will be

$$\mathcal{R} = \frac{33.1416}{1000 \times 6} = .005\,523\,6 \text{ oersted}$$

The total reluctance will be

$$\frac{1}{6} + .0055236 = .17219 \text{ oersted}$$

Substituting the values of (I), (n), and ($\mathcal{R}$) in equation (76) gives

$$\Phi = \frac{1.2566 \times 2 \times 500 \times 10}{.17219} = 72\,970.$$

Ans. 72 970. maxwells (approx.).

PROBLEMS ON MAGNETISM

(1) A magnetic circuit is 40 cm. in length, has a cross-section of 4 square centimeters, and is composed of a material whose permeability is 1500. What is the reluctance of the circuit?

Ans. $\frac{1}{150}$ oersted.

2. What is the m.m.f. in gilberts produced by a current of 7.5 amperes through a winding around a magnetic circuit of 1200 turns?

Ans. 11 309.+ gilberts.

(3) A magnetic circuit is composed of three parts connected in series, having reluctances of .032, .015, and .053 oersted, respectively. What m.m.f. would be required to produce a flux of 10 000 maxwells?

Ans. 1000 gilberts.

(4) How many turns would be required in a coil to produce the above m.m.f., if each turn is to carry a current of 1 ampere?

Ans. 795 turns (approx.).

(5) It is desired to magnetize a piece of iron until there are 6000 lines per square centimeter. What cross-section is required to have a total of 100 000 lines?

Ans. 16⅔ sq. cm.

(6) Two magnetic circuits are acting in parallel and they have reluctances of .05 and .04 oersted respectively. What is the total reluctance of the two combined?

Ans. .0222 oersted.

(Note: Add reluctances in parallel the same as resistances.)

109. Electromagnet.—A simple electromagnet consists of a piece of iron about which is wound an electrical conductor through which a current of electricity may be passed. Commercial electromagnets assume numerous different forms depending upon the particular use to which they are to be placed. They are used in electric bells, telephones, relays, circuit breakers, generators, motors, lifting magnets, etc. The use of the electromagnet in handling magnetic materials has become quite common in recent years. A magnet manufactured by the Electric Controller and Supply Company, Cleveland, Ohio, which is used for the above purpose, is shown in Fig. 71.

110. Hysteresis.—If a piece of iron be magnetized, then demagnetized and magnetized in the opposite direction and again demagnetized it will be found that the degree of magnetization will be different for the same value of (H) depending upon whether the field is increasing or decreasing in strength. The magnetization of the iron lags behind the magnetizing force and, as a result, the values of (β) for

Fig. 71

certain values of (H) will be greater when the magnetizing force is decreasing than they will be for the same values of (H) when the magnetizing force is increasing. Fig. 72 shows the relation between (β) and (H) when the iron is carried through what is termed a complete cycle; that is, it is magnetized to a maximum positive (β), as at (a) in the figure; then demagnetized and magnetized to a maximum negative (β), as at (b) in the figure, which gives the upper curve (a c b). The lower curve (b d a) is obtained in a similar way by demagnetizing the sample from a negative (β) to zero and then magnetizing it to a maximum positive (β), returning the iron to its original magnetic condition, which completes the cycle.

111. Hysteresis Loss.—When a piece of iron is carried through a magnetic cycle, as described in the previous section, all the energy spent in magnetizing it is not returned to the circuit when the iron is demagnetized, which results in a certain amount of electrical energy being expended to carry the iron through the cycle. This energy appears in the iron as heat. The energy lost per cycle depends upon the kind of iron being tested, the volume of the sample, and the maximum value of (β) raised to the 1.6 power.

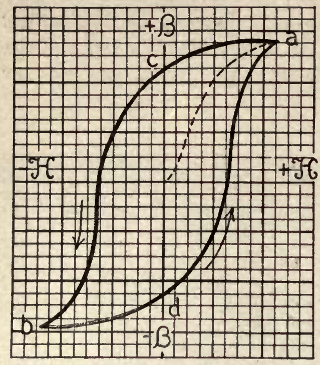


Fig. 72

Joules (energy per cycle) = $V \times \beta^{1.6} \times \eta \times 10^{-7}$ (78)

The constant (η) takes into account the kind of iron being tested and (V) is the volume in cubic centimeters. If the iron is carried through (f) cycles per second, the loss of power in watts is given by the equation

$$W_h = \eta \times f \times V \times \beta^{1.6} \times 10^{-7} \text{ watts} \qquad (79)$$

TABLE NO. VI

VALUE OF HYSTERETIC CONSTANT (η) FOR DIFFERENT MATERIALS

Best annealed transformer sheet metal	.001
Thin sheet iron (good)	.003
Ordinary sheet iron	.004
Soft annealed cast steel	.008
Cast steel	.012
Cast iron	.016

Example.—A piece of iron is magnetized to a maximum (β) of 9000 lines per sq. cm. It is carried through 60 complete cycles per second. What is the power lost in 10 cubic centimeters if the hysteretic constant (η) is .003?

Solution.—In order to raise the value of (β) to the 1.6 power you must make use of logarithms. (A description of the use of logarithms is given in Chapter 20.) In the table of logarithms you will find opposite the number 900 the mantissa 95424. (The mantissa of the logarithm of 900 is the same as the mantissa of the logarithm of 9000.) Place the figure 3, the characteristic, before this number, which is one less than the number of significant figures in 9000 and you have the log $9000 = 3.95424$. Multiply this log by 1.6 and you have 6.326 784. Now 6.326 78 is the log of the result you want to obtain. Looking up the mantissa 32678 in the table, you find it corresponds to 2122. The result must contain seven figures before the decimal point (because the characteristic is six), hence, the result is 2.122×10^6. Substituting this value in equation (79), together with the values of (f), (V), and (η), gives

$$W_h = .003 \times 60 \times 10 \times 2.122 \times 10^6 \times 10^{-7}$$
$$= .18 \times 2.122 = .38$$

Ans. .38 watts.

112. Law of Traction.—The formula for the pull of, or lifting power of, an electromagnet when it is in actual contact with the object to be lifted is

$$\text{Pull in pounds} = \frac{\beta^2 A}{72\,134\,000} \qquad (80)$$

In the above equation (β) is the number of lines per square inch and (A) is the area of contact in square inches. The value of (β) required to produce a given pull, when the area of contact is known, can be calculated by the use of the equation

$$\beta = 8494 \frac{\text{Pull in pounds}}{\text{Area in square inches}} \qquad (81)$$

In the above equation (β) will be lines per square inch.

CHAPTER VII

ELECTROMAGNETIC INDUCTION—FUNDAMENTAL THEORY OF THE DYNAMO

113. Electromagnetic Induction.—In 1831, Michael Faraday discovered that an electrical pressure was induced in a conductor that was moved in a magnetic field, when the direction of motion of the conductor was such that it cut across the lines of force of the field. If this conductor forms part of a closed electrical circuit, the electromotive force induced in it will produce a current. Currents that are produced in this way are called induction currents and the phenomenon is termed electromagnetic induction. In this great discovery lies the principle of the operation of many forms of commercial electrical apparatus, such as dynamos, induction coils, transformers, etc.

114. Currents Induced in a Conductor by a Magnet.—If a conductor (AB), Fig. 73, that is connected in series with a galvanometer (G), located so that it is not influenced to any great extent by the permanent magnet, be moved in the field of the magnet, the moving system of the galvanometer will be deflected to the right or left of the zero position. This deflection is due to a current in the circuit which is caused by the induced e.m.f. in the conductor that was moved in the magnetic field. When the movement of the conductor in the field ceases, the galvanometer system will return to its zero position, which indicates there is no current and hence no induced e.m.f. in the circuit. Hence, the conductor must be actually cutting the magnet lines of force in order that there be an induced e.m.f. produced in the circuit. If the conductor was moved downward across the field in the above case and the deflection of the galvanometer needle was to the right, it will be found, upon moving the conductor upward across the field or in the opposite direction to its motion in the first case, that the galvanometer needle will be deflected to the other side of its zero position. Since the direction in which the needle of the galvanometer is deflected depends upon the direction of the current through its winding, it is apparent the current in the circuit in the second case is in the opposite direction to what it was in the first case; and since the current is due to the induced e.m.f. in the conductor (AB), it must also be in the opposite direction. If the motion of the conductor in the magnetic field is continuous, up and down past the end of the magnet, there will be a current through the galvanometer first in one direction and then in the opposite direction, and the galvanometer needle will swing to the right and left of its zero position. The motion of the conductor, however, may be rapid enough so that the galvanometer needle has not sufficient time to take its proper position with respect to the current in the conductor and as a result it remains practically at zero, the vibration or deflection to the right or to the left being very small.

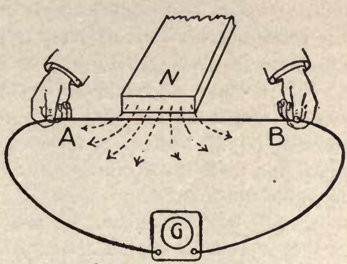


Fig. 73

The same results can be obtained by using the opposite pole of the magnet, except the deflection of the galvanometer needle due to a given direction of motion of the conductor will be just the reverse of what it was with the other pole. This shows that there is some definite relation between the direction of motion of the conductor, the direction of the magnetic field, and the direction in which the induced e.m.f. acts. If the wire were held stationary and the magnet moved, the same results would be obtained as though the wire were moved past the magnet. Hence, it is only necessary that there be a relative movement of the conductor and the field; either may remain stationary. An electromagnet may be used instead of the permanent magnet and the same results will be obtained under similar conditions.

If the conductor were moved very slowly across the magnetic field, the galvanometer needle would be deflected through a much smaller angle than it would be if the conductor were moved faster across the field. The deflection of the galvanometer needle depends upon the value of the current through its winding and since the deflection is smaller when the conductor is moved slowly than it is when the conductor is moved fast, it must follow that the induced e.m.f. for a slow movement of the conductor is less than it is for a fast movement, even though all the magnetic lines of force forming the magnetic field be cut by the conductor. The above results show that the value of the e.m.f. induced in a conductor, due to the relative motion of the conductor and a magnetic field, depend upon the rate at which the conductor is moving. If a second conductor be connected in series with the first, so that their induced e.m.f.'s act in the same direction, the resultant e.m.f. is increased. This is equivalent to increasing the effective length of the conductor in the magnetic field.

The induced e.m.f. may be increased by placing a second magnet along the side of the first so that their like poles are pointing in the same direction. This second magnet increases the strength of the magnetic field and the conductor cuts more lines of force due to any movement.

If the conductor be moved in a path parallel to the lines of force forming the magnetic field or along its own axis, there will be no deflection of the galvanometer needle, which indicates there is no current in the circuit and hence, no induced e.m.f. Then, in order that there be an induced e.m.f. set up in a conductor due to its movement with respect to a magnetic field, the path in which the conductor moves must make some angle with the direction of the magnetic lines of force. The value of the induced e.m.f. due to the movement of a conductor in a magnetic field will increase as the angle between the direction of the lines of force and the path in which the conductor moves increases, and it will be a maximum when the conductor moves in a path perpendicular to the direction of the magnetic field and perpendicular to itself.

There will be an induced e.m.f. set up in the conductor even though the circuit of which the conductor forms a part be open. This induced e.m.f. will exist between the terminals of the circuit where it is opened, just the same as an e.m.f. exists between the terminals of a battery that is on open circuit.

The question naturally arises: Is the magnet weakened when it is used in producing induced currents in a conductor as previously described, and if not, what is the source of energy that causes the current to exist in the conductor? The magnet is in no way weakened when it is used as previously described, and the induced current is produced by the expenditure of muscular energy just as an expenditure of chemical energy in a cell produces an electrical current in a closed circuit to which the cell is connected. When a conductor with a current in it is located in a magnetic field in a position other than parallel to the field, there is a force produced which tends to cause the conductor to move across the field. The direction of this force is just opposite to the one that must be applied to the conductor to cause it to move so there will be an induced e.m.f. set up which will produce the current. In other words, the induced e.m.f. set up in a conductor will always be in such a direction that the current produced by it will oppose the motion of the conductor.

115. Currents Induced in a Coil by a Magnet.—If a coil of wire (C) be connected in series with a galvanometer (G), as shown in Fig. 74, a deflection of the galvanometer needle can be produced by thrusting a magnet (M) in and out of the coil. When the magnet is thrust into the coil, a deflection of the needle will be produced, say, to the right, and when the magnet is withdrawn a deflection of the needle will be produced to the left. If the magnet be turned end for end, the deflections of the galvanometer needle will be just the reverse of what they were for the previous arrangement. If the coil (C) be turned through an angle of 180 degrees—so that the side that was originally toward the magnet will now be away from it—and the magnet be placed in its original position, the deflec-

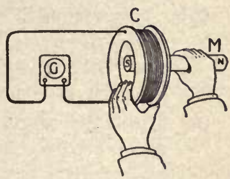


Fig. 74

tions of the galvanometer needle produced by a movement of the magnet in or out of the coil will correspond in direction to those produced when the coil was in its original position and the magnet had been turned end for end.

If the coil be moved on or off of the magnet, the same effect is produced as would be produced by moving the magnet in or out of the coil. The e.m.f. in this case, as in the previous one, will depend upon the rapidity of the movement of the magnetic field with respect to the coil, or *vice versâ.*

If the number of turns of wire composing the coil be increased or decreased, there will be a corresponding increase or decrease in the e.m.f. induced in the winding due to a given movement of the coil or magnet with respect to the other. The induced e.m.f. in the various turns all act in the same direction, they are all equal, and the resultant e.m.f. is equal to their sum.

116. Magnitude of the Induced E.M.F. and Factors upon Which It Depends.—From the discussion in the two previous sections it is seen that the induced e.m.f. in a circuit depends upon the following factors:

(a) The rate of movement of the conductor and the magnetic field with respect to each other. The more rapid the movement the greater the e.m.f. induced, all other quantities remaining constant.

(b) The strength of the magnetic field or the number of lines of force per square centimeter. The stronger the field the greater the e.m.f. induced, all other quantities remaining constant.

(c) Upon the angle the path, in which the conductor moves, makes with the direction of the lines of force. The nearer this path is to being perpendicular to the magnetic field and the position of the conductor, the greater the induced e.m.f.

(d) The length of the wire that is actually in the magnetic field. The more wire there is in the magnetic field, the greater the induced e.m.f.

The above facts can be condensed into the following simple statement: The magnitude of the induced e.m.f. in any circuit depends upon the rate at which the conductor, forming part of the circuit, cuts magnetic lines of force; that is, it depends upon the total number of lines of force cut per second by the conductor. When the conductor cuts one hundred million (100 000 000) lines in each second during its motion, an electrical pressure of one **volt** is induced in the conductor. If the conductor cuts lines of force at the rate of two hundred million (200 000 000) in each second, the induced pressure is equal to two volts; and if the conductor cuts eleven thousand million (11 000 000 000) lines in each second, there will be an induced e.m.f. of 110 volts. If the circuit of which this conductor forms a part be closed, there will be a current in the conductor, which has a strength equal to the induced pressure divided by the total resistance of the circuit.

Example.—A conductor cuts across a magnetic field of 110 000 000 lines of force 100 times per second. (The conductor always moves across the field in the same direction.) How many volts are induced in the wire?

Solution.—A conductor cutting 11 000 000 lines of force 100 times per second would be equivalent to cutting (11 000 000 × 100), or 1 100 000 000 lines once per second. Cutting 1 100 000 000 lines of force per second will induce in a conductor (1 100 000 000 ÷ 100 000 000), or 11 volts.

Ans. 11 volts.

117. Direction of Induced E.M.F.—From the previous discussion it is seen that the direction of the induced e.m.f. depends upon the direction of the magnetic field and the direction in which the conductor is moved with respect to the field.

If a piece of copper be bent into the form shown by (E C D F), Fig. 75, and a second piece (AB) be placed across the first and the combination placed in a magnetic field as shown by the vertical arrows in the figure, there will be a current around the metallic circuit thus formed when the conductor (AB) is moved to the right or to the left of its initial position. When the conductor (AB) is moved it cuts across some of the lines of force and there is an induced pressure set up in it which produces a current. The direction of this current will be reversed when the direction of motion of (AB), or the direction of the magnetic field, is reversed.

When the wire is moved in the direction indicated by the arrow (K) in the figure, the end (B) is positive and the other end (A) is negative, or the potential of (B) is higher than that of (A). This difference in pressure between (B) and (A) will cause a current in the circuit, from (B) through (C) and (D) to (A) and from (A) to (B). The wire (AB) is the part of the circuit in which the electrical pressure is generated and the electricity passes from a lower to a higher potential through this part of the circuit, just as the electricity passes from the negative to the positive pole of the battery through the battery itself.

A simple way of determining the direction of induced e.m.f. in a circuit, when the direction of motion of the con-

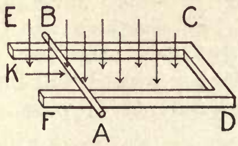


Fig. 75

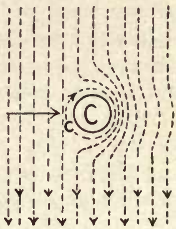


Fig. 76

ductor and the direction of the magnetic field are known, is as follows: Suppose a conductor (C), Fig. 76, is moved to the right, as indicated by the arrow, in a magnetic field whose direction is downward, as shown by the small arrow heads at the lower part of the figure. The lines of force might be thought of as elastic bands that are pushed aside when the conductor is moved in the field, but finally break and join again on the left side of the conductor, leaving a line linked around the conductor, as shown by the small circle (c). The direction of this line of force about the conductor is clockwise, or it corresponds to a line produced by a current toward the paper. Hence, the current in the conductor is from the observer toward the paper. It must be remembered that the current is from a point of relatively low potential to one of higher potential in this part of the circuit.

118. Rules for Determining Direction of Induced E.M.F.—There are a number of different ways of remembering the relation between the direction of the electrical current, the direction of the conductor's motion, and the direction of the magnetic field. One of the best rules is what is known as Fleming's "Right-Hand Rule," and it is as follows: Place the thumb and the first and second fingers of the right hand all at right angles to each other. Now turn the hand into such a position that the thumb points in the direction of motion of the conductor, and the first finger points in the direction of the lines of force, then the second, or middle, finger will point in the direction of the current that is set up in the conductor by the induced pressure. An illustration of the "Right-Hand Rule" is shown in Fig. 77.

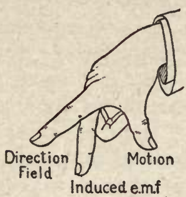


Fig. 77

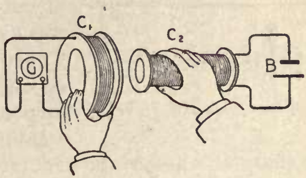


Fig. 78

119. Primary and Secondary Coils.—If a coil of wire (C_1) be connected in series with a galvanometer (G), as shown in Fig. 78, and a second coil (C_2) that has its winding connected to a battery (B) be moved into or out of the coil (C_1), there will be a deflection produced on the galvanometer, just as though a permanent magnet had been used instead of the coil (C_2). The coil (C_1), in which the induced e.m.f. is produced, is called the **secondary** and the coil (C_2), in which the inducing current exists, is called the **primary.**

There are a number of different ways of producing an induced e.m.f. in the secondary coil besides moving one coil with respect to the other. Four of these methods are as follows: (Both coils are stationary and one surrounds the other, or they are both wound around the same magnetic circuit).

(a) **By making or breaking the primary circuit.**—Imagine two conductors (AB) and (CD), Fig. 79, that are parallel to each other and very near together but are connected in two electrically independent circuits. The conductor (AB) is in series with the galvanometer (G) and constitutes the secondary circuit. The conductor (CD) is connected in series with a battery (B) and a switch (S) that can be used in opening and closing the primary circuit. When the primary circuit is completed by closing the switch (S), there will be a current through the conductor (CD) from (C) to (D). This current will produce a magnetic field about its path and the field around the conductor (CD) will cut the conductor (AB) which will result in an induced e.m.f. being set up in the secondary circuit that will send a current through the circuit from (B) to (A). The direction of this induced e.m.f. can be determined by means of the "Right-Hand Rule." There will be an e.m.f. set up in the secondary for a period of time corresponding to the time required to establish the current in the primary.

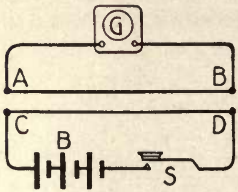


Fig. 79

As soon as the primary current ceases to change in value, there will be no movement of the magnetic field and the conductor (AB) with respect to each other.

If now the primary circuit be broken, the magnetic field surrounding the conductor (CD) will collapse, and as a result the conductor (AB) will cut the field again, but in the opposite direction to what it did when the current in the circuit (CD) was being established. There will be a current produced in the secondary that is practically constant in duration if the primary circuit is made and broken a sufficient number of times. The conductors forming the primary and secondary circuits are usually wound into coils, and they may be placed side by side or one outside the other. The e.m.f. induced in the secondary, due to a certain change of current in the primary, can be greatly increased by winding the two coils on an iron core. The magnetic field that passes through the two windings, due to the current in the primary is a great deal stronger when they are placed on the iron core than it is when an air core is used and, as a result, a greater number of lines of force will cut the secondary winding when the primary circuit is completed or broken.

The induction coil consists of two windings, a primary and a secondary, placed upon an iron core with some sort of a device connected in the primary circuit for interrupting the primary current. See Fig. 80. The relation between the primary and the secondary e.m.f. is practically the same as the relation between the number of turns of wire in the primary and in the secondary windings.

(b) Varying the strength of current in the primary.—This in reality is practically the same as the previous method, except the circuit is not entirely broken. Any change in the value of the primary current will result in a change in the magnetic field surrounding the primary winding, and as this field expands or contracts it will cut the conductor composing the secondary and, as a result, there will be an induced e.m.f. set up in the secondary winding. The direction of this induced e.m.f. will depend upon whether the field is expanding or contracting, which, in turn, depends upon the change of current in the primary — whether it be increasing or decreasing. The telephone induction coil is a good application of this means of producing an alternating current in the secondary due to a change in the value of the current in the primary. The connections of a telephone coil are shown in Fig. 81. (S) and (P) represent the secondary and the primary windings of the induction coil, which are usually wound, one outside of the other, on an iron core composed of a bundle of small iron wires. (R) is the receiver that is connected in series with the telephone line and the secondary winding. The transmitter (T) is connected in series with the battery (B) and the primary winding. The construction of the transmitter is such that when the air is set in vibration about the transmitter, due to any cause, there will be a change in the

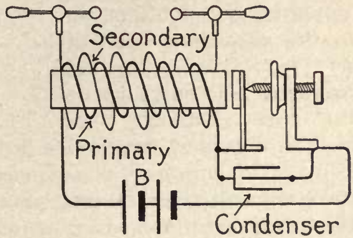


Fig. 80

value of the resistance it offers to the current in the circuit of which it is a part. The vibration of the air then causes a varying current through the primary winding of the induction coil, which, in turn, produces an e.m.f. in the secondary winding and as a result of this e.m.f. there will be a current over the telephone line that produces an effect on the receivers both at the sending and the receiving stations. It must be understood that the diagram, Fig. 81, does not show the complete circuit of the telephone.

(c) Reversing the current in the primary.—If a switch were constructed so that its operation would reverse the current in the primary winding, there would be an e.m.f. induced in the secondary winding due to a change in the magnetic field surrounding the two windings. This method is applied in practice in what is called a **transformer.** The switch, however, is not used, as the current in the primary winding is an alternating current—a current that is reversing in direction at regular intervals. The operation of the transformer will be taken up under the subject "Alternating Current."

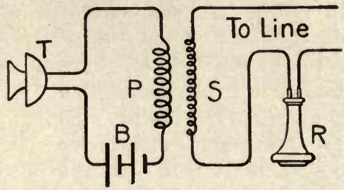


Fig. 81

(d) Moving the iron core about which the windings are placed.—The magnetic field produced by a given value of current in the winding of a coil will depend upon the kind of material composing the magnetic circuit, whether it be a material of high or low permeability. If the iron core upon which the windings are placed be moved so as to increase the reluctance in the magnetic circuit, there will be a decrease in the lines of force, and, as a result, there will be an induced e.m.f. set up in the secondary winding. If the core be moved so as to decrease the reluctance of the circuit, there will be an increase in the number of magnetic lines, or an increase in field strength, and an induced e.m.f. will be produced in the secondary winding in the opposite direction to that produced when the field strength decreased. This principle is employed in what is called the inductor type of alternating-current generator. An e.m.f. is produced by rotating iron poles between the primary and the secondary windings, which changes the number of the lines of force through the secondary due to the current in the primary.

120. **Mutual Induction.**—The reaction of two independent electrical circuits upon each other is called **mutual induction.** These circuits of course must be so placed with respect to each other that the magnetic field due to the current in either of them will produce an effect in the other. A good practical example of mutual induction is that of a telephone wire that runs parallel to, say, an electric-light circuit. The magnetic field surrounding the electric-light circuit cuts the telephone conductor and sets up in it an induced e.m.f. This induced e.m.f. will produce a current in the telephone circuit which interferes with the satisfactory operation of the telephone line. Often the conversation on one telephone circuit can be heard on another circuit due to this same cause. The wires composing the circuits should have their positions interchanged, as shown in Fig. 82. The e.m.f.'s induced in the two wires composing the telephone circuit are opposite in direction with respect to the telephone circuit and they will all exactly neutralize each other when the two wires are properly changed in position. The changing of the position of two wires is called a **transposition.**

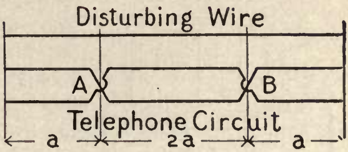


Fig. 82

121. **Self-Induction.**—If the value of the current in a wire forming a coil be changed in any way, there will be a change in the strength of the magnetic field surrounding the wire. This change in strength of the magnetic field will produce an e.m.f. in the conductor in which the current is changing just the same as though the field were changed in strength by a current in an independent electrical circuit. This cutting of the wire by the magnetic field produced by a current in the wire itself is called **self-induction.** When a coil carrying a current has its circuit broken, there will be a spark formed at the break due to the induced e.m.f. This induced e.m.f. will depend upon the form of the coil and the kind

of material associated with the coil. A straight conductor will have a small e.m.f. induced in it when the circuit is broken, as the magnetic field surrounding the conductor is not very strong. If the conductor be bent into a coil the induced e.m.f. will be greater than that for the straight conductor, as very nearly all the magnetic lines of force produced by each turn cut all the other turns composing the coil, and the total number of lines that cut the winding is greatly increased. This induced e.m.f. can be further increased by providing the coil with an iron core, which increases the field strength due to a given current in the winding.

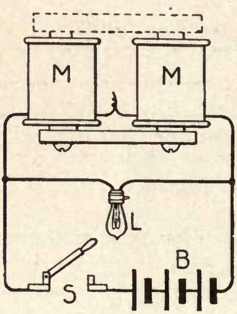


Fig. 83

In electric-gas lighting it is desired to have a circuit of large self-induction so that there will be a good spark formed when the circuit is broken at the gas jet. The heat of this spark is sufficient to ignite the gas. The self-induction of such a circuit is increased by connecting in series with the battery and other parts of the circuit a coil wound upon an iron core. This kind of a coil is often spoken of as a "kick coil."

If a lamp (L) be connected across the terminals of an electromagnet (M), as shown in Fig. 83, the lamp will burn very bright just for an instant after the battery circuit is opened. This is due to the induced e.m.f. set up in the winding of the electromagnet when the field contracts and cuts the various turns. The e.m.f., of course, is only momentary, as the field soon disappears when the circuit is broken by opening the switch (S). The voltage the lamp is constructed to operate on and the battery voltage should be practically the same in order to give the best results.

122. Inductance.—The inductance of any circuit depends upon the form of the circuit and the kind of material surrounding the circuit. There is an increase in the value of the inductance of a coil with an increase in the number of turns and an increase in the permeability of the material composing the magnetic circuit. A coil is said to have unit inductance when an induced e.m.f. of one volt will be produced due to a change in the current in the winding of one ampere in one second. That is, if the current changes, say, from two to three amperes in one second and there is an induced e.m.f. of one volt, the coil is said to have unit inductance. The unit of inductance is the **henry,** and inductance is usually represented by the symbol (L).

The inductance of any coil can be calculated by the use of the following equation when the dimension of the coil and other quantities are known:

$$L = \frac{4 \times \pi \times n^2 \times \mu \times A}{10^9 \times l} \qquad (82)$$

In the above equation (n) is the number of turns of wire on the coil, (μ) is the permeability of the material composing the magnetic circuit, (A) is the area of the magnetic circuit in square centimeters, and (l) is the length of the magnetic circuit in centimeters.

123. Lentz's Law.—A careful consideration of the ways by which induced currents may be produced, whether it be due to self or mutual induction, will result in the following simple fact. In all cases of electromagnetic induction, the current produced by the induced e.m.f. will always be in such a direction as to tend to stop the cause producing it. Thus, if a magnet be moved toward a coil, the current in the coil will be in such a direction that the side of the coil toward the magnet will be of the same polarity as the end of the magnet toward the coil. This results in the induced current tending to stop the motion of the magnet. When the magnet is moved away from the coil, the current in the coil will be in the opposite direction to what it was before and the side of the coil toward the magnet is of the opposite polarity to the end of the magnet toward the coil, and as a result they attract each other, which tends to prevent the magnet being moved.

If a coil of wire (C_1), in which there is a current, be moved toward a second coil (C_2), that is, connected in series with a galvanometer (G), Fig. 84, there will be an induced e.m.f. set up in the coil (C_2), which will cause a current through the galvanometer and thus produce a deflection of its needle. The current produced in the second coil (C_2) will be in such a direction as to make the sides of the two coils toward each other of the same polarity. These two poles repel each other and thus there is a force opposing the movement of the coils toward each other. When the coil (C_1) is moved away from (C_2), the sides of the two coils adjacent to each other are of opposite polarity and they attract each other. This results in a force which tends to prevent the coils moving apart. It must be remembered that this force of attraction or repulsion between the two coils is present only when there is a current in both coils.

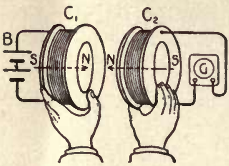


Fig. 84

If the two coils be wound on an iron core and the value of the current in the primary winding be changed, there will be a current in the secondary in such a direction as to oppose any change in the value of the magnetic field produced by the current in the primary.

124. General Rules for Direction of Induced Pressures.—

(a) If a primary coil be moved into a secondary coil, the current in the secondary, due to the induced e.m.f., will be in the opposite direction to the primary current.

(b) If a primary coil be moved out of a secondary coil, the current in the secondary, due to the induced e.m.f., will be in the same direction as the primary current.

(c) Where the current is increasing in value in the primary coil, there will be a current in the secondary coil, due to the induced e.m.f. that is in the opposite direction to that in the primary coil.

(d) When the current is decreasing in value in the primary coil, there will be a current in the secondary coil, due to the induced e.m.f. that is in the same direction as that in the primary coil.

In the above cases the secondary is closed. If the secondary be open there will be an induced e.m.f. set up, which would produce a current in the direction indicated above, if the circuit was closed. Rules (c) and (d) apply when the primary and the secondary are stationary and the current is changing in value in the primary.

125. **Eddy Currents.**—If a disk of copper, or other conducting material, be rotated below a suspended magnet, as shown in Fig. 85, currents will be produced in the disk, which circulate in paths similar to those shown by the dotted lines in the figure. These currents tend to oppose the motion producing them and, as a result, the magnet, if it is free to move,

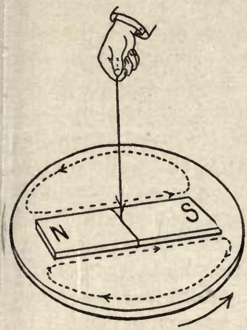


Fig. 85

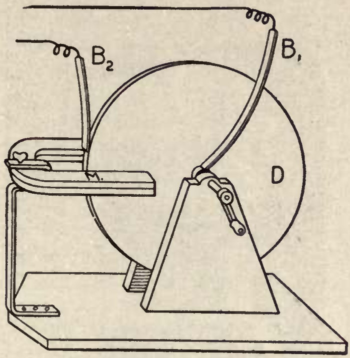


Fig. 86

will be rotated in the same direction as the disk. If, however, the magnet is held in position and the disk is rotated, a greater force must be applied to cause the disk to rotate than is required when the magnet is free to turn.

Currents induced in masses of metal that are moved in a magnetic field, or are cut by a moving magnetic field, are called **eddy currents.**

Faraday's dynamo, as shown in Fig. 86, consisted of a disk of copper (D) rotated between the poles of a permanent magnet (M), the electrical connection to the machine being made by means of brushes (B_1) and (B_2) that rested upon the center and edge of the disk.

126. **Application of Eddy Currents.**—A good example of the practical application of the fact that eddy currents are set up in a mass of metal revolved in a magnetic field, is found in almost all types of integrating wattmeters. A disk of copper

is fastened on the same shaft as the rotating portion of the meter is mounted upon, and this disk revolves between the poles of several permanent magnets, as shown in Fig. 87. This combination of disk and magnets constitutes a small generator and serves as a load for the motor part of the meter. The torque required to drive the disk in the field of the magnets is proportional to the speed, and since the driving torque of the motor is proportional to the product of the impressed voltage and the load current, or the watts, the speed of the moving part of the meter must be proportional to the watts. The integrating meter will be taken up more in detail in the chapter on "Electrical Measuring Instruments."

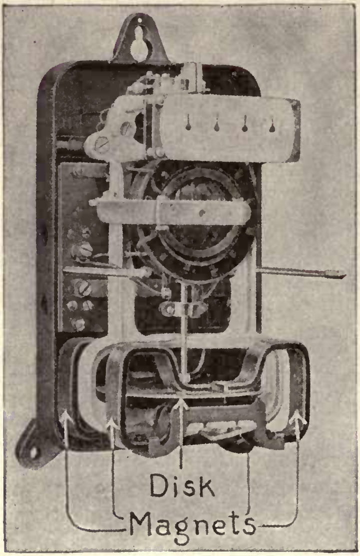


Fig. 87

127. Eddy-Current Loss.—The energy expended in producing eddy currents is converted into heat and represents a loss. These losses are quite large in dynamos, motors, transformers, etc., and it is always best to reduce them to a minimum when it is possible. The best way of reducing them is to split the mass of metal up into sheets, the plane of these sheets being parallel to the direction of the lines of force. It is customary to build up all volumes of metal that are likely to have eddy currents produced in them from thin sheets, or laminations, as they are called. Induction-coil cores are made from short lengths of small wire instead of using a solid core. Armature cores and the cores of transformers are laminated so as to reduce the loss due to eddy currents. These laminæ are usually between .014 and .025 inch in thickness for dynamos, and the space between them that is taken up by the oxide that forms on their surface is about .002 inch. Losses due to eddy currents could be reduced to an inappreciable value by decreasing the thickness of the laminæ, but there is a practical limit on account of the decrease in effective iron area, caused by the waste of space taken up by the insulation between adjacent laminæ.

When the laminæ are perfectly insulated from each other, the following equation can be used in calculating the power in watts lost in iron due to eddy currents:

$$W_e = k \times V \times f^2 \times t^2 \times \beta^2 \qquad (83)$$

In the above equation (k) is a constant, depending upon the resistance of the iron per cubic centimeter, which is usually about 1.6×10^{-11}; (V) is the volume of the iron in cubic centimeters; (t) is the thickness of one lamina in centimeters; (f) is the frequency of magnetic cycles per second; and (β) is the maximum number of lines per square centimeter to which the iron is magnetized.

Example.—Find the eddy-current loss in 1000 cubic centimeters of iron, composed of laminations .04 cm. thick (including insulation), that is subject to a maximum (β) of 10 000 lines per square centimeter and a frequency of 60 cycles per second.

Solution.—Taking the value of $(k) = 1.6 \times 10^{-11}$ and substituting in equation (83) gives

$$W_e = \frac{1000 \times 60^2 \times (.04)^2 \times 10\,000^2}{1.6 \times 10^{11}}$$

$$W_e = \frac{1000 \times 3600 \times .0016 \times 100\,000\,000}{1.6 \times 10^{11}}$$

$$W_e = \frac{36 \times .16}{1.6} = 3.6$$

Ans. 3.6 watts.

128. Non-Inductive Circuit.—In the construction of certain coils it is desired to have them as nearly non-inductive as possible. This is accomplished by winding the coil with two wires laid side by side, as shown in Fig. 88, their inner ends being joined electrically. When the winding is completed, the two outside ends form the terminals of the coil. The current in such a coil is in one direction in one-half of the turns and in the remaining half of the turns in the opposite direction. The result is that the magnetic effect of the current in one-half of the turns is equal and opposite to the other half and they exactly neutralize, and the inductance of the coil will be zero, or the coil will be **non-inductive.**

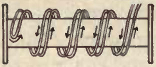


Fig. 88

CHAPTER VIII

ELECTRICAL INSTRUMENTS AND EFFECTS OF A CURRENT

129. Classification of Instruments.—No attempt will be made in this chapter to describe all of the various forms of instruments on the market at the present time, it being deemed best to confine the description in almost every case to those that are in most common use. Electricity is not a material substance like water and cannot be measured in the same way since it has no dimensions such as length, breadth, or weight. An electrical current is studied and measured by the effects it produces in an electrical circuit. The operation of all instruments depends upon some effect produced by the current and this leads to the classification of instruments into four groups depending upon the particular effect employed in their operation. These effects are:

(a) **Electro-chemical effect.**
(b) **Magnetic effect.**
(c) **Heating effect.**
(d) **Electrostatic effect.**

Note: The electrostatic effect is not an effect of a current primarily, but of electrical pressure.

In addition to the above classification, instruments may be divided into the following groups:

(a) Instruments suitable for direct-current measurements only.

(b) Instruments suitable for alternating-current measurements only.

(c) Instruments suitable for both direct- and alternating-current measurements.

In the following discussion of instruments, they will be grouped according to the effect upon which their operation depends, and their adaptability to the measurement of direct or alternating current will be pointed out at the same time.

Ammeters, Galvanometers, and Voltmeters

130. Distinction between Ammeters, Galvanometers, and Voltmeters.—An **ammeter** is an instrument to be used in measuring the current in a circuit, and for that reason ammeters will always be connected in series with that part of the circuit in which it is desired to ascertain the value of the current.

A **galvanometer** is an instrument used in detecting the presence of a current in a circuit, or for measuring the value of the current. It is really the same as an ammeter as far as construction and operation are concerned, but it is usually used in measuring very small currents as compared to those measured by ammeters.

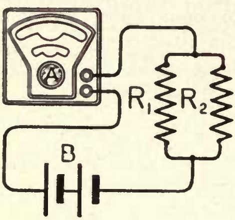


Fig. 89

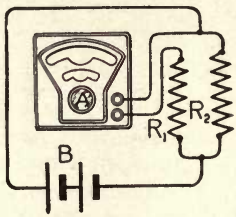


Fig. 90

In Fig. 89, the ammeter (A) is connected in series with the battery (B) and the two resistances (R_1) and (R_2), which are in parallel. The ammeter in this case reads the total current in the main circuit but it does not give the current in either of the resistances (R_1) or (R_2). If, however, the instrument be connected, as shown in Fig. 90, it will indicate the current in the resistance (R_1). By changing the instrument to the branch containing the resistance (R_2), the current in this branch can likewise be determined.

A **voltmeter** is an instrument for measuring the difference in electrical pressure between any two points to which its terminals may be connected. Thus, if it is desired to know the difference in electrical pressure between the terminals of any part of an electrical circuit, such as the difference in pressure between the terminals of a lamp that is connected to some source of electrical energy, as shown in Fig. 91, the voltmeter is connected to the two terminals and its indication is a measure of the pressure over the lamp. The ammeter and the voltmeter both operate on the same principle, that is, their indications depend upon the current passing through them. The voltmeter indication depends upon the pressure between its terminals, because the current through it varies with this difference in pressure, the resistance of the instrument remaining constant.

The resistance of an ammeter should be very low for the following reason: An ammeter will always be connected directly in the circuit and there will be a difference in electrical pressure between its terminals when there is a current through it, which is at any instant numerically equal to the product of the current and the resistance of the instrument. This drop across the ammeter should be small in order that the power required to operate the instrument be low in value, it being equal to the product of the current through the ammeter and the difference in pressure between ammeter terminals. If the ammeter in Fig. 89 had a resistance whose value was something near the value of the combined resistance of the two coils (R_1) and (R_2) in parallel, practically half the output of the battery would be consumed in the ammeter and would represent a loss. If, on the other hand, the ammeter had a very low resistance, a very small part of the output of the battery would be consumed in it. The division of the current between the two branches of the circuit shown in Fig. 90 would be quite different after the ammeter was introduced in either branch to what it was before, if the ammeter had a large resistance. If the ammeter had a small resistance in comparison to that of either of the branches, the change in the division of the current between the two branches when the ammeter was introduced in either of them would be a great deal less than in the previous case.

The resistance of a voltmeter, on the other hand, should be as large as possible for the following reason: The loss of power in the voltmeter is equal to the product of the current through it and the difference in pressure between its terminals, and since it is to indicate the difference in pressure, the only way this loss can be reduced is to increase the resistance of the instrument, which results in a smaller current. Suppose the voltmeter (V), shown in Fig. 91, had a resistance equal to that of the lamp (L), then the power required to operate the voltmeter would be equal to that required to operate the lamp, since there would be the same value of current in each, and the same difference in pressure between their terminals. This condition of affairs would result in a considerable loss and it could be reduced by increasing the resistance of the voltmeter. An ammeter connected in the line leading from the generator (G) to this lamp would indicate the combined current in the lamp and the voltmeter circuits. Hence, in order to get the current in the lamp circuit, the value of the current in the voltmeter circuit should be subtracted from the value of the total current. If the resistance of the voltmeter be large in comparison to that of the lamp, the current in its circuit will be small in comparison to the lamp current and the ammeter indication will be practically equal to that in the lamp circuit. The above discussion leads to the conclusion that an ammeter and a voltmeter need differ only in their resistance, the principle of operation being the same.

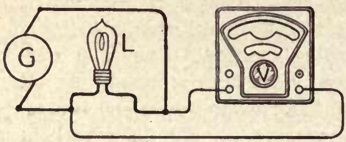


Fig. 91

131. Ammeter Shunts.—In the construction of ammeters it is usually customary to make them with two circuits between their terminals. One circuit has a very low resistance and carries the greater portion of the current to be measured, while the other circuit has a comparatively large resistance and carries a small current. The current in the branch of larger resistance usually produces the deflection of the moving system of the instrument. The other branch constitutes what is termed the ammeter shunt. The shunt and moving system are usually mounted in the same case, when the instrument is used in measuring currents ranging from a very low value to perhaps 600 amperes. For large currents they are usually constructed separately.

If the resistance of the shunt is known, the current through it can be determined by measuring the difference in pressure between its terminals—by means of a suitable voltmeter, usually a millivoltmeter—and then dividing this difference in pressure in volts by the resistance gives the value of the current. Instruments used on switchboards as a rule have their shunts connected directly in the line, and small leads run from the terminals of this shunt to the moving system, which is mounted in a convenient place on the face of the board. An instrument and its shunt are shown in Fig. 92. The needle of this instrument comes to rest in the center of the scale when there is no current in its winding, and the direction of its deflection will depend upon the direction of the currents in the shunt.

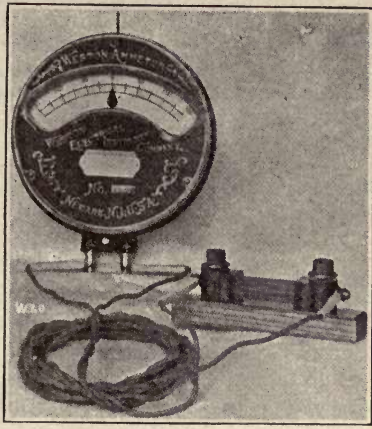


Fig. 92

Instruments Whose Operation Depends Upon Electro-Chemical Effect of a Current

132. **Electrolysis.**—If two conducting plates, such as platinum, be immersed in acidulated water and a current of electricity be passed through the solution from one plate to the other, the water will be decomposed into its two constituents, oxygen and hydrogen. Such a combination of plates and solution constitutes what is called an **electrolytic cell,** and the process of decomposing the liquid is called **electrolysis.** The solution through which the electricity is being conducted is called the **electrolyte,** and the two plates that are immersed in the solution are called **electrodes.** The plate by

which the electricity enters the solution is called the positive electrode, or **anode**, and the plate by which the electricity leaves the solution is called the negative electrode, or **cathode**. The parts into which the electrolyte is decomposed are called **ions**. The ion liberated at the positive electrode is called the **anion**, and the one liberated at the negative pole is called the **cathion**. The vessel, plates, and other apparatus used in electrolysis constitute what is termed a **voltameter**, when such apparatus is used to measure quantity or current. When water is decomposed, hydrogen appears at the negative plate, or it is the cathion, and oxygen appears at the positive plate, or it is the anion. A simple

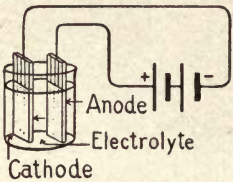


Fig. 93

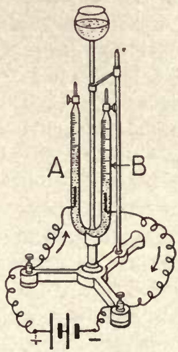


Fig. 94

electrolytic cell is shown in Fig. 93. The gas liberated at the two electrodes in this case passes off into the air. The voltameter, however, can be so constructed that the liberated gas will collect in an enclosed U-shaped tube, as shown in Fig. 94. The direction of the current in the circuit is indicated in the figure by the arrow. The oxygen will collect in the tube (A) and force the water down, while the hydrogen will collect in (B) and force the water down. The weight of the oxygen gas liberated by a certain quantity of electricity will be about eight times that of the hydrogen gas, but the oxygen gas will occupy only half the space that the hydrogen gas occupies, since a given volume of hydrogen gas is approximately one-sixteenth as heavy as the same volume of oxygen gas, and as a result the volume of gas collecting in the (B) tube will be practically twice the volume of gas in the (A) tube.

133. **Electrolysis of Copper Sulphate.**—When a current exists between two platinum plates immersed in a solution of copper sulphate $CuSO_4$ made by dissolving copper sulphate crystals (bluestone) in water, the solution will be broken up by electrolysis into Cu (metallic copper) and SO_4 (sulphion). The hydrogen gas liberated at the negative electrode takes the place of the Cu in the $CuSO_4$ forming H_2SO_4 (sulphuric acid) and the Cu is deposited on the negative plate. Oxygen will be liberated at the positive electrode as in the previous case. All of the Cu contained in the solution will be deposited on the negative plate if the current be allowed to pass through the electrolytic cell for a considerable time. When the Cu has all been removed from the solution it will be practically colorless. The reaction taking place in the cell can be represented as follows:

$$CuSO_4 = Cu + SO_4 \qquad (84)$$

Copper sulphate is decomposed into copper and sulphion. The Cu is deposited on the negative plate.

$$SO_4 + H_2O = H_2SO_4 + O \qquad (85)$$

The sulphion and water combine forming sulphuric acid and oxygen. The oxygen is liberated and passes off into the air and the sulphuric acid remains in the solution.

In the above case the negative plate will increase in weight due to the deposit of copper upon it and this increase in weight is proportional to the quantity of electricity passing between the two electrodes.

If copper plates be substituted for the platinum plates, the sulphuric acid will attack the positive electrode and just as much copper will be thrown into solution as is deposited upon the negative electrode. This results in no change in the electrolyte, but there is a wasting away of the positive plate and an equal increase in weight of the negative plate as the electrolytic action continues.

134. **Electroplating.**—The principles of electrolysis are applied in coating objects with a layer of metal and the process is called electroplating. The object to be plated always

forms the cathode of the electrolytic cell and the metal to be deposited is held in solution and as the process continues metal is supplied to the solution from a plate which forms the anode of the cell. This plate should, of course, be of the same material as the metal in the solution. All articles cannot be coated with certain metals without having first been coated with some other metal. As an example, articles composed of iron, tin, lead, and zinc cannot be silver- or gold-plated without first being copper-plated.

135. **Electrotyping.**—An electrotype of a column of standing type is made as follows: First, an impression in wax is made, then the surface of this impression is dusted over with powdered graphite to make the surface a conductor. This mold is then placed in a copper-plating bath, it forming the cathode, and receives a thin coating of metallic copper. When sufficient copper has been deposited, the mold is removed from the solution and the copper plate that was formed is separated from the mold and backed with type metal to a thickness of about ⅛ inch, and then mounted on a wooden block. It is necessary to back the copper plate with type metal because it is so thin that it would not stand the pressure to which it is subjected in the printing press.

136. **Polarity Indicator.**—The polarity of a direct-current circuit can be determined as follows: Immerse the ends of two wires that are connected to the line wires, whose polarity it is desired to determine, into a vessel of water, taking care that the two ends do not come into contact with each other. Since approximately twice as much hydrogen gas (by volume) is liberated at the negative electrode as oxygen gas at the positive electrode, the polarity of the circuit being tested is easily determined. A simple **polarity indicator** can be constructed as follows: Place in a small glass tube a solution of iodide of potassium, to which a little starch has been added. Two short pieces of wire should be sealed into the ends of the tube. When a current is passed through this solution iodine is liberated at the positive terminal and the solution is turned blue around this terminal.

137. **Prevention of Electrolytic Action.**—Electrolytic action is oftentimes the source of a great deal of trouble, especially in the deterioration of underground metals, such as gas, water, and sewer pipes, and the lead covering on telephone

and power cables. Electricity takes the path of least resistance in completing its circuit and, as a result, all conductors that are buried in the ground and not insulated from it, usually conduct some electricity, especially in localities where street car and power companies are operating with grounded circuits. There will be no decomposition of the pipe or lead sheath where the electricity flows onto them, but at the point where it leaves, an electrolytic action will take place which results in the metal of the pipe or cable sheath being carried away. This, of course, means that the pipe or cable sheath will be greatly damaged or completely destroyed if the action is allowed to continue. To prevent this action, one end of a conductor is electrically connected to the pipe or cable sheath at the points where the electricity tends to leave them and the other end of the conductor is buried, or grounded. The electrolytic action still continues but it takes place at the end of the conductor in the ground and the damage is not serious. In some cases the pipes are wrapped with an insulating tape or coated with an insulating compound, which tends to prevent the electricity passing on or off of them, thus reducing the electrolytic action. The connecting of a cable sheath or pipe to the ground is called **bonding**. Rail joints are bonded by connecting the ends of the rails electrically by means of a flexible copper conductor.

138. Weight Voltameter.—Since the weight of a metal deposited or the weight of water decomposed by a given quantity of electricity is known, the electrolytic cell may be used as a quantity measuring instrument. Thus, if two copper plates be immersed in a solution of copper sulphate and a quantity of electricity passed between them, there will be a change in weight of the two plates. This change in weight of the plates can be determined and from it the quantity of electricity that passed between them can be calculated. An instrument of this kind can be used in measuring the current in a circuit, if it remains constant in value for a certain time. Thus, if a unit quantity of electricity pass between the two plates in one second, there will be a current of one ampere in the circuit. If ten units of quantity of electricity pass between the plates in ten seconds, there will still be a current of one ampere, or if ten units of quantity pass in two seconds, there will be a current of five amperes. Hence, in order to measure a current that is constant in value, with the voltameter, it is only necessary to note the time taken to produce a certain deposit. The weight of the total deposit divided by the time gives the weight of the deposit per second and this value divided by the weight each coulomb will deposit gives the current in amperes, since the current is the number of coulombs per second. Call the total gain in weight in grams (W), the time in seconds taken to produce the gain in weight (t), and the deposit produced by one coulomb (K). Then

$$\text{Amperes} = \frac{\text{gain in weight in grams}}{\text{gain in grams per coulomb} \times \text{time in seconds}} \qquad (86)$$

or

$$I = \frac{W}{K \times t} \qquad (87)$$

Table No. VII gives the weight in grams that one coulomb or one ampere in one second will deposit (called the electro-chemical equivalent).

TABLE NO. VII

ELECTRO-CHEMICAL EQUIVALENTS IN GRAMS PER COULOMB

K for silver	.001118 gram
K for copper	.000329 gram
K for zinc	.000338 gram
K for lead	.001071 gram
K for nickel	.000304 gram

A commercial form of voltameter is shown in Fig. 95. The two outside plates form the anode and they are connected electrically. There will be a metallic deposit on both sides of the middle plate which form the cathode, due to the presence of the two outside plates.

Example.—The increase in weight of a platinum plate in a silver voltmeter was 4.0248 grams when the circuit in which the voltameter was connected was closed for 15 minutes. What current was there in the circuit?

Solution.—Substituting in equation (87) gives

$$I = \frac{4.0248}{.001118 \times 15 \times 60} = 4$$

Ans. 4 amperes.

139. Adaptability of Voltameters.—The voltameter is really a quantity-measuring instrument and it will only measure the current when the rate of flow of electricity is constant and, as a result, it is not suitable for ordinary work. Determinations

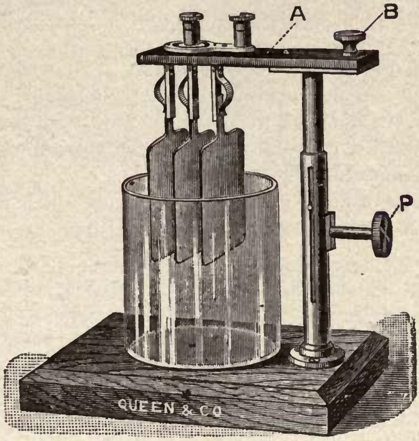


Fig. 95

of the value of a current made by this instrument are very accurate, when properly made, and they are used as primary standards in checking up the indications of other current-measuring instruments.

The voltameter is not suitable for pressure measurements, since its resistance is not constant and, as a result, the current through it would not always be proportional to the pressure impressed upon the circuit of which it is a part. Voltameters can not be used in the measurement of an alternating current, since there would be a reversal of chemical action each time there was a change in the direction of the current. If the same quantity passed through the voltameter in one direction as passed through it in the other, there would be no metallic deposit on either electrode.

Instruments Whose Operation Depends Upon Magnetic Effect of a Current

140. Magnetic Effect of a Current.—The magnetic effect of a current was discussed in detail in the chapter on "Electromagnetism" and it is only necessary to bear in mind the following facts:

(a) There is a magnetic field about a conductor in which there is a current.

(b) The direction of the magnetic field will depend upon the direction of the current in the conductor.

(c) The strength or intensity of this field will vary with the value of the current in the conductor and the distance from the conductor.

Instruments whose operation depends upon the magnetic effects of a current in a conductor may be classified as follows:

A. Those in which permanent magnets are used, they being acted upon by the magnetic field produced by the current. Either the magnet or the conductor carrying the current may form the moving part.

B. Those having soft iron parts which are moved due to the magnetic effect produced by the current in the conductor.

C. Those in which no iron is used, but having two coils, one of which is movable. This coil is moved due to a magnetic force that is exerted between them when there is a current in both coils.

CLASS "A"

141. Tangent Galvanometer or Ammeter.—If a magnetic needle be supported in the center of a coil of wire, as shown in Fig. 96, there will be a force tending to turn the needle from its position of rest in the earth's magnetic field when there is a current in the coil. This force will increase with an increase in current in the coil and, as a result, the needle will be deflected more and more as the current is increased until it occupies a position that is almost at right angles to its initial position. If a suitable scale be mounted, as shown in the figure, so that the ends of the needle, or a pointer that is fastened to the needle, will move over the scale, the deflection of the needle from the position of rest, due to a certain current, can be determined.

The force which tends to return the needle to its initial position is due to the magnetic field of the earth. In using the instrument, the coil carrying the current should be placed with its plane parallel to the plane of the needle and allowed to remain in this position while all the readings are being taken. Such an instrument is usually called a **tangent galvanometer,** or **ammeter,** because the value of the current through the coil is equal to some constant times the tangent of the angle through which the needle moves. The indications of an instrument of this kind are disturbed by the presence of magnetic fields other than that of the earth, or the current in the coil of the instrument itself, and as a result its operation is not very saisfactory except under ideal conditions.

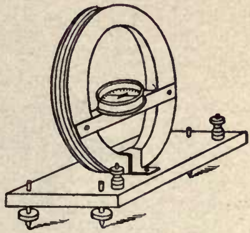


Fig. 96

142. D'Arsonval Instrument.—In the D'Arsonval type of instrument, the permanent magnet is the stationary portion and the conductor carrying the current forms the movable part of the instrument. The instrument is named after a French scientist, who first put it into a useful form. The conductor carrying the current to be measured is bent into the form of a coil and may be either suspended or supported in the magnetic field of the permanent magnet. In the most sensitive forms of the instrument the coil is usually suspended by a conducting thread, such as phosphor-bronze or plated quartz fiber. The electricity is conducted to and from the coil by means of this support and another electrical connection at the bottom of the coil—which may consist of a second fiber of the same material as the upper one—or it may be a very fine wire coiled into a spiral, or a wire may dip into a cup of mercury. A D'Arsonval galvanometer is shown in Fig. 97. The deflections of the coil are measured by means of a telescope and suitable scale, together with a small mirror mounted on the moving system of the instrument. The image of the scale in the mirror may be read by means of the telescope, and as the mirror turns, the part of the scale visible through the telescope changes.

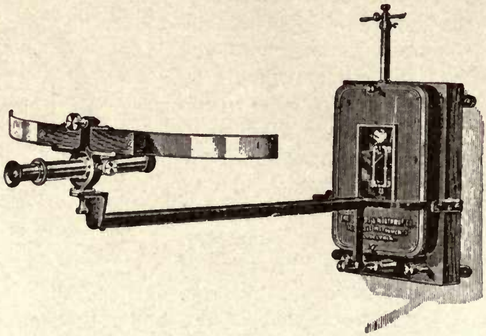


Fig. 97

An instrument of this kind can be constructed so that it is very sensitive and will respond to extremely small currents. It is not subject to outside disturbances to any great extent, such as stray magnetic fields, changes in the strength of the earth's magnetic field, etc. This instrument can be constructed and adjusted so that it may be used in measuring either current or pressure.

143. D'Arsonval Ammeters and Voltmeters.—The Weston ammeter and voltmeter are both good examples of D'Arsonval instruments. The moving coil in these instruments is mounted on pointed pivots that are extremely hard and rest in agate jewels, which results in a very small frictional resistance to the movement of the coil. A light pointer is attached to the coil and so arranged that it moves over a suitable scale properly graduated and lettered so that the indication of the instrument may be easily determined. A sectional view of the moving system of a Weston instrument is shown in Fig. 98, with a portion of the instrument cut away so as to show the construction. The permanent magnet is of the horseshoe type and has two pole pieces fastened to its ends by means of heavy screws. The inner surface of each of these pole pieces is cut so it forms an arc, the center of which is midway between the two inner surfaces of the magnet. A soft iron cylinder is mounted between the two pole pieces and serves to improve the magnetic circuit. This

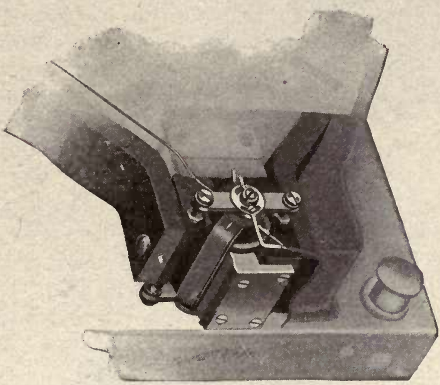


Fig. 98

cylinder is mounted on a piece of brass that is fastened to the two pole pieces, as shown in the figure, there being a small gap between the cylinder and the pole pieces. The coil is mounted so that it can turn about the cylinder. The force tending to return the coil to its zero position is supplied by two springs. These springs are so arranged that one winds up when the other unwinds, due to a movement of the coil. The electrical connection to the coil is made through these two springs.

Practically the same moving system is employed in the construction of ammeters and voltmeters. In the ammeter, a low resistance, capable of carrying the current the instrument is supposed to measure, is connected between the binding post on the instrument case; and the moving system is connected in parallel with this resistance. Binding posts are provided of ample size to carry the current. A Weston portable ammeter is shown in Fig. 99.

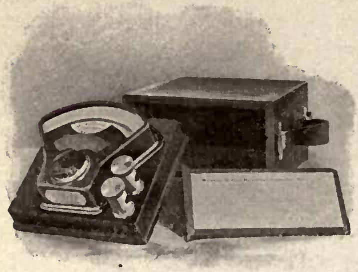


Fig. 99

In the voltmeter, a resistance coil is connected in series with the moving system between the terminals of the instrument. The value of the resistance to be placed in series with a moving system will depend upon the voltage a full scale reading of the instrument indicates. The range of any voltmeter may be increased by connecting additional resistances in series with it. Thus, if a resistance equal to that of the voltmeter itself be connected in series with the instrument, the voltmeter will indicate only half the pressure between the two points to which the terminals of the combination are connected. Resistances, called **multipliers,** can be obtained from companies manufacturing instruments to be used in increasing the range of a voltmeter.

Fig. 100

A contact key is usually mounted on each voltmeter case and so arranged that the circuit of the instrument may be opened or closed by manipulating the key. The instrument can be made so that a maximum scale deflection will correspond to one or more voltages. Thus an instrument may be constructed so that one connection will measure (0-3) volts and another will measure (0-150) volts. The resistance of these two circuits should be in the ratio of 3 to 150. A Weston portable voltmeter is shown in Fig. 100.

Instruments of the D'Arsonval type are suitable for general use because they are "dead-beat"; that is, the coil or moving system goes immediately to its proper position without swinging back and forth, as in many of the other types.

144. Adaptability of Instruments with Permanent Magnets.—Instruments whose operation depends upon a permanent magnet can be used only in direct-current measurements, because the direction of the deflections is dependent upon the direction of the current through them.

CLASS "B"

145. Plunger Type Ammeter or Voltmeter.—The construction of a plunger type ammeter or voltmeter is shown in Fig. 101. The coil (C) carries the current to be measured. There will be a magnetic force exerted on the rod of iron (R), when there is a current in the coil (C), which will tend

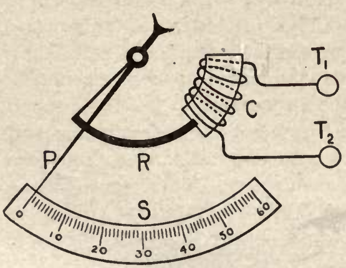


Fig. 101

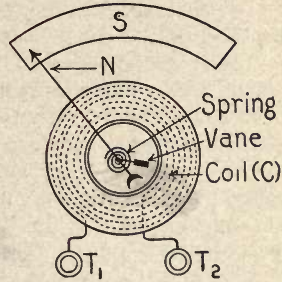


Fig. 102

to draw the rod into the coil, and thus cause the pointer (P) to move over the graduated scale (S). Gravity is the controlling force against which the magnetic force of the coil acts. The rod (R) and the coil (C) are both formed to the same curvature. The rod (R) is composed of very soft iron and it becomes a magnet due to the action of the current in the coil and, as a result, is drawn inside the coil. The distance the rod moves will depend upon the value of the controlling force and the ampere turns on the coil at any instant. In an ammeter, the coil (C) is wound with a few turns of large wire, while in a voltmeter it is wound with a large number of turns of small wire, the ampere-turns producing a given deflection in the two cases being the same.

146. Magnetic Vane Ammeter or Voltmeter.—Instruments of this type operate on the principle that a piece of soft iron placed in a magnetic field and free to move will always move into such a position that it will conduct the maximum number of lines of force, or it will tend to move into the strongest part of the field and parallel to the field. Fig. 102 shows a diagram of an instrument of this kind. The current to be measured is passed around the coil (C) producing a magnetic field through the center of the coil. A small piece of soft iron called the **vane** is mounted on a shaft that is supported in jewel bearings. This shaft is not in the exact center of the coil so that the distance the vane is from the inner edge of the coil will change as it moves about the shaft. The magnetic field inside the coil is strongest near the inner edge and, as a result, the vane will move so that the distance between it and the inner edge of the coil would be as small as possible, if it were not for a restoring force supplied by a coiled spring. The tendency of this vane to rotate increases with the current in the coil and, as a result, the pointer attached to the moving system moves over the scale with an increase in current.

In some types of instruments there is both a stationary and a movable vane. They both become magnetized to the same polarity and, as a result, repel each other. This force causes the moving system to be deflected. Ammeters and voltmeters operating on this principle differ only in the size of wire and the number of turns in the coil (C).

147. Thomson Inclined-Coil Instruments.—The construction of a Thomson instrument is shown in Fig. 103. The coil (C) carrying the current is mounted at an angle to the shaft (S) supporting the pointer (P). A strip or bundle of strips of iron (I) are mounted on the shaft (S) and held by a spring, when there is no current in the coil, so that its position is nearly parallel to the plane of the coil. When a current is passed through the coil, the iron tends to take up a position with its longest dimension parallel to the magnetic field, which results in the shaft being rotated and the pointer moved over the scale. The degree of this movement will depend upon the value of the current in the coil.

148. Adaptability of Instruments with Soft Iron Parts.—The instruments described in the previous three sections may be used in measuring either direct or alternating currents and pressures. Their indications, however, are not reliable when used in direct-current work because they are influenced by outside fields and masses of iron. There is also a lag of the magnetic condition of the piece of soft iron behind the magnetizing force, which results in their indications being lower than the true value as the current is increasing, and higher

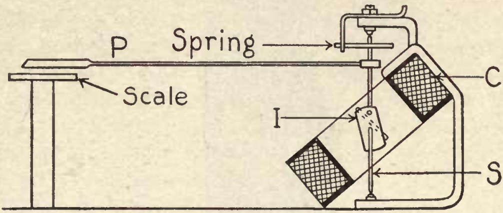


Fig. 103

as the current is decreasing. With alternating currents, these objections are not present and the operation of the instruments will be found to be quite satisfactory, provided the outside field does not change at the same frequency as the current to be measured.

CLASS "C"

149. Electrodynamometer.—The electrodynamometer is, perhaps, the best example of an instrument whose operation depends upon the magnetic force exerted between two coils, both of which have a current in them. The two coils are usually placed at right angles to each other, as shown in Fig. 104, one of them being fastened rigidly to the frame of the instrument, while the other is supported or suspended and its position controlled by a spring. When a current exists in both coils, the movable one tends to turn into such a position that its magnetic field is parallel to the magnetic field produced by the current in the stationary coil. This movable coil, however, is brought back to its zero position by turning the thumb screw, which is connected to the upper end of the spring, causing the spring to be twisted in the opposite direction to that in which the coil tends to move. The tortion in the spring exactly balances the tendency for the coil to turn when the thumb screw has been turned through the proper

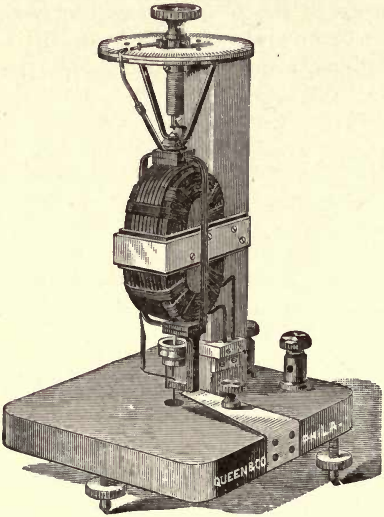


Fig. 104

angle. A pointer is fastened to this thumb screw and moves over a graduated scale. The effect produced by a given current through the two coils, which are connected in series, is then read as so many divisions on the scale.

When the instrument is used as an ammeter, the two coils consist of a few turns of large wire, depending, of course, on the current capacity of the instrument. Quite often the stationary coil is divided into two parts, only part of the turns being used in series with the movable coil for one connection, while all the turns may be used if desired. The current required to produce a full scale deflection when all the turns in the stationary coil are in use will be less than the current required when only a portion of the turns are used.

When the instrument is used as a voltmeter, the coils are composed of a large number of turns of small wire. Often an additional resistance is provided to be used in series with the instrument, which increases its range as a voltmeter.

150. Adaptability.—The indications of instruments of the electrodynamometer type are influenced by stray magnetic fields and, as a result, they are not altogether satisfactory for direct-current measurements. This error, however, can be reduced to practically zero, if the disturbing effect remains constant—which is not very often the case—by taking the average of two readings of the instrument with the current through it in opposite directions in the two cases. The above errors do not occur when instruments of the electrodynamometer type are used in alternating-current measurements—unless frequency of the distributing field is the same as the frequency of the current in the instrument—as the current is continuously reversing in direction.

Instruments Whose Operation Depends Upon Heating Effect of a Current

151. Heat Generated in a Conductor Carrying a Current.—When there is a current produced in a conductor, the energy expended in overcoming the conductor's resistance is manifested in the form of heat. Dr. Joule discovered that the heat developed in a conductor carrying a current was proportional to

(a) The resistance of the conductor.
(b) The square of the current in the conductor.
(c) The time the current exists in the conductor.

He also determined by experiment that 778 foot-pounds of work would raise the temperature of 1 pound of water 1° Fahrenheit. This quantity, 778 foot-pounds, is called the **mechanical equivalent of heat, or Joule's equivalent.** A pound of water can be heated electrically by immersing a conductor carrying a current in the water until its temperature is raised

1° Fahrenheit, or the same work will be done electrically as was previously done mechanically. Joule found by experiment that 1 ampere under a pressure of 1 volt in a circuit for 1 second, or 1 watt expended, would do the same work as 0.7373 foot-pound expended in 1 second, or

$$1 \text{ watt} = 0.7373 \text{ foot-pound per second} \qquad (88)$$

The **British thermal heat unit** (abbreviated b.t.u.) is defined as the amount of heat required to raise one pound of water 1° Fahrenheit at its maximum density (39.1° Fahrenheit). Since 778 foot-pounds of work is equivalent to 1 b.t.u. and 1 watt is equal to .7373 foot-pound per second, then 1 watt acting for 1 second will develop .000 947 7 b.t.u., or

$$\text{b.t.u.} = .000\,947\,7 \times (E \times I) \times t \qquad (89)$$

Substituting for (E) its value, (I × R), gives

$$\text{b.t.u.} = .000\,947\,7 \times I^2R \times t$$

Example.—What current must be passed through a resistance of 100 ohms immersed in 10 pounds of water in order that its temperature be raised 80° Fahrenheit in 5 minutes?

Note: (All losses due to radiation are to be neglected and all the energy is supposed to be converted into heat).

Solution.—There will be 80 b.t.u. required for each pound of water or a total of 80x10 = 800 b.t.u. Substituting in equation (89) gives

$$800 = .000\,947\,7 \times I^2 \times 100 \times (5 \times 60)$$

$$I^2 = \frac{800}{.000\,947\,7 \times 100 \times 300} = \frac{8}{.284\,31}$$

$$I^2 = 28.13$$

$$I = 5.3+$$

Ans. 5.3 + amperes.

152. Commercial Applications of the Heating Effect of a Current.—Numerous practical applications are made of the heating effect of a current in a conductor, such as electric irons, cooking stoves, heaters, lamps, electric welding, fuses, etc. Since the heat generated in any part of a circuit is proportional to the resistance of the part considered, it follows that it is always desirable to have all conductors used in transmitting electrical energy of as low resistance as possible in order that the loss in transmission be a minimum. On the other hand, when it is desired to generate heat, resistance is introduced and the value of the heat generated can be determined by the use of equation (89). If none of the heat generated in a circuit were carried away, the temperature of the conductor would continue to rise as long as there was a current in it. As a matter of fact, however, the temperature of a conductor will rise until the heat radiated is exactly equal to the heat generated in a given time. This rise in temperature may be excessive and for that reason the Fire Underwriters limit the value of the current a conductor should carry. Table G, in Chapter 20, gives the current-carrying capacity of different sized wires. These values may be exceeded without any injurious effect, but it is always essential to keep within the values allowed by the Underwriters as the likelihood of a fire due to an overheated or burnt-out circuit is less than it would be if the circuit were overloaded. The size of the conductor used in electrical heating utensils is just sufficient to carry the current without being injured.

In electric welding a large current is passed between the surfaces that it is desired to weld together and the heat generated is sufficient to raise the materials to a welding temperature. The heat generated in an incandescent lamp raises the temperature of the filament to such a value that it will emit light.

The electric fuse is a device whose function is to automatically open a circuit in which there is an excessive current. The fuse usually consists of a material that will melt at a much lower temperature than the material composing the remainder of the circuit. It is nothing more than a weak spot in the circuit which is capable of conducting the current the circuit is supposed to carry, but will melt when the current through it becomes excessive. The values of the current required to fuse different sizes of wires is given in Table H, in Chapter 20.

153. **Hot-Wire Instruments.**—The heat generated in a conductor due to a current in it will cause the conductor to expand. The amount of this expansion will depend upon the rise in temperature, which, in turn, depends upon the cur-

rent in the conductor. The principle on which hot-wire instruments operate is shown diagrammatically in Fig. 105. A wire (A B) of comparatively high resistance, low temperature coefficient, and non-oxidizable metal, has one end attached to the plate (C), then passed around a pulley (P) that is secured to a shaft (S), and its free end is brought back and mechanically, though not electrically, attached to the plate (C). The spring (F) keeps the wire under tension, it being attached to the plate (C), which is so guided that it can move in a direction at right angles to the shaft (S). An arm (G) is also attached to the shaft (S), it being counterweighted at the upper end and bifurcated at the lower end. A fine silk thread (T) has one end attached to one of the arms of (G), then passed around a small pulley (H), which is mounted on a shaft that carries a pointer (I), and finally has its other end attached to the second arm of (G). The material composing the arms of (G) is springy and serves to keep the silk fiber in tension. The current to be measured passes through the wire (A), entering and leaving through two twisted conductors, as shown in the figure. When a current is passed through (A) it is heated and expands, which results in the tension in (A) being less than that in (B)—they were originally the same—and equilibrium can be restored only by the pulley (P) rotating in a clockwise direction. This rotation of the pulley (P) causes the lower end of the arm (G) to move toward the left, and the silk thread that passes around the pulley (H) causes it to rotate in a clockwise direction and, as a result, the pointer (I) is deflected to the right, it being rigidly attached to the pulley (H). The operation of this instrument is quite satisfactory, as any change in the temperature of the room in which it is used does not affect the correctness of its indications, since both parts of the wire (A B) are affected to the same extent, which results in no movement of the pointer. In a great many instruments no adjustment or

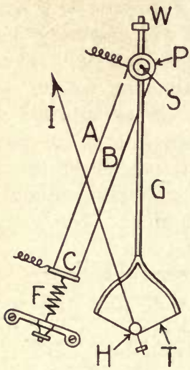


Fig. 105

compensation is provided for errors due to changes in room temperatures. In the case of ammeters, a low-resistance instrument is usually used in parallel with a suitable shunt, while in the case of voltmeters a high resistance instrument is employed.

154. **Adaptability of Hot-Wire Instruments.**—Hot-wire instruments may be used equally well in both alternating and direct-current measurements, the heating effect of the current being independent of its direction.

Instruments Whose Operation Depends Upon the Electrostatic Effect

155. **Condenser.**—Two conductors separated by an insulator, which is called the **dielectric**, constitute what is called a condenser. When the terminals of a condenser are connected to some source of electrical energy, such as a battery or a dynamo, there will be a certain quantity of electricity stored in the condenser. The value of the quantity

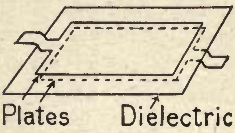


Fig. 106

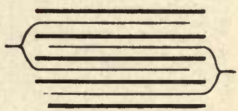


Fig. 107

stored will depend upon the capacity of the condenser and the electrical pressure to which its terminals are subjected. A condenser is said to have a capacity equal to unity, or 1 **farad,** when a unit of quantity, 1 coulomb, will produce a difference in pressure between its terminals of 1 volt. A simple form of condenser is shown in Fig. 106, which consists of two metallic plates separated by a sheet of paraffine paper. The capacity of such a condenser will depend upon the area of the plates used in the construction, the number of plates, the distance between the plates, or the thickness of the dielectric, and the kind of material composing the dielectric. The value of an insulating material as a dielectric is called its **specific inductive capacity.** The inductive capacity of different materials varies considerably, but it is less through air than it is through any solids or liquids. As a result, a condenser that has air for a dielectric will have less capacity than one that has a solid or liquid dielectric, the dimensions of the condensers being the same. The specific inductive capacity of a material is measured in terms of air as a standard, and it is the ratio of the capacities of two condensers, one of which has the material, whose dielectric constant is to be determined, as a dielectric, and the other has air as a dielectric. The dimensions of the two condensers must be the same. Table No. VIII gives the value of the specific inductive capacity of some of the materials that are commonly used in the construction of condensers.

TABLE NO. VIII

SPECIFIC INDUCTIVE CAPACITIES

Material	Specific Inductive Capacity	Material	Specific Inductive Capacity
Air	1.00	Porcelain	4.38
Alcohol (Amyl)	15.50	Resin	2.52
Glass (Plate)	3.00 to 7.00	Rubber	2.30
Gutta-percha	2.50	Shellac	3.35
Mica	6.70	Sulphur	2.50 to 3.80
Paraffine	1.90 to 2.40	Turpentine	2.20
Petroleum	2.10	Vaseline	2.17

Condensers used in practice usually consist of more than two plates, as shown in Fig. 106. An arrangement similar to that shown in Fig. 107 is usually used where alternate plates are connected together and form one terminal, while the remaining plates are connected together and form the other terminal. The capacity in farads of such a combination of plates as that shown in Fig. 107 can be calculated by the use of the equation

$$C = \frac{K (n - 1) a}{4.452 \times 10^{12} \times d} \qquad (90)$$

where (n) represents the total number of plates used in the construction of the condenser, (K) represents the constant of the dielectric, (a) represents the area of each plate in square inches, and (d) is the distance between the plates in inches.

Example.—Determine the capacity of a condenser of 100 sheets of tinfoil 10 × 10 inches, that are separated by plate glass whose dielectric constant is 5. and 0.1 of an inch in thickness.

Solution.—Substituting the values of the above quantities in equation (90) gives

$$C \text{ (in farads)} = \frac{5 \times (100-1) \times 10 \times 10}{4.452 \times 10^{12} \times 0.1} = .000\,000\,111\,2$$

Ans. .000 000 111 2 farads.

The farad is a unit of capacity entirely too large for practical use so a smaller unit, or the **microfarad**, is used. The microfarad is equal to one-millionth of a farad.

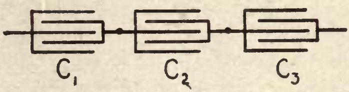


Fig. 108

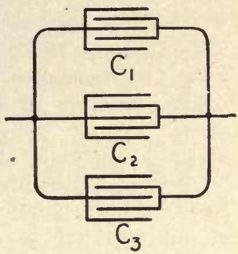


Fig. 109

156. Connection of Condensers in Series and Parallel.—Condensers may be connected in series or in parallel, or in any combination of series and parallel, just as resistances. The capacity of a combination of condensers may be calculated by the use of one of the following equations. When a number of condensers are connected in series, as shown in Fig. 108, the total capacity (C) of the combination will be given by the equation

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \text{etc.} \qquad (91)$$

This results in the combined capacity of several condensers in series being less than the capacity of any one of them.

If there are only two connected in series, the combined capacity will be equal to

$$C = \frac{C_1 C_2}{C_1 + C_2} \qquad (92)$$

It is seen that the above equation is similar to the one used in calculating the combined resistance of a number of resistances in parallel.

When a number of condensers are connected in parallel, as shown in Fig. 109, the total capacity (C) of the combination will be equal to

$$C = C_1 + C_2 + C_3 + \text{etc.} \qquad (93)$$

The combined capacity of several condensers in parallel will be greater than the capacity of any single condenser. This equation is similar to the one used in calculating the combined resistance of several resistances in series.

157. Relation of Impressed Voltage, Quantity, and Condenser Capacity.—If a condenser is said to have unit capacity when 1 coulomb of electricity will produce a difference in electrical pressure between its terminals of 1 volt, then 1-volt pressure applied at the terminals will produce a charge of unit quantity, 1 coulomb, if the capacity is 1 farad. If 1-volt pressure produces a charge of 2 coulombs, the capacity is 2 farads; or if 1-volt pressure produces a charge of one-half coulomb, the capacity is one-half farad. If the capacity of a condenser is constant, the quantity of charge is directly proportional to the impressed voltage; or if the impressed voltage is constant, the quantity of charge is directly proportional to the capacity. These two statements may be combined in an equation which states that the quantity varies directly as the capacity and the impressed voltage, or

$$Q = C\,E \qquad (94)$$

The above equation gives the value of the quantity in coulombs stored in a condenser whose capacity is (C) farads, when it is subjected to a pressure of (E) volts. Since the microfarad is the more common unit of capacity, it being equal to the one-millionth part of a farad, the above equation may be rewritten with the value of (C) in microfarads, which gives

$$Q = \frac{C_{m.f.}}{10^6} E \qquad (95)$$

It is often desirable to measure the quantity in a unit smaller than the coulomb, in which case the **microcoulomb** is used, it being the one-millionth part of a coulomb.

PROBLEMS OF CONDENSERS

(1) Calculate the capacity of a telephone condenser composed of 1001 sheets of tinfoil 3 × 6 inches, separated by paraffine paper .007 of an inch thick, and having a dielectric constant of 2.

Ans. 1.15 + microfarads.

(2) Two condensers of 4 and 6 microfarads, respectively, are connected in series. Calculate their combined capacity.

Ans. 2.4 microfarads.

(3) What quantity of electricity will be stored in the two condensers in problem 2 when they are connected in series and there is an electrical pressure of 100 volts applied to the terminals?

Ans. .000 24 coulomb, or 240 microcoulombs.

(4) Two condensers of 4 and 6 microfarads, respectively, are connected in parallel. Calculate their combined capacity.

Ans. 10 microfarads.

(5) What quantity in microcoulombs will be stored in each condenser when there is a pressure of 100 volts applied to the terminals of the combination in problem 4?

Ans. 400 microcoulombs in 4 m.f. condenser; 600 microcoulombs in 6 m.f. condenser.

(6) What pressure is required to charge a 2-microfarad condenser with a charge of .0002 coulomb?

Ans. 100 volts.

(7) What is the capacity of a condenser when 100 volts will give it a charge of .000 15 coulomb?

Ans. 1.5 microfarads.

158. Electrostatic Voltmeter.—The electrostatic voltmeter is really nothing more than a condenser constructed so that one plate may move with respect to the other. When a condenser is charged, there is a force tending to draw the plates together, due to the charges of opposite kind on the two sets of plates, and it is this force that produces the deflection in the case of an electrostatic voltmeter. In some instruments only two plates are used, while in others a number of plates are used to form each terminal, the construction being such that the movable plates move between the stationary plates.

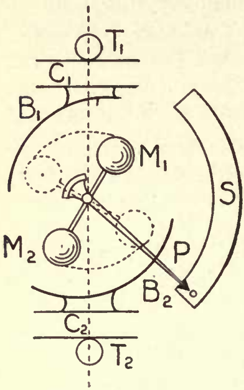


Fig. 110

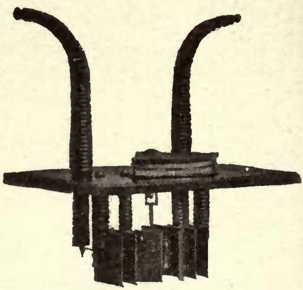


Fig. 111

An electrostatic voltmeter suitable for measuring extremely high voltages is shown diagrammatically in Fig. 110. The principal parts are the moving elements (M_1) and (M_2), the curved plates (B_1) and (B_2), the condensers (C_1) and (C_2), scale (S), pointer (P), and terminals (T_1) and (T_2). The plate (B_1) is connected to the inner plate of (C_1) and (B_2) to the inner plate of (C_2). The plates (B_1) and (B_2) are so arranged with respect to (M_1) and (M_2), which are electrically connected, that an angular deflection of the pointer over the scale in the positive direction (above zero) shortens the gap between the moving elements and the fixed plates. The charges on the plates (B_1) and (B_2) are of opposite sign and they induce opposite charges on (M_1) and

(M_2), which results in a force that tends to cause the moving system to turn about its own axis, or into such a position that (M_1) and (M_2) are nearer (B_1) and (B_2). The movement, however, is restrained by means of a spiral spring and the deflection is indicated by the pointer (P) on the scale (S). The form of the plates (B_1) and (B_2) is such that the deflection increases almost directly as the impressed voltage. The condensers (C_1) and (C_2) are so constructed that either or both of them may be short-circuited, which results in the pressure required to produce a full scale deflection being less than when they are in circuit, thus giving a wide range to the instrument. The moving system is immersed in a tank of oil, which affords a good insulation and buoys up the moving system, practically removing all the weight from the bearings. Instruments of this type are constructed to measure voltages up to 200 000 volts. An interior view of the various parts is shown in Fig. 111. There are many other forms of electrostatic voltmeters on the market, but their operation is based on the same fundamental principle as the one just described.

159. Adaptability of Electrostatic Instruments.—Electrostatic instruments may be used in measuring either direct or alternating pressures. Their operation is more satisfactory, however, on an alternating-current circuit, because a.c. pressures are, as a rule, larger in value than d.c. pressures. Their operation is not at all satisfactory when the pressure to be measured is below 50 volts, and for this reason they cannot be used in combination with a shunt in the measurement of currents, as the resistance of the shunt would have to be large in order that there be the proper difference in pressure between its terminals to operate the meter. A high-resistance shunt of this kind in any circuit would mean a large loss in comparison to that which would occur if a low-resistance shunt could be used.

Measurement of Electric Power and Construction of Wattmeters

160. Measurement of Power.—The power that is used in any part of a direct-current circuit may be determined by measuring the current with an ammeter, and the difference in pressure, by means of a voltmeter, between the terminals of the portion of the circuit in which it is desired to ascertain the power. The power can then be calculated by multiplying the ammeter reading, in amperes, by the voltmeter reading, in volts, or

$$W = I E \qquad (96)$$

Thus the power taken by the ten incandescent lamps shown in Fig. 112 can be determined by connecting the ammeter (A) and the voltmeter (V), as shown in the figure, and noting their indication when the lamps are turned on. (All of the lamps are not shown). The product of these instrument readings, in volts and amperes, will give the power in watts.

When the connections are made, as shown in Fig. 112, the

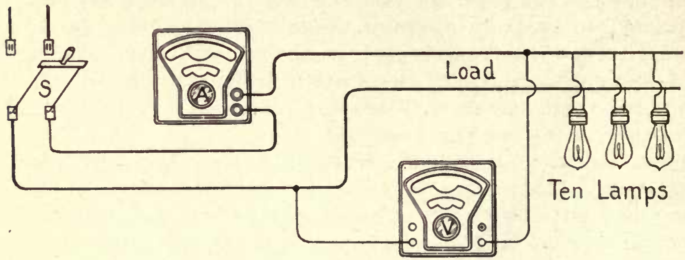


Fig. 112

ammeter indicates the current through the lamps and voltmeter combined. This results in a small error in the calculation of the power taken by the lamps, provided the current through the voltmeter is small in comparison to the current through the lamps. For very accurate measurements, the current through the voltmeter should always be subtracted from the total current indicated by the ammeter. If the voltmeter be connected across the line before the ammeter—that is, the ammeter would be between the voltmeter connection and the lamps—the indication of the voltmeter would not be the true value of the pressure between the terminals of the lamps, as there would be a certain drop in pressure across the ammeter. The drop across the ammeter should be subtracted from the voltmeter indication in order to obtain the true pressure across the lamps. With a low-resistance ammeter, this drop is very small and may be neglected except when very accurate results are desired.

161. **Principle of the Wattmeter.**—Wattmeters are so constructed that their indication is proportional to the product of a current and an electrical pressure; hence, they indicate the power direct. Instruments of this kind are called **wattmeters,** because they measure watts.

The principle of the wattmeter can be illustrated by reference to Fig. 113, which shows an electrodynamometer with one coil connected in series with the line and the other coil connected across the line. The coil connected in series with the line is wound as though it were to be used as an ammeter, and consists of a few turns of large wire, while the coil connected across the line is wound as though it were to be used as a voltmeter and consists of many turns of fine wire. These two coils will be called the **pressure** coil and the **series coil,** respectively.

The actual operation of such a meter can best be explained by taking a practical example similar to that shown in Fig. 113. The current through the lamps passes through the current coil of the meter and produces a certain magnetic effect, which changes in value as the current changes in value. There will also be a magnetic effect produced by the current that exists in the pressure coil. The current in the pressure coil, or circuit, will vary with the difference in pressure between the terminals of the circuit, since the resistance of the circuit remains constant and, as a result, the magnetic field about the pressure coil will vary with the voltage of the line. The deflection of the moving coil of the electrodynamometer is proportional to the product of the magnetic effects of the two coils, and since the magnetic effects of the two coils are proportional to the current and the voltage, respectively, the indication of the instrument must be proportional to the product of (E) and (I), or it indicates watts.

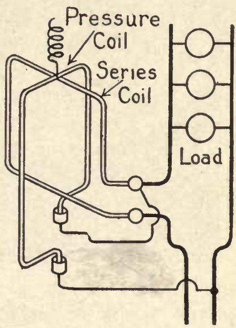


Fig. 113

When an instrument of this kind is connected in a circuit in which a fluctuating current, due to a varying load, exists, the pressure between lines remaining constant, the indications will vary directly with the load current. The magnetic effect due to the current in the pressure circuit remains constant, since the voltage or pressure impressed upon this circuit remains constant. When the load current remains constant and the voltage varies, the magnetic effect of the current in the series coil remains constant and the magnetic field about the pressure coil changes and the deflection varies with the voltage.

162. Whitney Wattmeter.—The principle of this wattmeter is the same as that of the dynamometer wattmeter just described, except that the construction is modified to make the instrument portable and more suitable for commercial work. In this wattmeter the heavy current winding is composed of two coils, which are supported in suitable frames and enclose a coil composed of fine wire. This coil is mounted on a shaft with pointed ends resting in jeweled bearings. Two volute springs serve to hold the coil in its zero position and balance the turning effort of the coil when there is a current in it. These two springs also serve to conduct the electricity into and from the movable coil, instead of the mercury cups, as in the previous case. A balance is obtained by turning the torsion head until the needle that is attached to the movable coil is indicating no deflection, the reading of the pointer attached to the torsion head is then noted and represents the indication of the instrument. The scale of the instrument may be divided into degrees, and the deflection read on this scale must be multiplied by some constant to obtain the power indicated by the instrument, or the scale may be so drawn that the power

Fig. 114

in watts can be read directly from it. The general appearance of the instrument is shown in Fig. 114.

163. Weston Wattmeter.—The principle of this instrument is practically the same as the one described in the previous section. No torsion head, however, is used and the pressure coil, instead of being maintained at practically the same position for all indications of the instrument, rotates about its axis through an angle of approximately eighty degrees. Two volute springs serve to conduct the electricity into and from the movable coil. They also offer the opposing force to that produced by the magnetic effect of the currents in the two coils. This form of instrument has an advantage over the other forms described in that no manipulation is necessary and the needle points at once to the scale mark showing the watts. A Weston instrument is shown in perspective in Fig. 115 and diagrammatically in Fig. 116. In Fig. 116 (C_1) and (C_2) represent the two current coils, which are connected in series between the two posts numbered (1) and (2). The pressure connections can be made to (3) and (5), or (3) and (6). The resistance between (3) and (6) is usually just half the value of the resistance between (3) and (5).

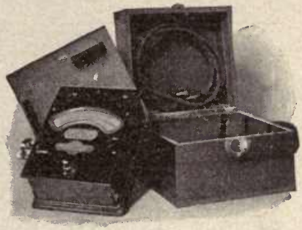


Fig. 115

164. Compensated Wattmeter.—The power indicated by a wattmeter will be in error just the same as the value of the power determined by the voltmeter and ammeter readings is in error, due to the current taken by the voltmeter, or the drop across the ammeter, unless some means be provided that will counteract or compensate for this error. This compensation is provided in the Weston wattmeter in the following way: The pressure circuit is always to be connected across the line after the current coil, which results in the current coil carrying the current that passes through the pressure circuit. This current in itself would produce a deflection, even though there be no load on the circuit, and, as a result, the meter would always indicate a higher value of power than that actually taken by the load. If, however, the pressure circuit be wound around the series coil the same number of times there are turns in the series coil, and this winding be so connected that the magnetic effect of the current in it is opposite to that of the current in the series coil, the magnetic field produced by the pressure current passing through the series coil will be completely annulled and there will be no deflection of the moving system until there is a load current through the series coil. The turns of wire that are wound around the series coil are called **compensating turns** and they are shown in Fig. 116. When a separate source of current and potential is used in calibrating wattmeters, there should be no compensating turns in the circuit, and terminal (4) should be used instead of terminal (3). The resistance of the pressure circuit should be the same in both cases, and a small coil (R), whose resistance is equal to that of the compensating turns, is connected in the pressure circuit instead of the compensating turns.

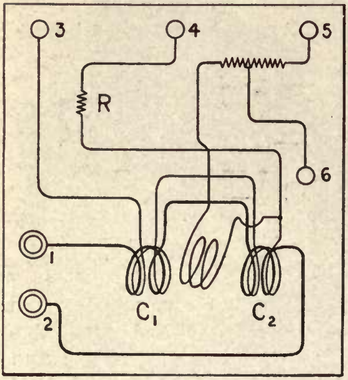


Fig. 116

165. Adaptability of Wattmeters.—All wattmeters that have been described will operate on either direct- or alternating-current circuits. Their indications on direct-current circuits will, however, be influenced by stray magnetic fields, and, in the majority of cases, a reversal of current through the coils, although the current remains constant in value, will result in a different indication. When the instruments are used in an alternating-current circuit, these errors are very much reduced—provided the disturbing field is not alternating—since the current passes through the circuit in one direction for the same time it passes in the opposite direction.

166. Watt-Hour Meters.—The Weston wattmeter, described in section (163), is called an indicating wattmeter, since it gives the instantaneous value of the watts expended in a circuit, just as a voltmeter and ammeter indicate the fluctuation in voltage and current. The watt-hour consumption in any circuit could be determined by means of such a meter by multiplying the average indication of the meter for a

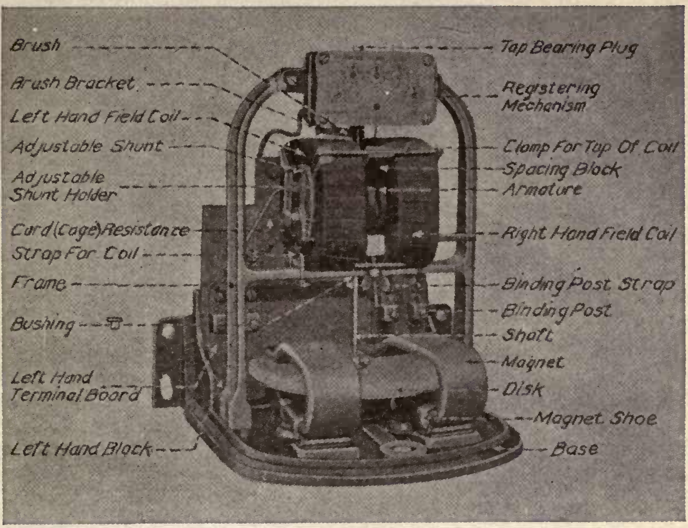


Fig. 117

given time by the time expressed in hours. An integrating wattmeter automatically multiplies the average of the instantaneous readings by the time. The Thomson integrating wattmeter, shown in Fig. 117, is similar to the dynamometer wattmeter, but the movable coil rotates. It is really a small electric motor without any iron in its working parts. The revolving part, or armature, is the pressure coil and the field in which this coil rotates is produced by the load current in stationary coils mounted outside of the armature. The force tending to produce rotation is proportional to the product of the two magnetizing effects and this is proportional to the watts in the circuit, just as in the case of the electrodynamometer. The magnetizing effect of the current in the armature is made continuous by winding the armature with a number of coils, which are symmetrically placed on the armature frame and connected to the external circuit through a small commutator and two brushes. The current through the armature coils is reversed at such a time that the turning effort is always in the same direction.

The speed of the armature is made proportional to the driving force by mounting, on the same shaft that carries the armature, a copper disk which is arranged to revolve between permanent magnets and constitutes a small generator. The torque required to drive this disk is directly proportional to the speed, and hence, if the torque produced by the action of the two magnetizing effects be doubled, the speed of the meter will be doubled. The speed of the meter at any instant is proportional to the product of (E) and (I), or the power. The average speed for a unit of time, say one hour, would be proportional to the average power times the time it acts (average E $\times$ I $\times$ time in hours), which gives the value of the energy in watt-hours.

An indicating device is usually attached to the meter, the pointers of which are driven by a worm that is rigidly fastened to the shaft upon which the armature is mounted. The relation between the movement of the pointers on the dials is usually such that the dial readings give the energy direct in watt-hours, or kilowatt-hours. In some cases, however, the dial readings must be multiplied by a constant in order to obtain the true watt-hour or kilowatt-hour consumption.

A diagram of the connections of a Thomson watt-hour meter is shown in Fig. 118. The coils (C_1) and (C_2) represent the series coils connected in series with the line and carrying the load current. The pressure circuit, which is connected across the line, consists of the resistance coil (S) and the winding on the armature (A). The coil (S) serves a double purpose: it prevents an excessive current passing through the pressure circuit and it creates a magnetic field which is just sufficient to produce the required turning effort to overcome the static friction of the meter. If this magnetic field were not produced by the coil (S) or a similar coil, the armature of the meter would not start to rotate with a small load current in the coils (C_1) and (C_2), and its indications, as a result, would always be lower than the true value of the energy. The magnetic field produced by the coil (S) is in the same direction as that produced by the current in the coils (C_1) and (C_2). The effect of this field on the armature can be varied by changing the position of the coil (S) with respect to the armature. With this adjustment, the friction of the meter may be properly compensated for and it will start to rotate with an extremely small current in the series coils. Meters of this kind are called **integrating wattmeters,** since their dials indicate the average of the product of the instantaneous power times the time that power acts; or their indication is proportional to the energy. The watt-hour meter just described will operate in an alternating-current circuit, but not very satisfactorily on account of the inductance of the windings.

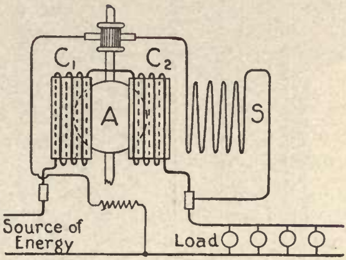


Fig. 118

167. Coulomb, or Ampere-Hour Meters.—There are several recording meters on the market whose indications are proportional to the average current through them times the time the current exists in the circuit, and entirely independent of the voltage producing the current. Such instruments are often called **coulomb, or ampere-hour meters.** Meters of this kind can be used in measuring energy, when properly calibrated, provided the pressure producing the current remains constant. The voltage of a line, as a rule, is not always the same, but will fluctuate quite a number of volts and, as a result, a coulomb meter will not indicate the true energy.

The old **Edison chemical meter** was nothing more than a coulomb, or ampere-hour meter. It consisted of two zinc plates immersed in a solution of zinc sulphate. The quantity of electricity that had passed through the meter was determined by weighing the plates and, from their change in weight, the quantity was calculated by means of the electrochemical equivalent. Fluctuations in line voltage produced no effect upon the indications of the meter directly; voltage changes, however, produce a change in the value of the current and this changed the meter's indication. The customer's bill was calculated on the assumption that the voltage remained constant.

168. Maximum Demand Meters.—In order to charge the purchaser of electrical energy a fair amount for the energy consumed in a given time, it is often desirable to know the maximum amount called for during any time, in order that he may be properly taxed or that part of the supply equipment that must be held in reserve for him so that he may take that maximum demand at any time. An instrument used in measuring the value of this maximum demand is called a **maximum demand,** or **demand,** meter.

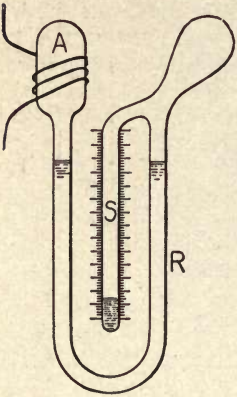


Fig. 119

The Wright demand meter is shown in Fig. 119. It consists of a U-shaped tube with enlarged ends and a side tube (S) opening out of one of them. A few turns of wire are wound around the enlarged end of the tube (A), that has not the side outlet, so that the heat generated in the wire due to the passage of a current through it will warm the air in the chamber. The U-shaped tube is filled with liquid to about the height shown in the figure. The expansion of the air in the chamber (A), due to the heat, forces the surface of the liquid in the left-hand leg of the tube downward and the surface of the liquid in the right-hand one upward. If the current strength is sufficiently high to cause the liquid in the right-hand tube to rise to the point where the outlet tube is connected, the liquid will overflow into the tube (S). The greater the current in the winding about (A), the greater the overflow from the tube (R) into (S), and a scale properly graduated placed alongside the tube (S) will show the maximum amperage that has passed through the winding about (A). The indication of the instrument is rather slow; that is, it takes some time for the liquid in (R) to rise to the point where it will overflow into (S), even though the proper current is passing through the winding about (A). This prevents the customer being penalized due to a momentary short-circuit on his line or the large current taken for a short time in starting motors. The meter is reset, usually when the consumer's integrating meter is read, by simply inverting the tube and draining all of the liquid out of the tube (S) back into the U-shaped tube. Changes in the temperature of the atmosphere do not interfere to any great extent with the correct registration of the meter, and it will work equally well in either a direct- or an alternating-current circuit. The whole instrument is placed in a case that can be locked or sealed, as shown in Fig. 120, so that it cannot be reset by a party not authorized to do so.

Fig. 120

CALIBRATION OF INSTRUMENTS

169. Calibration of Voltmeters by Means of a Standard Instrument.—The accuracy of a voltmeter's indications may be determined by connecting it in parallel with another voltmeter whose calibration is known (called a standard), and comparing their indications for various impressed voltages. The connections of the instruments are shown in Fig. 121, where (S) represents the standard instrument, (X) the instrument to be calibrated, and (R) a suitable rheostat for varying the pressure over the voltmeter terminals.

170. Calibration of Voltmeters by Means of a Potentiometer.—The potentiator is a special arrangement for measuring an electrical pressure by comparison. It is shown diagrammatically in Fig. 122. The pressure to be measured is connected between the terminals (A—) and (A+). There is a variable known resistance connected between these two points. Across a portion of this resistance, such as that between the points (1) and (2), there is connected a shunt circuit which consists of a sensitive galvanometer (G), a standard cell (SC), a contact key (K), and a high resistance (H) that may be easily cut in or out of the circuit.

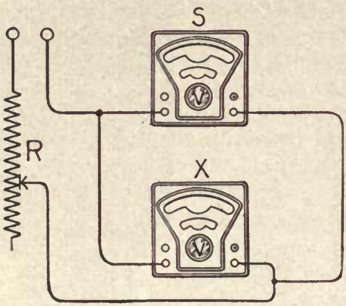


Fig. 121

The operation of the potentiometer is as follows: First, assume it is desired to know the value of some pressure that is connected to the points (A—) and (A+). The resistance (R) between the points (1) and (2) should be adjusted to 1000 (this need not always be 1000) times the voltage of the standard cell, which is 1.434 for a Clark cell at 15° Centrigrade, and 1.018 30 for a Weston normal cell. Assuming a Weston cell is used, then the value of the resistance in (R) will be 1018.30 ohms. Now, there will be a difference in pressure between the points (1) and (2), due to the current in the resistance (R) produced by the pressure impressed upon the terminals (A—) and (A+). The current through the resistance (R) is in such a direction that the point (1) is at a higher potential than the point (2). This difference in pressure between the points (1) and (2) would tend to produce a current in the shunt circuit when the key (K) was closed. The standard cell, however, is connected in the circuit in such a way that its electromotive force tends to counteract the difference in pressure between the points (1) and (2) and there will be no current in the shunt circuit when the drop in potential over (R) is exactly equal to the e.m.f. of

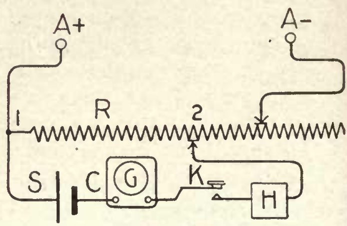


Fig. 122

the standard cell. The drop over the resistance (R) can be varied by changing the value of the total resistance between (A—) and (A+). There will be no deflection of the galvanometer when a balance is obtained. The high resistance (H) should be cut out of circuit for a final adjustment. The purpose of this resistance is to protect the standard cell from supplying too large a current while adjusting the drop over (R), which is likely to change the value of its e.m.f. and perhaps ruin the cell. When this balance is secured, there will be 1.018 30 volts drop in pressure over 1018.30 ohms in the main part of the circuit, or 1 volt over every 1000 ohms. The total difference in pressure between (A—) and (A+) will then be equal to the resistance between (A—) and (A+) divided by 1000.

Ordinary resistance boxes may be used for the resistances shown in the scheme, but commercial forms of the potentiometer are constructed with all the keys, resistances, etc., contained in a single case.

171. Calibration of Ammeters by Means of a Standard Instrument.—An ammeter may be calibrated by connecting it in series with a standard instrument and comparing their indications for different values of current. The scheme of connections is shown in Fig. 123, in which (S) represents the standard instrument, (X) the instrument to be calibrated, (B) a storage battery or some source of electrical energy, and (R) a rheostat suitable for changing the value of the current in the circuit by a change in its resistance.

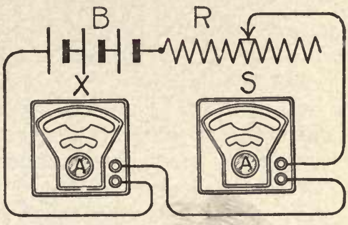


Fig. 123

A standard resistance may be connected in series with an ammeter and the current in the circuit determined by dividing the drop over the resistance—which may be determined by means of a voltmeter or a potentiometer—by the resistance of the standard resistance.

172. Calibration of a Wattmeter by Means of a Voltmeter and an Ammeter.—The connections for calibrating a wattmeter or a watt-hour meter by means of a voltmeter and an ammeter are shown in Fig. 124. The current in the series coil of the wattmeter exceeds that in the ammeter by an amount equal to the current in the voltmeter. The true power, then, should be calculated by adding to the ammeter reading (I_a) the voltmeter current (I_v) and multiplying the sum by the voltmeter reading (E), or

$$W = (I_a + I_v) E \qquad (97)$$

The per cent error introduced by not taking the voltmeter

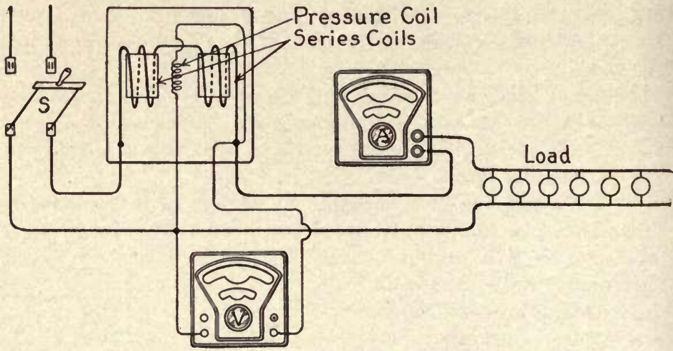


Fig. 124

current into account is very small, except in the calibration of low reading wattmeters.

When a separate source of current and pressure are used, the current taken by the voltmeter produces no error and the true power is given by the equation

$$W = E \times I \qquad (98)$$

The indication of the dial on a watt-hour meter can be checked by maintaining the e.m.f. and current constant for a given time and noting the difference in the dial readings before and after the test. The energy indicated on the dial should equal the product of (E), (I), and (t), or

$$\text{k.w. hours} = E \times I \times t \qquad (99)$$

The time (t) in the above equation should be in hours. The dial indication can be accurately determined from the number of revolutions of the armature, if the number of revolutions of the armature per unit indication on the dial is known. This relation is called the **gear ratio,** and once determined it can be used in succeeding tests.

173. Calibration of Wattmeters by Means of Standard Wattmeter.—Two wattmeters are shown connected in the same circuit in Fig. 125. The instrument (S) is a standard,

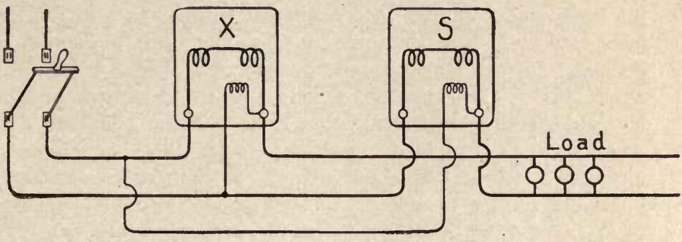


Fig. 125

or one whose calibration is known, while (X) is an instrument to be calibrated. If the series coils of the two instruments have the same resistance, the pressure impressed upon the pressure circuits of the two meters is the same, when the connections are made, as shown in the figure. The same load current exists in the series coils of both instruments and the indication of (X) can, therefore, be determined in terms of the indication of (S).

CHAPTER IX

THE DIRECT-CURRENT GENERATOR

174. The Dynamo.—The dynamo is a machine for converting mechanical energy into electrical energy, or electrical energy into mechanical energy by means of **electromagnetic induction,** the principles of which were discovered by Faraday about 1831. The dynamo, when used to transform mechanical energy into electrical energy, is called a **generator,** and when used to transform electrical energy into mechanical, it is called a **motor.** The generator does not create electricity, but simply imparts energy to it, just as energy is imparted to the electricity as it passes through the primary cell. The e.m.f. which is generated in the dynamo produces a current in a closed circuit connected to the machine and this current will pass from a higher to a lower potential in the external circuit and from a lower to a higher potential in the internal circuit of the machine itself. This corresponds to the flow of water through a pipe connected to a pump. In the external circuit, the water flows from a higher to a lower pressure, while the action of the pump causes it to flow from a lower to a higher pressure through the pump itself.

The dynamo consists fundamentally of two parts—a **magnetic field,** which may be produced by permanent magnets or electromagnets, and an **armature,** which consists of a coil or number of coils usually wound or mounted on an iron core and so arranged that they may be revolved or moved in the magnetic field of the machine. The movement of the coils in the magnetic field results in the conductor forming the coils cutting the magnetic lines of the field and an e.m.f. is induced in the winding.

175. Kinds of Generators.—Generators may be grouped into two main classes, depending upon the nature of their output, viz., direct-current and alternating-current.

The current in a circuit connected to a **direct-current generator** is in the same direction all the time, while in the case of the **alternating-current generator** it is continuously reversing in direction. This chapter will deal with the direct-current machine, the discussion of the alternator being deferred to a later chapter.

The mechanical construction of dynamos permits their being divided into three classes, the fundamental electrical principle being the same in each case.

(a) **Revolving armature** and stationary field magnet.

(b) **Revolving field** and stationary armature.

(c) **Armature and field winding both stationary,** but constructed so that an iron core may be revolved near them.

The external circuit is connected to the armature winding in the first class by means of collector rings, see section (177), or by means of a commutator, see section (178), while the connection to the field winding is permanent since it is stationary. In the second class the armature is permanently connected to the external circuit, and the connection is made to the field winding by means of slip rings. There are no moving conductors in the third class, but the magnetic flux through the armature winding that is produced by the current in the field winding is caused to change in value by changing the position of a part of the magnetic circuit. This part of the magnetic circuit is called the **inductor** and it is arranged so that it may be rotated near the armature and field windings.

Direct-current generators may also be divided according to their output, viz.,

(a) **Constant-Current Generators.**

(b) **Constant-Potential Generators.**

The output of the constant-current generator is at a constant current and variable pressure, while the output of the constant-potential generator is at a constant potential and variable current.

176. Simple Dynamo.—If a single loop of wire, such as (ABCD), Fig. 126, be revolved about an axis, such as (EF), in the magnetic field of a permanent magnet, or an electromagnet, as shown in the figure, there will be an electromotive force induced in the two sides of the loop (AB) and (CD). This induced electromotive force will produce a current in the loop if the conductor forming the loop be closed. The direction of the induced e.m.f. in the two sides of the loop may be determined by a simple application of Fleming's dynamo rule, as given in section (118). The motion of one side of the loop, such as (AB), with respect to the field is just the reverse of the motion of the other side (CD). As a result of this difference in motion of the two sides of the loop with respect to the magnetic field, the e.m.f. induced in one side of the loop will be from the observer, while that induced in

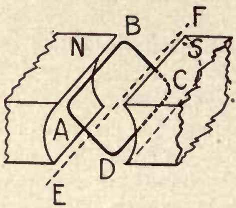


Fig. 126

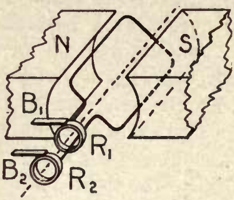


Fig. 127

the other side will be toward the observer. These two e.m.f.'s are acting in series and, since their directions are opposite with respect to the position of the observer, they both tend to produce a current in the same direction around the loop. The value of the current in the loop will depend upon the induced e.m.f. and the ohmic resistance of the loop. There will be no induced e.m.f. in the ends of the loop since they do not cut any of the magnetic lines.

177. Simple Alternator.—If the loop, shown in Fig. 126, be cut at one end and the two ends thus formed be connected to two metallic rings (R_1) and (R_2) mounted on the shaft and insulated from each other, as shown in Fig. 127, the combination will constitute what is called a **simple alternator.** An external circuit can be connected to the coil or armature by means of two brushes (B_1) and (B_2) that rub on the two metallic rings. The e.m.f. induced in the armature will now produce a current through the external circuit and the armature in series. The value of this current will, as in the previous case, depend upon the value of the induced e.m.f. and the ohmic resistance of the entire circuit.

The e.m.f. induced in the two sides of the loop at any time will depend upon the number of magnetic lines cut in one second, or the rate at which the lines are being cut. This rate of cutting of magnetic lines will depend upon the length of the two sides of the loop, the strength of the magnetic field, and the direction in which the conductor is moving with respect to the magnetic field. Assuming the strength of the magnetic field is uniform and it remains constant, and the loop revolves about its axis at a constant rate, then the e.m.f. induced in the loop will change in value, due only to a change in the direction of motion of the two sides of the loop with respect to the magnetic field. Thus, when the loop is in the

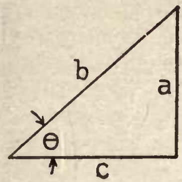


Fig. 128

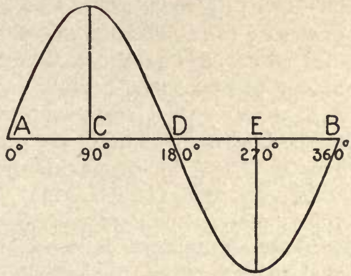


Fig. 129

horizontal position, the direction of the field also being horizontal, the two sides of the loop will be moving in a path, just for an instant, perpendicular to the direction of the field, and the number of lines of force that the two sides of the loop will cut, due to a given motion of the coil, will be a maximum. When the loop is in a vertical position, or perpendicular to the direction of the magnetic field, any small movement of the loop will result in no lines of force being cut by the two sides and, hence, no e.m.f. will be induced. The value of the e.m.f. induced in the two sides of the loop for positions between those just given, will depend upon the part, or component, of the motion that is perpendicular to the direction of the magnetic field. This component is proportional to the sine of the angle between the position of the coil and the plane perpendicular to the magnetic field. The sine of an angle (θ), see Fig. 128, is equal to the length of the line (a) divided by the length of the line (b). This relation remains the same regardless of the size of the triangle so long as the angle (Θ) does not change in value. From the table of "Trigonometrical Functions" in Chapter 20, may be found the values of the sines of different angles from 0° to 90°.

A curve can be drawn which will show graphically the relation between the induced e.m.f. in the coil and its angular position with respect to some reference plane, say the plane parallel to the magnetic field. Draw a line (AB), Fig. 129, and divide this line into, say, 90 equal parts, each part will then correspond to four-degrees movement of the coil about its axis. Starting with the coil in a plane perpendicular to the magnetic field, and let this correspond to the point (A) in the figure, the e.m.f. induced in the coil for any angular displacement from this position should be measured off to a convenient scale on a line drawn through the point on (AB), corresponding to the displacement of the coil. Thus, the e.m.f. will be a maximum when the coil has rotated through an angle of 90°, since the value of the sine of the angular displacement is increasing up to this point. It then decreases as the angle increases from 90° to 180° and becomes equal to zero when the coil has rotated through 180°. The direction of the movement of the two sides of the loop with respect to the magnetic field changes just as the coil passes through its 180° position and, as a result, the direction of the induced e.m.f. changes. The numerical values of the e.m.f. for the second 180° are identical to those for the first 180°, but they are opposite in sign. The difference in sign is represented in the curve by drawing the second part of the curve below the horizontal line.

178. Simple Direct-Current Dynamo.—Purpose of the Commutator.—The e.m.f. induced in the loop of wire described in the previous section can be made to produce a direct current—one that is constant in direction in the external circuit—in the following way: Suppose the two continuous metallic rings be replaced by a single ring composed of two parts that are insulated from each other, the distance between the ends of the two parts composing the rings being small in comparison to the total circumference of the combined ring. If the two ends of the loop be connected to these two parts of the ring, which we shall call **segments,** and two brushes that are insulated from each other be so mounted with respect to each other and the ring that they rest upon the insulation between the segments when the e. m. f. induced in the coil is zero, the connection of the external circuit with respect to the loop will be reversed at the same instant the direction of the induced e.m.f. in the loop changes. This results in the induced e.m.f. in the coil always tending to send a current through the external circuit in the same direction. The proper arrangement of the loop, segments, and the brushes is shown in Fig. 130. Such a machine is called a **simple direct-current dynamo,** because it delivers a direct current to the external circuit. The two-part ring constitutes a simple **commutator** of two segments, and its purpose, as pointed out, is to reverse the connection of the external circuit with respect to the

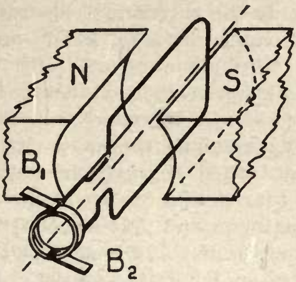


Fig. 130

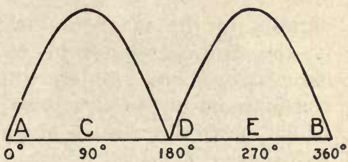


Fig. 131

armature winding, or *vice versâ,* so that the induced e.m.f. in the winding will send a direct current through the external circuit. A curve representing the value of the e.m.f. impressed upon the external circuit when the two-part commutator is used is shown in Fig. 131. An e.m.f. such as that represented in Fig. 131 is called a **pulsating** e.m.f., because it pulsates or changes from zero to a maximum and back to zero at regular intervals.

179. Multiple-Coil Armatures.—If the armature of a direct-current generator were constructed with a single coil composed of one or more turns, the current delivered by such a machine would pulsate in value the same as the e.m.f., as shown in Fig. 131. The operation of such a machine would be very unsatisfactory in a great many cases. Fortunately the e.m.f. between the brushes of the machine can be made more nearly constant in value in the following way:

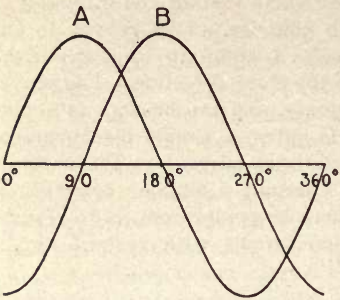


Fig. 132

Suppose two closed coils (A) and (B) be placed on the armature at right angles to each other, then the induced e.m.f. in one of them will be a maximum when the induced e.m.f. in the other one is zero. Now as the armature rotates from such a position that the plane of coil (A) is perpendicular to the magnetic field—zero e.m.f. induced in it—and the plane of coil (B) is parallel to the magnetic field—maximum induced e.m.f. in it—the induced e.m.f. in coil (A) will increase and the induced e.m.f. in coil (B) will decrease, and this action will continue until the armature has turned through an angle of 90°. After the armature has turned through an angle of 90°, the e.m.f. in coil (A) is a maximum and that in coil (B) is zero. For the next 90°, the e.m.f. in coil (A) is decreasing and the e.m.f. in coil (B) is increasing, but in the opposite direction. The corresponding values of induced e.m.f. will occur in the two coils at intervals which differ in value by one-fourth revolution, or 90°. The two curves (A) and (B) in Fig. 132 show the relation of the e.m.f.'s in the two coils.

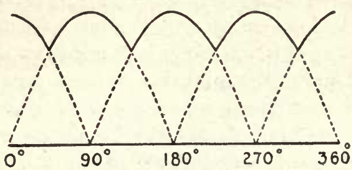


Fig. 133

If now a four-segment commutator be used and two coils be symmetrically placed on the armature, the terminals of each coil being connected to opposite commutator segments, the e.m.f. between the brushes of the machine will never fall to zero value but will be of the form shown by the full line in Fig. 133, when the brushes are properly placed with respect to the commutator. The e.m.f. can be made more nearly constant by placing more coils on the armature in such a position with respect to the first ones that the induced e.m.f. in them does not reach a maximum or zero value at the same time it does in the others, and connecting them in such a way that the induced e.m.f. in all of the coils acts in series and in the same direction as far as the external circuit is concerned.

180. The Armature of a Dynamo.—The loops of wire, or coils, in which the e.m.f. is induced by a movement of them with respect to the magnetic field, together with the iron parts upon which they are mounted, insulating material, and slip rings or commutator—in the cases where the coils move—constitute what is called the **armature** of a dynamo. The classification of armatures, their construction, and methods of winding will be taken up in detail in the chapter on "Armatures for Direct-Current Dynamos."

181. Magnetic Field of a Dynamo.—In the majority of cases the magnetic field of a dynamo is produced by electromagnets. In the case of **magnetos,** however, the magnetic field is created by several powerful permanent horseshoe magnets. Such a machine is shown in Fig. 134. Small machines are usually **bipolar,** that is, they have one N-pole and one S-pole which create the magnetic field in which the armature rotates. These magnetic fields assume a number of different forms, a few of which are shown in Fig. 135.

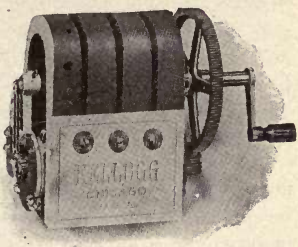


Fig. 134

In large machines it is customary to use **multipolar** field magnets in which any even number of poles are arranged alternately around the armature. The magnetic circuit of a machine whose field is created by an electromagnet usually consists of five parts, as shown in Fig. 136. (1) The **field cores** (C) are the centers of the coils carrying the magnetizing current. (2) The **yoke** (Y) connects the field cores together at one end, as shown in the figure. (In some machines there is no yoke in the magnetic circuit, see Fig. 135 A.) (3) The **pole pieces** (P) are the metallic parts of the magnetic circuit next to the armature. They are usually cut to conform to the curvature of the armature and in some cases are an entirely different piece of metal than the field cores, being fastened to the end of the field cores by means of bolts. The surface of the pole pieces next to the armature

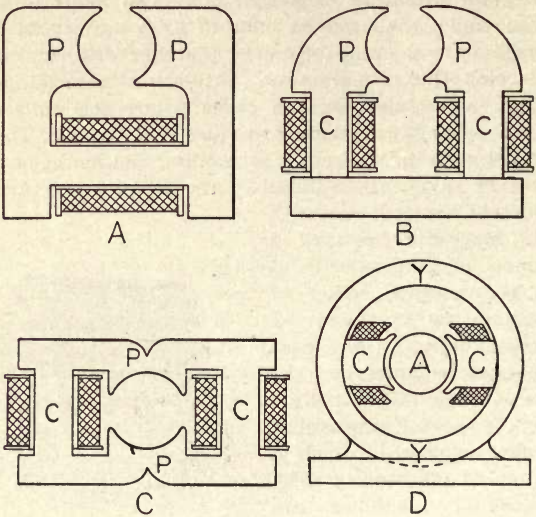


Fig. 135

is called the **pole face**; and the projecting edges, when so constructed, are called the **horns.** (4) The **air gap** (G) is the space between the pole face and the armature core. (5) The **armature core** conducts the magnetic lines from one air gap to another.

The coils carrying the magnetizing current may be placed on the magnetic circuit as shown in Fig. 135 D or they may be placed on the magnetic circuit as shown in Fig. 135 C. When the field windings are placed, as shown in Fig. 135 D, the magnetomotive force created by the current in one winding is in series with that created in the other winding, or the magnetomotive force on any magnetic circuit is that produced by two windings in series. If the windings be placed upon the magnetic circuit, as shown in Fig. 135 C, the magnetomotive force acting on each magnetic circuit would be that of a single coil. This results in only half the ampere-turns per coil being required when they are placed as shown in Fig. 135 D, as would be required if the coils were placed as shown in Fig. 135 C.

182. Materials Used in the Construction of the Magnetic Circuit.—There are three materials that are commonly used in the construction of the magnetic circuit of a dynamo — **cast iron, wrought iron, and cast steel.** There are a number of factors which govern the selection of the materials to be used in a particular machine, such as initial cost, weight, efficiency demanded by purchaser, regulation, etc.

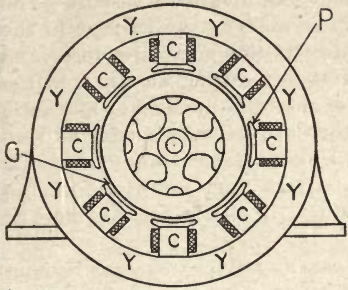


Fig. 136

The cheapest of the above materials is cast iron and it is the poorest of them all magnetically. So the saving in the initial cost of the iron per pound would more than likely be offset by the fact that a larger bulk of cast iron would be required to form a certain magnetic circuit than would be required if wrought iron, for example, were used. There would also be an increase in the cost of copper required to magnetize the large cast-iron core, since the length of each turn would be more than when some better magnetic material was used.

Wrought iron, on the other hand, is the best magnetic material and at the same time the most expensive. It is used where economy in weight and reduction of cross-section are desired. Machines used aboard ships or electric automobiles, etc., are usually made of wrought iron on account of the large reduction in weight, which is a more important factor than the initial cost.

Cast steel occupies a place intermediate between cast iron and wrought iron both in cost and magnetic properties. Machines are, as a rule, constructed of more than one material. Thus the field cores will be of wrought iron, as that would mean a saving in copper since the length of wire per turn would be less than if cast iron were used; the yoke may be of cast iron as its area can be made much larger than that of the field cores and this increase in area will add strength to the machine. The armature core is usually constructed of wrought-iron sheets, so as to reduce the eddy-current loss to a minimum; the pole shoes may be cast or they are sometimes laminated in order to reduce the eddy-current loss in them.

183. Magnetic Leakage, Shape of Magnetic Circuit.—The total number of magnetic lines created by the current in the field winding do not pass through the armature core, and therefore, they are not all useful in inducing an e.m.f. in the armature winding. The ratio of the total number of magnetic lines created to the number that are actually useful in generating an e.m.f. is called the **leakage coefficient.** The value of this coefficient can never be less than unity and in the case of poorly designed machines, it will reach a value as high as 1.4.

The value of this coefficient can be reduced by constructing the magnetic circuit so it will be as short as possible, or of low reluctance, and without abrupt turns. Placing the field winding upon or near that part of the magnetic circuit offering the greatest reluctance will also reduce the value of the leakage coefficient.

184. Value of Induced E.M.F. in Armature Winding.—The induced e.m.f. in an armature winding depends upon the following factors:

(a) The useful flux (Φ) per pole of the machine.

(b) The number of poles (p) composing the magnetic circuit.

(c) The total number of inductors (Z) on the armature.

(d) The number of paths (b) in parallel through the armature.

(e) The speed (s) in revolutions per second.

(f) The number of magnetic lines (10^8) that must be cut per second in order that there be an e.m.f. of one volt induced.

These factors can all be combined in a simple equation which will give the value of (E) in volts between the brushes of the machine when it is operating without load, or when it is delivering no current.

$$E = \frac{\Phi \times p \times Z \times s}{10^8 \times b} \qquad (100)$$

The value of (b) in the above equation will depend upon the type of winding on the armature. For a simple lap winding (singly re-entrant) it is equal to the number of poles and for a simple wave winding (singly re-entrant) it is always two regardless of the number of poles. This will be taken up again in the chapter on "Armature Winding."

Example.—A six-pole generator is operating at 900 revolutions per minute. The useful flux per pole is 4 000 000 lines. The armature has a simple lap winding (singly re-entrant) of 198 inductors. What e.m.f. will be generated?

Solution.—First obtain the value of the speed in revolutions per second by dividing 900 by 60, or

$$900 \div 60 = 15$$

The machine is then running at 15 revolutions per second. Since the winding on the armature is a simple lap winding, the value to substitute for (b) in equation (100) is equal to the number of poles, or 6. Substituting the values of the various quantities in equation (100) gives

$$E = \frac{4\,000\,000 \times 6 \times 198 \times 15}{100\,000\,000 \times 6} = 118.8$$

Ans. 118.8 volts.

185. Separate Excitation and Self-Excitation of a Generator.—There are two methods by which the electromagnets of the generator may be energized, and they are

(a) **Separate excitation.**

(b) **Self-excitation.**

In the case of separate excitation, the field windings of the machine are connected to some source of energy, other than the dynamo under consideration, such as a storage battery or another dynamo, and the current in the field winding is independent of the e.m.f. generated by the machine that is being excited. The field current is adjusted in value by changing the value of the resistance in the field circuit, which is accomplished by what is known as a **field rheostat**, or by changing the e.m.f. of the generator that is supplying the current to the field. The connections for separate excitation are shown diagrammatically in Fig. 137. The rheostat (R_1) is connected in series with the field of the main generator

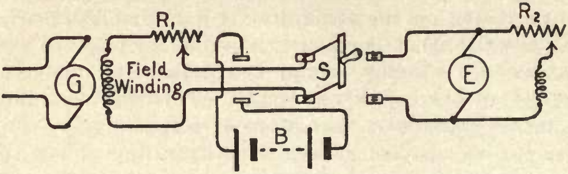


Fig. 137

(G). The field of the main generator may be connected to either the storage battery (B) or the small generator (E), which is called the **exciter**. A rheostat (R_2) is connected in series with the field of the generator (E) and by means of this rheostat the voltage generated in the armature of the exciter can be changed, and hence the current in the field of the generator (G), if (E) is supplying current to the field.

There are three different methods of self-excitation and they will each be taken up in turn in the following three sections.

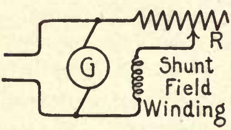


Fig. 138

186. Shunt-Wound Generator.—The field winding in the case of a shunt-wound generator consists of a large number of turns of relatively small wire that may be connected directly across the terminals of the machine. The potential difference between the two terminals of the machines produces a current in the field windings, which is regulated in value by a resistance or rheostat. A diagram of the connections of a self-excited shunt machine is given in Fig. 138.

187. Series-Wound Generator.—The field winding in the case of a series-wound generator consists of a few turns of large wire connected directly in series with the armature and load. The current in the field windings of a machine of this kind is of the same value as the current through the load. A diagram of the connections of a series-wound machine is given in Fig. 139.

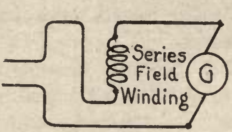


Fig. 139

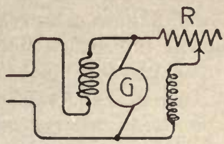


Fig. 140

188. **Compound-Wound Generator.**—In the case of a compound-wound generator, the field windings consist of two sets of coils. The coils of one set consist of a few turns of large wire connected in series with the armature and the load; the coils of the other set consist of a large number of turns of

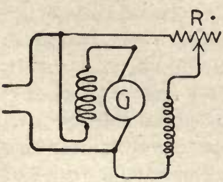


Fig. 141

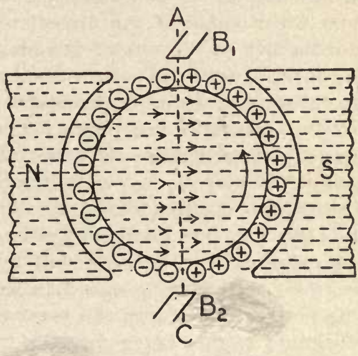


Fig. 142

small wire, all connected in series across the terminals of the machine. The compound generator is nothing more than a combination of a shunt and series generator.

When the shunt winding is connected directly across the armature, as shown in Fig. 140, the machine is called a **short shunt**; when it is connected across the armature and the series field, as shown in Fig. 141, the machine is called a **long**

shunt. In the case of a long shunt the current in the shunt field passes through the series field in completing its circuit through the armature; while in the case of a short shunt, the current in the shunt field passes directly through the armature without passing through the series field. The current in the shunt field can be regulated by a rheostat (R), while the current in the series field depends upon the current in the load to which the machine is connected.

189. Armature Reaction.—When a dynamo is operating under a load, the current in the armature will produce a magnetizing effect upon the field of the machine and this effect is called **armature reaction.** The direction of this magnetizing effect due to the armature current can be determined as follows: Take a simple drum armature with twelve coils equally spaced around the core and revolving in a bipolar magnetic field. (A cross-section through such an armature and field is given in Fig. 142.) The induced e.m.f. in the armature inductors on the right of a plane (AC), drawn perpendicular to the direction of the magnetic field, will be just the reverse of the direction of the induced e.m.f. in the conductors to the left of the plane (AC). The induced e.m.f. in the conductors is zero when they are in the plane (AC), and it changes in direction as the conductors pass from one side of the plane to the other. The plane (AC) is called the **normal neutral plane,** it being perpendicular to the magnetic flux when there is no current in the armature and, as a result, the field is not distorted. The brushes (B_1) and (B_2) should be placed in this plane, and when they are connected through an external circuit there will be a current in the armature conductors the value of which will depend upon the value of the induced e.m.f. and the total resistance of the circuit. The direction of this current in the inductors will be the same as that of the induced e.m.f. shown in Fig. 142, and it will produce a certain magnetizing effect upon the armature core. This magnetizing effect can best be shown by connecting the terminals of the machine to some source of e.m.f. in such a way that the current in the armature will be in the same direction as though it was produced by the induced e.m.f. (When the machine is connected to the external source of e.m.f., there should be no current in the field windings and the armature should be stationary.) The magnetic field due to the armature current alone is shown in Fig. 143. It is seen that this field is at right angles to the field of the machine. In actual operation the magnetizing effect of the armature current and the field current are both present at the same time and the resultant field is a combination of the two as shown in Fig. 144. This results in a non-uniform distribution of the magnetic flux through the generator pole pieces, air gaps, and armature core. The distortion takes place in the direction of rotation which results in a crowding of the flux in the trailing horns of the pole pieces.

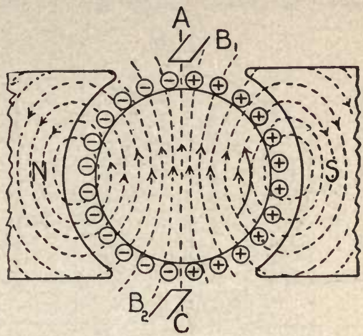


Fig. 143

The neutral plane of the resultant magnetic field will make an angle with the normal neutral plane, and the value of this angle will depend upon the amount of armature reaction. As a result of the neutral plane changing its position, the position of the brushes must also be changed so that it will correspond more nearly to the position of the neutral plane. With a change in the position of the brushes, there will be a change in the direction of the current in some of the armature conductors. Thus, if the brushes be shifted in the direction of rotation, as shown in Fig. 145, the direction of the current in the inductors in the angle (θ) will change and the magnetic effect of a current in the armature will no longer be in a direction perpendicular to the magnetic field of the machine, but in a direction such as that shown in Fig. 145. This magnetizing effect can be thought of as made up of two parts, one acting parallel to the magnetic field of the machine and another acting perpendicular to the magnetic field of the machine. The magnetizing effect of the armature current perpendicular to the field of the machine is called the **cross-magnetizing effect,** and the effect parallel to the field of the machine is called the **demagnetizing effect.** One of the above effects tends to weaken the magnetic field of the machine, while the other tends to distort the magnetic field.

190. Cross-Turns and Back Turns.—In the previous section it was pointed out that the plane of the brushes, known as the **commutating plane,** should be moved in the direction of rotation in order that the brushes be nearer the neutral plane. The position of this commutating plane will always be in advance of the normal neutral plane in the case of a generator, and behind the normal neutral plane in the case of a motor.

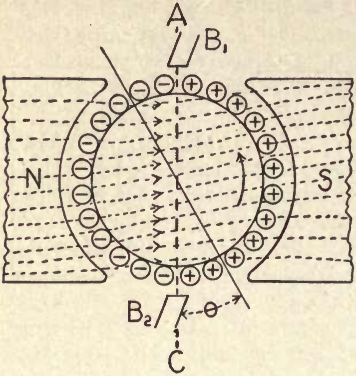


Fig. 144

The angle between the commutating plane and the normal neutral plane is called the **angle of lead** in the case of a generator, and the **angle of lag** in the case of a motor. The position of the two commutating planes is shown in Fig. 146, the full line (DE) representing the commutating plane of the generator and the dotted line (FG) representing the commutating plane of the motor. The conductors in the double angle (2θ) on one side of the armature can be thought of as being in series with the conductors in the angle (2θ) on the other side of the armature, and forming a number of complete turns about the core. The remaining conductors can be thought of as forming a second set of turns. The product of the turns in the double angle (2θ)

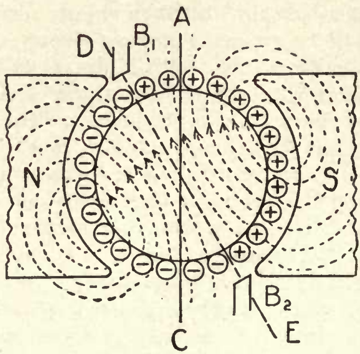


Fig. 145

and the current in them gives what is called the **demagnetizing ampere-turns** because their effect is to produce a weakening of the magnetic field of the machine. The remaining turns times the current in them are called the **cross-magnetizing ampere-turns** because they act at right angles to the magnetic field of the machines. The turns in the angle (2Θ) are called **back turns** and the remaining ones are called **cross-turns.**

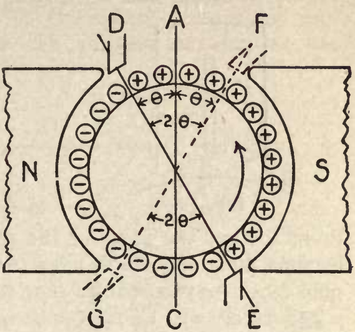


Fig. 146

191. Means of Reducing Armature Reaction.—Armature reaction interferes with the satisfactory operation of the dynamo and should be reduced to a minimum where possible. There are a number of ways of bringing about a reduction in the effect of armature reaction, some of the more important ones being:

(a) By increasing the length of the air gap of the machine.
(b) By slotting the poles parallel to the axis of the armature.
(c) By properly shaping the pole pieces.
(d) By using auxiliary poles.
(e) By placing a winding in perforations in the pole faces. (Invented by Mr. Ryan.)

(a) Increasing the length of the air gap increases the reluctance in the magnetic circuit that is acted upon by the cross-magnetizing ampere-turns, but at the same time increases the number of ampere-turns required in the field winding of the machines. Thus the effect of the distorting, or cross-turns, will not be so great as it would be if the magnetic field of the machine were weaker.

(b) Cutting slots in the pole faces parallel to the axis of the armature introduces a large reluctance in the path of the cross flux, produced by the cross-magnetizing ampere-turns, but does not introduce anything like as great a reluctance in the main magnetic circuit. Fig. 147 shows a stamping used in the construction of a field core, there being a small slot punched in each piece. When these stampings are all assembled there will be one long slot through the pole piece parallel to the axis of the armature.

(c) The shifting of the magnetic flux across the pole shoe of the machine can be greatly reduced by properly shaping

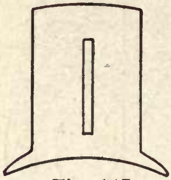


Fig. 147

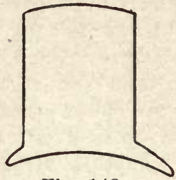


Fig. 148

them so that the parts of the air gap where the flux tends to become most dense will have the greater reluctance. Thus the pole faces may be cut so that the trailing horn, in the case of a generator, will be farther from the surface of the armature. The trailing horn of the pole piece may also be made longer than the advancing side, which also results in a more uniform distribution of the magnetic flux and the armature inductors will enter and leave the magnetic field more gradually than they would if an ordinary pole piece were used. Such a pole piece is shown in Fig. 148.

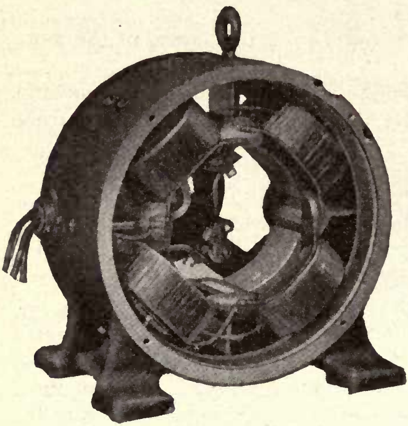


Fig. 149

(d) Auxiliary poles may be placed between the main poles of the machines and so connected that their magnetizing effect is just the reverse of that of the cross-magnetizing ampere-turns. The windings on these poles are connected so that they carry all or a definite portion of the full load current. This results in their effect varying directly as the load current, just as the effect of the cross ampere-turns varies with the load current, and if the effects balance for one particular load, they will practically balance for all other loads and the position of the neutral plane of the magnetic field will remain almost constant. The auxiliary poles of a machine are shown in Fig. 149.

192. Commutation.—The process of commutation can best be explained by reference to Fig. 150. The commutator segments are shown shaded while the various elements of the armature winding are shown connected in series, the junctions of these elements being connected to the commutator segments in regular order. The direction of rotation of the armature is indicated by the arrow (A), and the position of the neutral plane by the line (DE). The direction of current in the various elements is indicated by the small arrows. With a direction of current corresponding to that shown in the figure, the brush (B_1) must be positive.

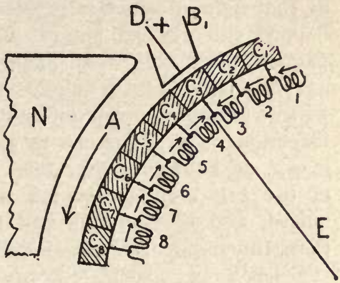


Fig. 150

Now as the armature rotates, the commutator segments in turn pass under the brush (B_1). If the contact surface of the brush is greater than the width of the insulation between the segments, which should always be the case, then an element of the winding will be short-circuited when the brush is in contact with the two segments to which the element is connected. The current in the short-circuited coil drops to zero when it is shorted, but it does not do so instantly on account of the inductance of the coil. As the armature rotates, the brush moves from commutator segment (C_4), Fig. 150, and the element of winding (4) is connected in series with the other elements in the left-hand path. When the element becomes a part of the left-hand path, it carries the same current the other elements in that path carry. Now if there is zero current in the coil that is finishing commutation, just as it moves from the short-circuited position, the current in it must increase almost instantly to a value equal to that in the other elements. The inductance of the element opposes this sudden increase in current and, as a result, there is a tendency for an arc to form between the brush and the commutator segment (C_4) until the current in the coil (4) has reached its proper value, or the inductance of the coil has been overcome. This condition of affairs would result in a continuous sparking at the brushes, which would not only represent a loss but would be injurious to both the commutator and the brushes. Sparking due to the cause just mentioned can be reduced and practically overcome by advancing the brushes beyond the neutral plane. When the brushes are thus advanced, there will be an e.m.f. induced in the coil undergoing commutation while it is short-circuited and this induced e.m.f. will be in such a direction as to produce a current in the same direction as the current in the elements to the left of the brush, as shown in Fig. 150. This results in the inductance of the coil being overcome while the coil is still short-circuited, and the current will meet with no opposition other than the ohmic resistance when the coil becomes a part of the left-hand circuit. Advancing the brushes beyond the neutral plane results in a slight lowering of the terminal e.m.f. of the machine, but this is more than offset by the advantage in the reduction in sparking.

193. Capacity of a Generator.—The output of a generator is limited by one of the three following factors, when sufficient power is applied to drive it. These factors are:

(a) Excessive drop in the armature of the machine.

(b) Excessive heating.

(c) Excessive sparking.

(a) As the load on a generator is increased, there is an increase in drop in the armature due to the (IR) drop and armature reaction. These two effects combined decrease the terminal voltage of the machine and this decrease is usually excessive when the machine is overloaded.

(b) The allowable temperature rise as prescribed by the American Institute of Electrical Engineers is as follows: "Under normal conditions of operating and ventilation, the maximum temperature rise referred to a standard room temperature of 25° C. should not exceed 50° C. for field coils and armature as measured by the increase in resistance; and 55° C. for commutator and brushes, and 40° C. for all other parts, bearings, etc., as determined by a thermometer." It is usually safe to operate a machine above these temperatures for a few hours, but an excessive heating of commutator, armature, or field coils, is likely to injure and in some cases destroy the insulation.

(c) The heat generated as a result of sparking usually limits the allowable sparking, as it causes a rise in temperature of the commutator and the brushes.

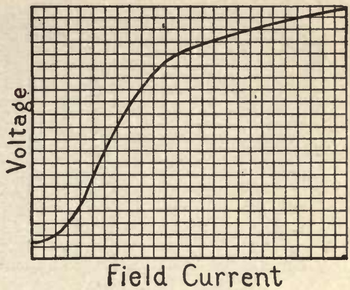


Fig. 151

194. Building Up of a Self-Excited Shunt Generator.—The iron composing the magnetic circuit of a generator usually retains some of its magnetism and when the armature is revolved in this weak magnetic field, there is a small e.m.f. induced which produces a current in the field windings. This current, if the windings are properly connected, will increase the magnetic flux through the armature, which in turn will increase the e.m.f. and field current, etc. A curve showing the relation between terminal voltage and field current is given in Fig. 151. Such a curve is called a **magnetization curve.** The abrupt bend in the curve near the top indicates that the magnetic circuit is practically saturated.

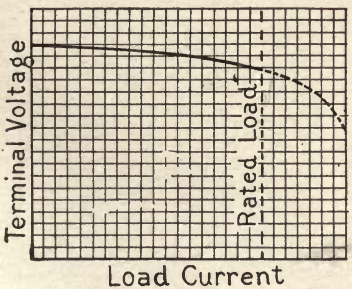


Fig. 152

195. External Characteristics of Shunt, Series, and Compound Generators.—The external characteristic curve of a generator is a curve that shows the relation between the current output of the generator and the terminal voltage.

In the case of the shunt generator, assuming the speed remains constant and the field resistance is not changed after it is adjusted to give normal terminal voltage at no load, the voltage at the terminals of the machine will decrease with an increase in load on account of armature reaction and copper drop. The curve in Fig. 152 shows the relation between the terminal voltage and the load current for a shunt generator. The drop in voltage will be different for different machines, depending upon the resistance of the armature and the amount of armature reaction.

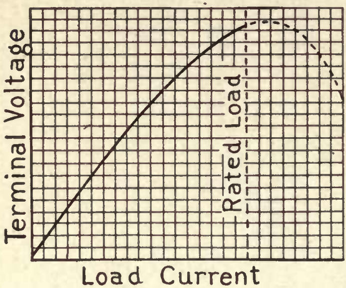


Fig. 153

In the case of a series generator, the terminal voltage is zero with zero load, but it increases as the load current increases because the field excitation is increasing. The field strength of the machine will continue to increase very rapidly with an increase in load until the iron becomes saturated, when the effects of armature reaction and copper drop produce a decrease in terminal voltage with a further increase in load, as shown in Fig. 153.

In the case of a compound generator, the series winding may be so connected as to produce a magnetizing effect that aids the shunt field, and with an increase in load there is an increase in total field excitation. If this increase in field excitation is just sufficient to maintain the terminal voltage practically constant, the machine is said to be **flat-compounded.** If there is a rise in terminal voltage with an increase in load, the machine is said to be **over-compounded,** and if the voltage drops with an

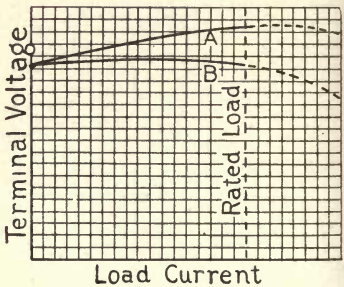


Fig. 154

increase in load the machine is said to be **under-compounded.** The external characteristic curve of an over-compounded generator is shown by curve (A) in Fig. 154, and the external characteristic curve of a flat-compounded generator, by curve (B).

196. Adaptability of Shunt, Series, and Compound Generators.—The shunt generator is usually used where it is desired to have a practically constant voltage, and the distance from the machine to the load is not very great, resulting in a small voltage loss in the line.

The series generator is usually used in supplying a constant current to a load at a varying potential, such as a number of arc lamps connected in series.

The compound machine can be constructed so that the voltage at its terminals, or at the load, can be maintained constant or allowed to increase or decrease with a change in load. Thus it can operate a number of lamps at a constant pressure even though they be located some distance from the generator, or the voltage at the end of the line can be made to increase with an increase of load, as is quite often the case in railway work. A modern compound generator is shown in Fig. 155.

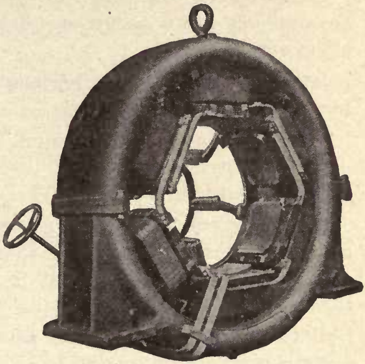


Fig. 155

197. Losses in Generators.—The losses in generators may be divided into two main groups:

(A) I^2R, or electrical losses.

(B) Stray-power losses.

(A) The I^2R losses occur in the field windings and the armature. If (I_c), (I_s), and (I_a) represent the currents in the shunt-field winding, series-field winding, and armature, respectively, and (R_c), (R_s), and (R_a) represent the resistance of the shunt-field winding, series-field winding, and armature, respectively, then the loss in the shunt-field winding (W_c), series-field winding (W_s), and armature (W_a) can be determined by the following equations:

$$W_c = I^2_c R_c \quad (101)$$

$$W_s = I^2_s R_s \quad (102)$$

$$W_a = I^2_a R_a \quad (103)$$

(B) The stray-power losses consist of

(a) Hysteresis and eddy-current losses chiefly in the armature core.

(b) Friction losses at bearings and brushes, and air friction, or windage, as it is called, due to the fan-like action of the moving parts.

The stray-power losses cannot be calculated with the same degree of accuracy that the (I^2R) losses can; but they can, however, be quite accurately determined for a given machine by experiment.

198. Efficiency of Generators.—There are three efficiencies for a generator:

(a) **Efficiency of conversion.**

(b) **Electrical efficiency.**

(c) **Commercial efficiency.**

(a) The efficiency of conversion is the ratio of the total electrical power generated to the total mechanical power supplied. Let (P) represent the mechanical power supplied, then

$$\text{Efficiency of conversion} = \frac{EI + (\text{electrical losses})}{P} \times 100 \quad (104)$$

Where (EI) represents the output in watt.

(b) The electrical efficiency is the ratio of the total electrical power delivered to the total electrical power developed.

$$\text{Electrical efficiency} = \frac{EI}{EI + (\text{electrical losses})} \times 100 \quad (105)$$

(c) The commercial efficiency of a generator is the ratio of the electrical output to the mechanical input, or

$$\text{Commercial efficiency} = \frac{EI}{P} \times 100 \quad (106)$$

The commercial efficiency is the most important of the three, as it includes all the losses in the machine.

199. Commercial Rating of Generators.—Generators are rated according to their k.w. output. Thus a 100-k.w. 100-volt generator means the machine will deliver 100 k.w. to an external circuit connected to its terminals, and that the voltage will be 100 volts. If the output is 100 k.w. at 100 volts, then the current will be $10\,000 \div 100 = 1000$ amperes.

PROBLEMS ON DIRECT-CURRENT GENERATORS

1. Calculate the e.m.f. generated in the armature of a 10-pole direct-current generator wound with 1000 inductors, lap winding (simplex singly re-entrant), and revolving at 300 revolutions per minute. The magnetic flux per pole is 5 000 000 maxwells. Ans. 250 volts.

2. If the winding in the above problem was changed to a wave winding (simplex singly re-entrant), what e.m.f. would be generated? Ans. 1250 volts.

Note: See section (184).

3. If the speed in problem (1) is decreased to 250 revolutions per minute and the flux (Φ) per pole is raised to 6 000 000 maxwells, what would be the change in the e.m.f. generated? Ans. No change.

4. The armature of the machine in problem (1) has a resistance of .006 ohm, what will be the value of the terminal voltage when the machine is delivering a current of 750 amperes? (Assume the internal voltage remains constant.)
Ans. 245.5 volts.

5. How much should the flux per pole be increased in order that the terminal voltage in problem (4) remain constant?
Ans. Increase 90 000 maxwells.

6. There are 180 inductors on the surface of a bipolar drum-wound armature and in each of these inductors there is a current of 50 amperes. Calculate the demagnetizing and cross-magnetizing ampere-turns when the commutating plane makes an angle (Θ) of 10 degrees with the normal neutral plane.

Ans. 500 demagnetizing ampere-turns.
4000 cross-magnetizing ampere-turns.

7. The total flux produced by a field winding is 5 800 000 maxwells and the useful flux is 5 000 000 maxwells, calculate the coefficient of magnetic leakage.

Ans. Leakage coefficient = 1.16.

8. The output of a 110-volt generator is 300 amperes, what is the horse-power input if the efficiency of the machine is 90 per cent? Ans. 49.2 horse-power.

9. If the electrical loss in problem (8) is 1375 watts, what is the electrical efficiency of the machine? The efficiency of conversion?

Ans. Electrical efficiency, 96 per cent.
Efficiency of conversion, 93.8 — per cent.

10. What is the commercial efficiency of a machine that will deliver 500 amperes at 550 volts when the input is 400 horse-power? Ans. 92.1 + per cent.

CHAPTER X

DIRECT-CURRENT MOTORS

200. Fundamental Principle of the Direct-Current Motor.—If a conductor in which there is a direct current be placed in a magnetic field in such a position that it makes an angle with the direction of the field, there will be a force tending to move the conductor. This same force is present in the case of a generator, but it is overcome by the mechanical force that drives the machine. With an increase in current in the conductor or an increase in the strength of the magnetic field, there will be an increase in the force which tends to move the conductor.

201. Fleming's Left-Hand or Motor Rule.—There is a definite relation between the direction of current in a conductor, the direction of motion, and the direction of the magnetic field for a motor; just as there is a definite relation between these three quantities in the case of a generator. If the thumb and first and second fingers of the left hand be placed at right angles to each other, the second finger pointing in the direction of the current in the conductor, the first finger in the direction of the magnetic field, then the thumb will point in the direction in which the conductor will tend to move. This simple rule is known as Fleming's **left-hand or motor rule.** If the direction of the current in the conductor be reversed, the direction of the magnetic field remaining constant, the direction of motion will be reversed; or, if the direction of the magnetic field be reversed, the direction of the current remaining the same, the direction of motion will be reversed. If, however, the direction of the current and the direction of the magnetic field are both reversed, the direction of motion of the conductor will remain the same. Fig. 156 illustrates Fleming's **left-hand rule.**

202. Generator and Motor Interchangeable.—The essential parts of a direct-current motor are identical with those of a generator, namely, an armature and magnetic field. The connection of the armature conductors to the external circuit is made by means of a commutator which serves to reverse the direction of current in the armature winding at the proper time so that the forces tending to move the various conductors in the magnetic field all act together and a continuous rotation of the armature is produced. Any direct-current generator may be used as a direct-current motor or *vice versâ*, their construction being practically the same.

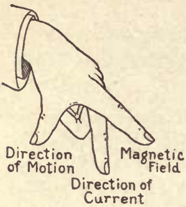


Fig. 156

203. Classes of Motors. — Direct-current motors may be divided into three main groups according to the method employed in exciting the field magnets. These are:

(a) **Shunt motors.**

(b) **Series motors.**

(c) **Compound motors.**

(a) The field windings of a shunt motor consist of a large number of turns of small wire connected directly across the terminals of the machine, or the line to which the machine is connected. The current in the field winding of a shunt machine is independent of the current in the armature so long as an increase in armature current produces no change in the voltage impressed upon the shunt field winding. The field strength of the shunt machine is regulated by changing the current in the field winding, which may be done by either changing the impressed voltage or the total resistance of the circuit.

(b) In the case of the series motor, the field winding consists of a few turns of large wire connected directly in series with the armature and the line. The current in the field windings is the same as the current in the armature, and the field strength varies with the load on the machine, the field current increasing with the load.

(c) The field windings of a compound motor are a combination of the shunt and the series windings. The magnetic effect of these two windings may aid or oppose each other, depending upon the way they are connected. When the two magnetizing effects act together, the machine is called a **cumu-**

lative compound motor; and when their magnetizing effects oppose each other, the machine is called a **differential compound motor.** In the case of the cumulative compound machine, the field strength increases with an increase in load since the two magnetizing effects act together; and in the case of the differential compound motor, the field strength decreases with an increase in load since the two magnetizing effects act opposite to each other.

204. Direction of Rotation of Machines when Changed from a Generator to a Motor.—The direction of current in the armature, field winding, and line for a self-excited shunt generator, and the polarity of the machine and direction

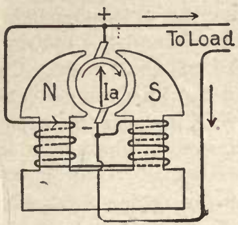


Fig. 157

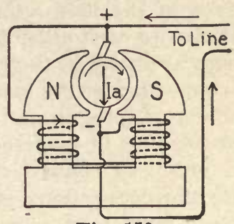


Fig. 158

of rotation are shown in Fig. 157. The arrow (I_a) represents the direction of the armature current. Let this machine be operated as a motor by connecting it to some source of energy, connecting the positive terminal of the machine to the positive line, and the negative terminal of the machine to the negative line. The direction of current in the field and armature for this connection is shown in Fig. 158. It will be seen by inspection that the direction of current in the field winding has remained the same in the two cases and that the direction of current in the armature has changed. Now applying Fleming's dynamo rule to Fig. 157 and his motor rule to Fig. 158—remembering the direction of current in the armature in one case is just the reverse of what it is in the other, and the field current is the same in both cases—you will find the direction of rotation of the armature in Fig. 158 will be the same as in Fig. 157.

In the change from a generator to a motor, as shown in Figs. 157 and 158, the polarity of the terminals of the motor was the same as that of the generator. When the polarity of the motor is just the reverse of that of the generator, the current in the shunt-field winding will be reversed in direction and the armature current will not change. This will also result in the direction of rotation of the armature remaining the same. Hence, a shunt generator will always run in the same direction when operated as a motor, as it did when it was run as a generator.

To change the direction of rotation of a shunt generator when it is changed to a motor, the connections of the armature or shunt-field winding must be reversed.

When a series generator is changed to a series motor, the direction of rotation will be reversed, because the direction of the current in the field winding and the armature bear the same relation to each other in both cases and the motion will be opposite as shown by the right- and left-hand rules. Changing the connection of the machine to the line will not change the direction of rotation as the current in both the armature and field winding is reversed when such a change is made. Then in order to change the direction of rotation of the armature, the connections of either the series field winding or armature must be reversed, which will result in a change in direction of either the magnetic field or of the armature current, but not of both.

The compound generator will act, as far as direction of rotation is concerned, when changed to a motor, the same as though it were a simple shunt machine, provided the machine is lightly loaded. If it is started under a heavy load there will be an excessive current in the armature and series-field winding, and if the magnetizing effect of the series-field winding is greater than that of the shunt-field winding, the machine will start up as though it were a series motor.

205. Armature Reaction in a Motor.—Let us assume that a shunt generator is operated as a shunt motor, the polarity of the machine being the same in both cases. The current in the shunt-field winding will remain constant in direction and, as a result, the direction of the magnetic field of the machine does not change. The direction of current in the armature, however, changes and as a result the direction of the magnetic field produced by it changes. When the brushes are in the normal neutral plane, as shown in Fig. 143, the field produced by the armature current is at right angles to that produced by the field current and it is acting downward, as shown in Fig. 159, instead of upward, as shown in Fig. 143. Since the magnetizing effects of the armature current and the field current are present at the same time, they form a resultant field whose general direction is similar to that shown in Fig. 160. It will be seen that the magnetic field in the case of a motor is shifted in a direction opposite to the direction of rotation, which is just the reverse of what occurred in the generator, as shown in Fig. 144. This results in the neutral plane of the magnetic field being shifted back of the normal neutral plane, as shown by the line (FG) in Fig. 160.

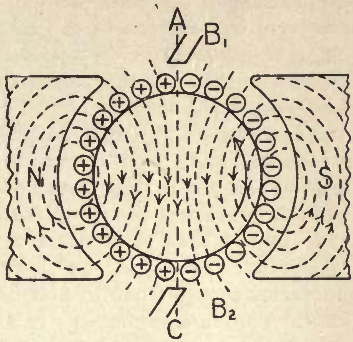


Fig. 159

206. Position of the Brushes on a Motor.—Since the neutral plane of the magnetic field is changed when the generator is changed to a motor, the plane in which the brushes are placed must be changed so that it will correspond more nearly to the position of the neutral plane. The brushes then will be given an angle of lag in the case of a motor while they were given an angle of lead in the case of a generator.

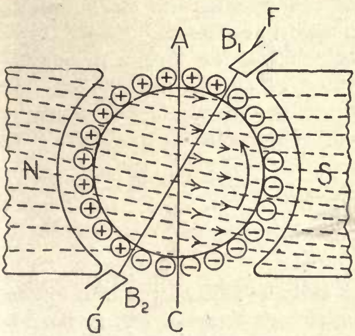


Fig. 160

The **demagnetizing** turns on the armature are in the angle (2Θ), as shown in Fig. 146, and the **cross-magnetizing** turns are those outside of this double angle. The turns in the double angle (2Θ) are still demagnetizing, although the current through the armature has been reversed, for the following reason: When the machine is used as a generator the brushes are in advance of the neutral plane, as shown in Fig. 145, and when it is used as a motor they are back of the neutral plane, as shown in Fig. 160. If the brushes were changed from one position to the other without reversing the current in the armature, the current in the turns located in the angle (2Θ) would be reversed in direction and the magnetizing effect of the ampere-turns in this angle (2Θ) would act with the magnetic field of the machine. The current in the armature, however, is reversed at the same time the position of the brushes is changed and, as a result, the magnetizing effect of the turns in the angle (2Θ) does not change in direction.

The brushes are usually placed a little back of the neutral plane in the case of a motor for the same reason they are placed in advance of the neutral plane in the case of a generator, as explained in section (192).

207. Torque Exerted on Armature.—The **torque** of a motor is equal to the product of the total force acting on the armature conductors times the distance of the conductors from the center of the armature, or

$$T = F \times L \qquad (107)$$

When the force (F) in the above equation is measured in pounds and the distance (L) between the point of application of this force and the center of the armature is measured in feet, the torque (T) will be given in **pound-feet.** The following equation can be used in calculating the torque in pound-feet in terms of the total number of conductors (Z) on the armature, the number of poles (p), the magnetic flux per pole (Φ), the number of paths in parallel through the armature (b), and the total armature current (I_a).

$$T = \frac{.1174 \times p \times Z \times \Phi \times I_a}{10^8 \times b} \qquad (108)$$

208. Mechanical Output of a Motor.—The output of a motor in foot-pounds per second is equal to the torque (T) in pound-feet multiplied by the speed in revolutions per second (r.p.s.) times 2π. Since one horse-power is equal to 550 foot-pounds per second, then the output of a motor in horse-power (h.p.) can be calculated by the use of the following equation:

$$h.p. = \frac{2\pi \times T \times (r.p.s.)}{550} \qquad (109)$$

If the speed is measured in revolutions per minute (r.p.m.), then

$$h.p. = \frac{2\pi \times T \times (r.p.m.)}{33000} \qquad (110)$$

209. Counter Electromotive Force.—When a machine is being operated as a motor, the armature is revolving in a magnetic field and there will be an induced e.m.f. set up in the conductors just the same as there would be if the machine were operated as a generator. Since the relation between the direction of motion of the conductors with respect to the direction of the magnetic field in the case of a motor is opposite to what it is in the case of a generator, the direction of the current in the conductors remaining constant, the induced e.m.f. in the armature of the motor will be just the reverse of what it is in the case of the generator. This e.m.f. opposes the flow of the electricity in the armature and hence takes energy from it, just as a force that acts in a direction opposite to the velocity of a body takes energy from the body, hence the motor action. This induced e.m.f. acts in a direction just opposite to the impressed e.m.f. at the terminals of the machine and for that reason it is called a **counter electromotive force.** Its value depends upon the same factors as the e.m.f. of a generator, and it may be calculated by the use of equation (100). A counter e.m.f. is absolutely necessary to the operation of a motor.

210. Normal Speed of a Motor.—The current in the armature of a motor depends upon the resistance of the circuit, and the effective electromotive force acting in the circuit. If the impressed voltage on the machine be represented by (E), the counter electromotive force by (E_c), and the effective electromotive force by (E_f), then

$$E_f = E - E_c \qquad (111)$$

The current (I_a) in the armature is equal to

$$I_a = \frac{E_f}{R_a} \qquad (112)$$

or

$$I_a = \frac{E - E_c}{R_a} \qquad (113)$$

In the above equations (R_a) represents the total resistance between the terminals of the machine, neglecting the shunt field. In a shunt machine (R_a) would be the resistance of the armature, while in a series and compound machine (R_a) would be the resistance of the series field and armature combined. Since the current is dependent upon the counter electromotive force, as shown in equation (113), the machine will run at such a speed that the difference between the impressed voltage (E) and the counter electromotive force will produce sufficient current in the armature to produce the required torque in order that the machine may carry its load. Thus, with an increase in load on a machine there will be an increase in torque required, and this increase in torque will mean an increase in armature current if the field strength remains constant. Now in order that the current in the armature increase, the resistance (R_a) and impressed voltage (E) remaining constant, the value of the counter e.m.f. must decrease. The only factor in equation (100) that can change is the speed, since the field strength, or flux per pole (Φ), is supposed to remain constant and the other factors are governed by the construction of the machine and cannot be changed without rebuilding. There will then be a reduction in the speed of a machine with an increase in load current, all other factors remaining constant.

211. Methods of Regulating the Speed of a Motor.—The speed of a motor may be regulated by any one, or certain combinations of the following methods:

- **(a)** Change in field strength produced by a change in field current.
- **(b)** Change in field strength produced by a change in the reluctance of the magnetic circuit.
- **(c)** Varying voltage over the armature by means of a rheostat.
- **(d)** Multi-voltage system.
- **(e)** By changing the position of the brushes.

(a) A rheostat placed in series with the shunt field of a motor, as shown in Fig. 161, may be used to change its speed. If the resistance of the shunt-field circuit be increased by increasing the part of the resistance (R) in circuit, the field current will be decreased and there will be a decrease in the magnetic flux (Φ) per pole which will result in an increase in speed, all other quantities remaining constant, in order that the required counter e.m.f. may be generated in the armature. The change in the value of (Φ) due to a change in the field current will depend upon the degree to which the iron of the magnetic circuit of the machine is saturated. If the circuit is well saturated there must be a relatively large change in field current to produce a small change in speed.

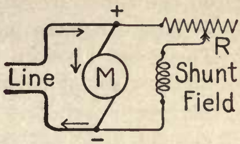


Fig. 161

There is a limit, however, to the amount you can weaken the field of a machine as the armature reaction increases with a decrease in field strength which results in serious sparking. The effect of armature reaction can be neutralized as explained in section (191) and the allowable range in speed obtainable by this method thus greatly increased. A number of different kinds of field rheostats are described in the chapter on operation.

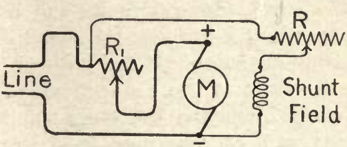


Fig. 162

(b) The magnetic flux in the magnetic circuit of a machine can be changed by varying the reluctance of the magnetic circuit. This is accomplished in the case of a motor manufactured by the Stow Manufacturing Company, in the following way: The field cores are hollow and are provided with movable iron cores. These cores are all connected mechanically so that their position in the field coils can be adjusted by means of a hand wheel on top of the machine. By moving them toward or away from the armature there will be a decrease or increase in the reluctance of the magnetic circuit and, as a result, an increase or decrease in the flux (Φ) per pole. This change in (Φ) will produce a change in the speed.

(c) If a rheostat (R_1) be placed in series with the armature of a motor, as shown in Fig. 162, the voltage across the terminals of the armature circuit can be varied by changing the resistance in the rheostat. A change in impressed voltage on the armature will mean a change in speed, because there will be a change in the value of the counter e.m.f. required. The Ward Leonard system, as described in section (213), is a form of variable voltage control.

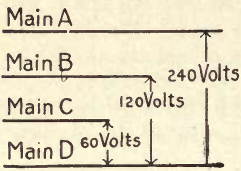


Fig. 163

(d) In the multi-voltage method of speed control, there are several different voltages available from which the motor may be operated. Thus, as shown in Fig. 163, there is a different voltage between the different lines and these may be combined, giving other voltages, which may be connected to the motor terminals by means of a suitable switch, or controller. This method is usually used in combination with the field rheostat method.

(e) If the brushes of a machine be shifted from the neutral plane of the magnetic field, there will be an increase in the speed for the following reason: The counter e.m.f. between the brushes of a motor is a maximum when the brushes are in the neutral plane because the e.m.f. induced in all the conductors, in series in the various paths through the armature windings, are acting in the same direction. If the position of the brushes be changed, it will result in the e.m.f. induced in some of the conductors in series opposing the e.m.f. in the others; and the resultant e.m.f. will be less than in the previous case, all other conditions remaining constant. Now as the brushes are shifted from the neutral plane, the speed must increase in order that the counter e.m.f. between the brushes may satisfy equation (113). This is not a practical method for varying the speed, as excessive sparking usually results when the brushes are moved very much from their proper position. The brushes, in the case of a motor, can be placed in the neutral plane by moving them back and forth, noting the change in speed. The position giving a minimum speed will correspond to the neutral plane (no load on the motor).

212. Interpole Motor.—In order to prevent a shift in the position of the neutral plane of the magnetic field of a motor, due to a change in armature current, which tends to distort the field, **commutating-poles,** or **interpoles,** are used. These poles are placed between the regular poles of the machine, and the windings on them carry the load current. Their magnetizing effect counteracts that of the armature current and the position of the brushes need not be changed with the change in load on the machine. If the direction of rotation of the armature be changed by changing the direction of the armature current, the polarity of the interpoles will also be changed and their magnetizing effect will still counteract that of the armature current.

213. Ward Leonard System.—In this system the field of the motor (M) is connected directly to the main line and the

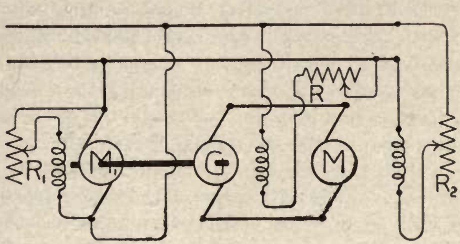


Fig. 164

armature is connected to an auxiliary generator (G), whose voltage can be regulated by means of the field rheostat (R), Fig. 164. In this arrangement the speed of the motor (M) is controlled by a change in impressed voltage, which in turn is controlled by the excitation of the generator (G). The field current for the generator (G) is taken directly from the line and its value is regulated by means of the rheostat (R).

214. Comparison of Methods of Speed Control.—The field rheostat method is perhaps the cheapest and simplest method of speed control and for that reason is no doubt used more than any of the others. It permits of a wide variation in speed when used with the interpole motor and the change in the speed can be made very gradually.

The change in reluctance method is quite satisfactory, but the initial cost of the machine is usually prohibitive for general use.

The armature rheostat method is very little used, as there is a large change in speed, with a change in load, and there is an excessive loss in the resistance for large armature currents.

The Ward Leonard and multi-voltage systems are very satisfactory in operation, but they are expensive to install.

A change in speed produced by shifting the brushes is not practical on account of difficulties due to sparking.

215. Starting Motors.—There is no counter e.m.f. generated in the armature of a motor when it is stationary and if the machine were connected directly to line a very destructive current would exist in the armature. The value of this current, just at the instant the circuit was closed, would be equal to (E) divided by (R_a) if there were no resistance in series with the armature. The resistance of the armature is usually very small and, as a result, the current would be large. By placing a resistance (R_x) in series with the armature, the current can be reduced to a safe value. Now as the armature starts to rotate there will be a counter e.m.f. generated and the effective e.m.f. acting in the circuit will be reduced, which will cause a reduction in current, and the speed will become constant in value when the effective e.m.f. acting in the circuit is equal to the product of the current and the total resistance, or

$$E - E_c = I_a (R_a + R_x) \qquad (114)$$

In the above equation (R_a) represents the resistance of the armature and (R_x) the resistance connected in series with the armature. If the resistance (R_x) be decreased, there must be an increase in speed, the armature current (I_a) remaining practically constant, in order that the effective e.m.f. ($E - E_c$) will be equal to the (I_aR) drop in the armature circuit. When all of the resistance (R_x) is cut out of the circuit, the effective e.m.f. is equal to the armature current (I_a) times the armature resistance, or

$$E - E_c = I_aR_a \qquad (115)$$

and

$$I_a = \frac{E - E_c}{R_a} \qquad (116)$$

The field circuit of the motor must, of course, be closed when it is being started in order that the armature conductors may cut lines of force and have a counter e.m.f. induced in them, and also that the proper torque be generated to cause the armature to rotate.

216. Starting Boxes, or Rheostats.—A resistance that can be connected in the circuit leading to the motor and so constructed that it may be slowly cut out as the motor speeds up, is called a **starting box, or starting rheostat.** A simple starting rheostat is shown in Fig. 165. The shunt field is connected directly to the supply mains and the armature is connected through the resistance (R_x). When the switch (S) is first closed, all of the resistance (R_x) should be in circuit and as the motor speeds up, it may be gradually reduced and finally all cut out.

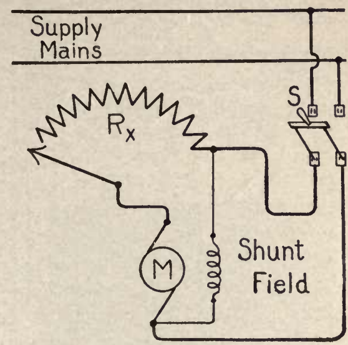


Fig. 165

217. Dead-Line Release.—In the operation of a shunt motor, as shown in Fig. 165, the armature may be destroyed by an excessive current resulting from the line becoming dead for a short time, which results in the speed of the motor decreasing immediately, and when the full line voltage is again applied the counter e.m.f., on account of the decrease in speed, will not be of sufficient value to prevent an excessive current in the armature. To prevent the above condition occurring, the starting box can be provided with what is called a **no-voltage** or **dead-line** release magnet, as shown in Fig. 166. The winding of this magnet may be connected in series with the shunt field winding, as shown in the figure; however, in adjustable speed motors, it is usually connected directly across the line. The arm (A) is moved from its initial position against the action of a coil spring and it is held in the extreme right-hand position by the magnet (M). If the current in the winding of (M) be reduced to such a value that the magnet will no longer hold the arm

(A), the arm will be released and it will return to its initial position. This will result in the armature and field circuits both being opened if the line to which the motor is connected should become dead. The arm (A) must then be moved by an attendant to its right-hand position in order to operate the motor when the line becomes alive.

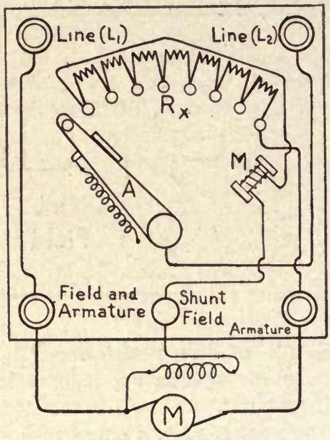


Fig. 166

218. Overload Release.—The armature of a motor may be burned out, due to an excessive current produced by the motor being overloaded, and the purpose of the **overload release** is to open the circuit or disconnect the motor from the line before the machine is injured, due to an excessive current. The overload release magnet winding carries the armature current and when this becomes excessive a piece of iron is attracted, which shorts the no-voltage release magnet and allows the arm to return to its initial position. A starting box equipped with an overload release is shown in Fig. 167.

219. Combined Starting and Field-Regulating Rheostats.—In a rheostat of this kind a field-regulating resistance is combined with a starting box. Such a rheostat as manufactured by the Cutler-Hammer Manufacturing Company is shown in Fig. 168. The movable arm consists of two parts and their outer ends move over separate sets of contacts. When the motor is being started, the arm is moved to the extreme right-hand position and the lower portion is held there by the no-voltage release magnet, while the upper portion may then be moved back over the upper row of contacts which are connected to the field-regulating resistance. A diagram of this starting box is shown in Fig. 169.

220. Speed Regulation.—The speed regulation of a motor is the change in speed from full load to no load expressed as a percentage of the full load speed, the field resistance and impressed voltage remaining constant. Thus, if the speed of a shunt motor is 1000 r.p.m. at full load and 1050 r.p.m. at no load, its speed regulation is

$$\frac{1050 - 1000}{1000} \times 100 = 5 \text{ per cent}$$

In order that the speed of the machine may remain constant with a change in load the field strength of the machine must be changed.

Characteristics of the Shunt Motor.—The change in torque, current, and speed that takes place as the load on a shunt motor changes is shown in Fig. 170. There is a decrease in speed with an increase in load. The current and torque both increase at about the same rate, with an increase in load, since the field strength remains practically constant.

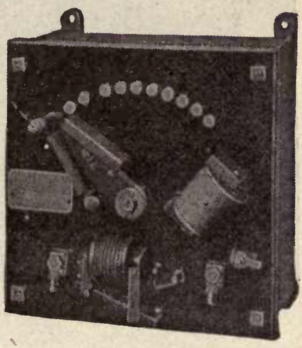


Fig. 167

221. Characteristics of the Series Motor.—The speed of a series motor will drop off a great deal more with an increase in load than in the case of a shunt motor because there is an increase in field strength with an increase in load. Care should be taken in the operation of series motors to see that their load never drops to zero while they are connected to the source of energy, as their speed will become excessive or they will "race." If the iron of the magnetic circuit is worked near saturation or above the "knee" of the magnetization curve, the change in speed will not be as great as it is when the iron is not so near saturation. The increase in torque with an increase in load must necessarily be greater than in the case of a shunt motor, as the decrease in speed is greater. The torque is proportional to the armature current and field strength, and the field strength varies almost directly as the armature current, the series winding and armature being connected in series. If the iron is below the knee of the magnetization curve the torque will then vary practically as the square of the current; when, however, the magnetic circuit is worked above the knee of the curve, the variation in torque due to a change in current becomes less. The change in torque, current, and speed that takes place as the load on a series motor changes, is shown in Fig. 171.

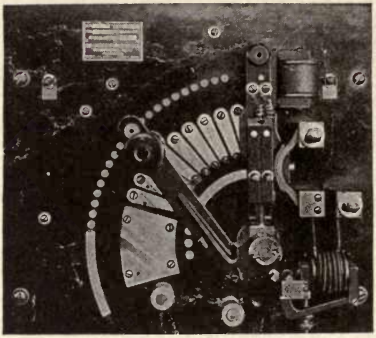


Fig. 168

222. Characteristics of the Compound Motor. When the compound motor is connected so its two fields aid each other, its characteristics are between those of the shunt and the series motor. If the magnetizing action of the series field opposes that of the shunt field, the speed remains nearer constant with an increase in load than it does for a shunt motor. The torque does not need to increase so rapidly as a result of the speed remaining constant, as it does in the case of a shunt motor. The armature current must increase, since the field strength is decreased in order that the same torque be produced in the case of a shunt and differential compound motor.

223. Adaptability of Different Motors.—There are three different classes of work to be performed by motors, each requiring a different relation between motor torque, and speed. Examples of these classes are as follows:

(a) When a motor is used on a crane or an elevator it must be capable of developing a constant torque at a variable speed, since it is desired to move a given weight at different speeds.

(b) In some classes of work, such as the operation of a motor used in driving generators at a constant speed, the motor will be subjected to a varying load as the output of the generator is changed, but its speed is to remain constant and hence it must be capable of developing a variable torque in order that it may carry the load.

(c) In certain classes of work the motor will be required to develop a variable torque at a variable speed. Such is the case in street-car motors. The torque required is a maximum when the car is being started and the speed a minimum, and as the speed increases the torque decreases.

Motors may then be divided into three classes, according to the character of the work to be performed, and they must develop either:

(a) Constant torque at variable speed.

(b) Variable torque at constant speed.

(c) Variable torque at variable speed.

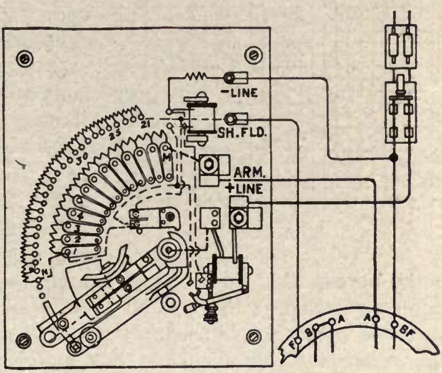


Fig. 169

The shunt and the compound motor meet the requirements in cases (a) and (b), and the series motor operated from a constant-potential line generally fulfills the requirements for case (c). The only motor that naturally meets the requirements in case (a) is the series motor operated on a constant-current circuit.

224. **Construction of Motors.**—The character of the work a motor is to perform will determine to a great extent its construction. The motor may be located in an exposed place; or it may be in a room filled with steam or dust and, as a result, it must be practically enclosed in order to provide ample protection to the windings, etc. If a motor is to be used in a street car, for example, its mechanical construction would need to be quite different from one that was to be used on an elevator, as the street-car motor would, no doubt, be subjected to more mechanical abuse than the elevator motor.

225. Railway Motors and Their Control.—There are two general methods for controlling railway motors, viz,

(a) The **rheostatic method.**

(b) The **series-parallel method** (in combination with rheostat).

(a) The connection in the case of the rheostatic method is shown diagrammatically in Fig. 172. Resistance is placed in series with the various motors and by cutting this resistance in and out of circuit, the voltage impressed upon the motor can be changed.

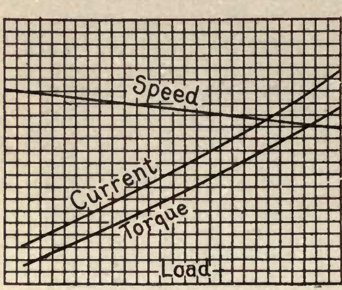


Fig. 170

(b) The series-parallel method consists first in placing two motors in series with a resistance in circuit with them, as shown in **Fig.** 173, then decreasing the resistance until the motors are connected in series directly across the line. This constitutes what is called a **running position** as there is no (I^2R) loss in a starting resistance, the entire voltage being impressed upon the two motors. The next connection places the motors in parallel and a resistance in series with them, as shown in Fig. 174. This resistance is then gradually cut out and the motors are finally operating directly across the line, which corresponds to the final running position.

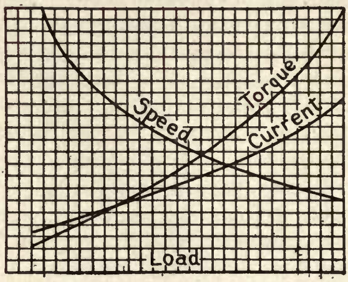


Fig. 171

The control of the switches governing the connections may be accomplished directly by hand or by an auxiliary control. In the first case the changes in connections are made by a motorman on the car platform, who moves the handle of a controller. This movement of the controller handle causes a cylinder inside the containing case to rotate. This cylinder has a number of contact arms mounted on its surface and these make contact with stationary fingers as the cylinder is rotated. A controller manufactured by the General Electric Company is shown in Fig. 175. A small handle to the right of the main controller handle, as shown in the figure, enables the motorman to reverse the direction of rotation of the motors by changing the connections. The complete wiring diagram of a street car is shown in Fig. 176.

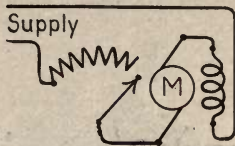


Fig. 172

When auxiliary devices are used to control the connections of the various motors the system is called a **multiple-unit control.** When this system is used, a number of cars can be coupled together and the motors on all

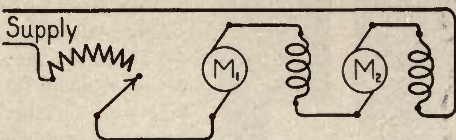


Fig. 173

of them controlled from any car. The equipment of each car consists of a **series-parallel controller,** whose electrical operation is similar to that just described, and so arranged that it is controlled from **master controllers** that are located in the motorman's cabs at the ends of the cars. The leads that run from the motor controllers to the master controllers run

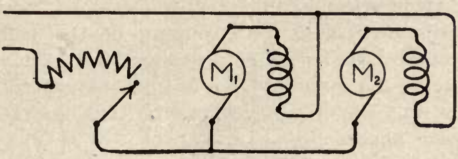


Fig. 174

the entire length of the train, the connection between cars being made by means of suitable couplers. The operation of any one of the master controllers will cause all of the motor controllers to operate in the same way and thus all of the various motor connections throughout the train are the same.

In the Sprague-General Electric Multiple-Unit Control System, the master-controller circuit takes current direct from the line and the motor controllers are operated by means of solenoids.

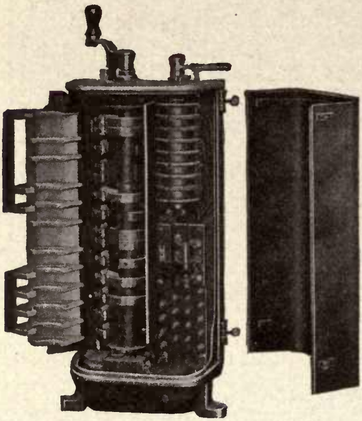


Fig. 175

In the Westinghouse Electric Company's Multiple-Unit Control System, the motor controllers are operated by compressed air, the valves controlling the air being governed by the master controllers. The master-controller circuit receives its current from a storage battery.

226. Automobile Motors.—The **series motor** is universally used for automobile work. The source of energy is a storage battery and the cells are so arranged that they can be connected in different ways, giving different voltages. This variation in voltage, together with a series-parallel combination of different sections in the series field affords an easy means of controlling the speed. Thus, if forty cells be used they may be connected in four groups of ten cells each and these groups then connected in parallel; as the speed of the motor increases, the grouping of the cells can be changed and also the series field connections. These changes in connections are governed by a suitable controller so arranged that the driver of the machine can operate it by a lever or hand wheel.

Automobile motors are very compact and usually constructed with a view to economy in weight. When they are located under the car, they are of the **enclosed type**; while if they are placed in an unexposed position, they can be of the **semi-enclosed or open type**. In some cases two motors are provided, one being attached to each wheel through

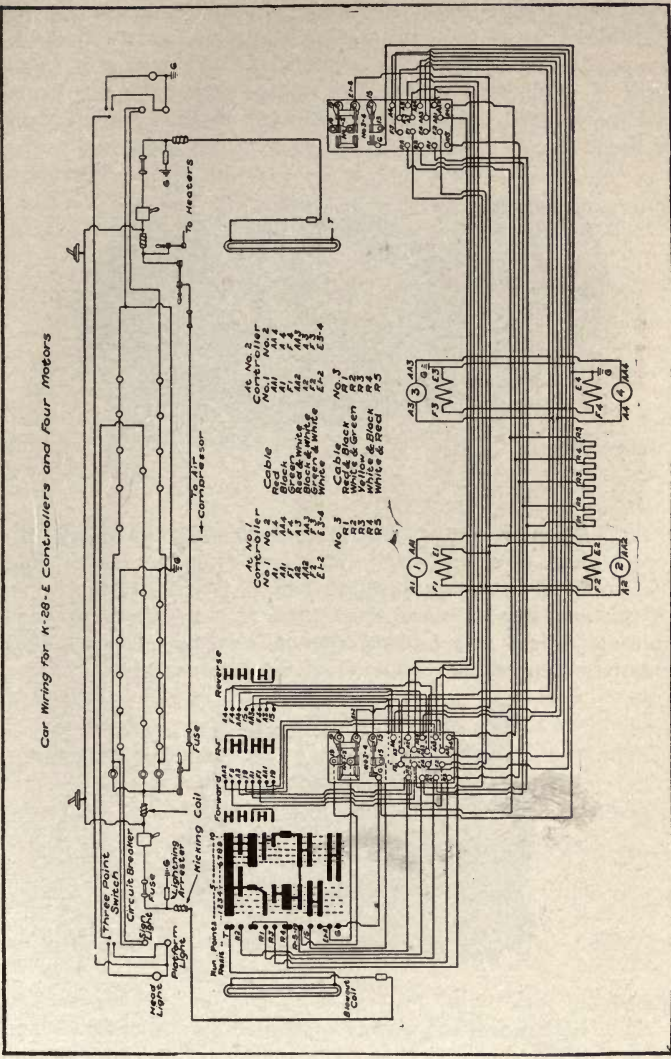

Car Wiring for K-28-E Controllers and Four Motors
Three Point Switch
Circuit Breaker
Sign Light
Fuse
Lightning Arrester
Kicking Coil
Head Light
Platform Light
To Heaters
To Air Compressor
Fuse
Blowout Coil
Forward
Reverse
Run Points
Rails
At No. 1 Controller
Cable
At No. 2 Controller
Red
Black
Green
Red & White
Black & White
Green & White
White
Red & Black
White & Green
Yellow
White & Black
White & Red

Fig. 176

a suitable transmission, the wheels turning independent of each other, while in other cases a single motor is employed, the connection to the wheels being made by means of some form of differential gear. The various parts of an automobile motor used by the Woods Electric Company are shown in Fig. 177.

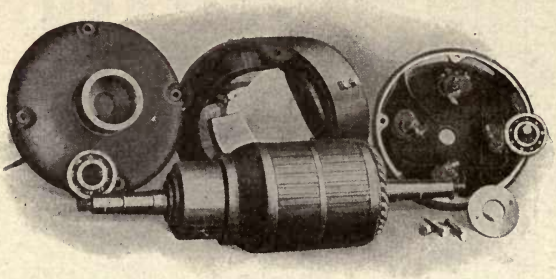


Fig. 177

227. Elevator and Crane Motors.—There are many different forms of elevator and crane motors on the market and the electrical operation of all of them is practically the same. In the majority of cases some kind of a brake is provided so that the load may be held after it is raised. These brakes may be either of the **friction** or of the **dynamic** type.

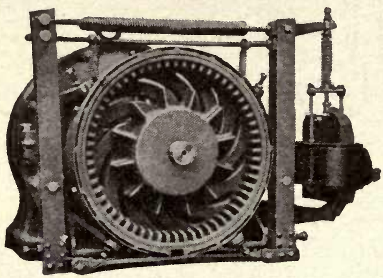


Fig. 178

The **friction brake** is usually controlled by a solenoid. When the motor is operating, the solenoid is energized and the brake does not act. If the motor is disconnected from the line and the solenoid de-energized, the brake clamps a pulley and prevents the armature turning.

In the **dynamic brake** the motor is converted into a generator and delivers current to some local circuit while it is coming to rest, which results in the motor stopping quicker than it would otherwise. The dynamic brake is usually used in combination with the friction brake, the friction brake becoming operative after the action of the dynamic brake ceases. A motor provided with a friction brake is shown in Fig. 178.

228. Efficiency of a Motor.—There are three efficiencies for a motor, namely,

(a) **Efficiency of conversion.**

(b) **Mechanical efficiency.**

(c) **Commercial efficiency.**

(a) The efficiency of conversion is the ratio of the total mechanical power developed to the total electrical power supplied (EI), or

$$\text{Efficiency of conversion} = \frac{(P + \text{stray-power losses})}{EI} \times 100 \quad (117)$$

(P in the above equation is the power available at the pulley.)

(b) The mechanical efficiency is the ratio of the mechanical power available at the pulley (P) to the total mechanical power developed, or

$$\text{Mechanical efficiency} = \frac{P}{(P + \text{stray-power losses})} \times 100 \quad (118)$$

(c) The commercial efficiency is the ratio of the available output (P) to the input (EI), or

$$\text{Commercial efficiency} = \frac{P}{EI} \times 100 \quad (119)$$

The commercial efficiency is by far the most important of the three; it includes all the losses in the machine.

229. Determining the Commercial Efficiency by Test.—The commercial efficiency of a motor can be determined by measuring the electrical input by means of a voltmeter and an ammeter, and at the same time measuring the mechanical output. When the values of these two quantities are known, they may be substituted in equation (119) and the efficiency calculated.

A satisfactory way of measuring the output of the motor is by means of a **Prony brake.** The construction and operation of this brake can best be explained by reference to Fig. 179. The brake proper consists of two parts (C) and (D) that are held together by two bolts (B_1) and (B_2). The bolts are provided with small hand wheels (H_1) and (H_2) by means of which the pressure of the brake upon the pulley can be varied. An arm (A) is attached to the brake and extends out at right angles to the shaft upon which the pulley (P) is mounted. When the brake is in use, the outer end of the arm (A) rests upon the platform of a pair of scales. The torque exerted by the armature in pound-feet is equal to the net reading of the scales in pounds multiplied by the horizontal distance (L), in feet, between the point where the arm (A) rests upon the scales and the center of the shaft. Call the scale reading (W), then

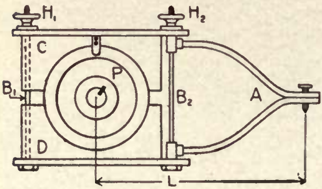


Fig. 179

$$T = W \times L \tag{120}$$

and the output in horse-power will be equal to

$$\text{h.p.} = \frac{2\pi \times T \times \text{r.p.m.}}{33\,000} \tag{121}$$

or

$$\text{h.p.} = \frac{2\pi \times W \times L \times \text{r.p.m.}}{33\,000} \tag{122}$$

The input, of course, will be in electrical units and either the output or input must be changed before equation (119) can be used in calculating the efficiency.

[Note.—The dead weight of the brake must always be subtracted from the scale reading in order to obtain the net weight or the value to be used in equation (122)].

Example.—In the test of a motor by the Prony brake method, the net scale reading was thirty pounds, the lever arm of the brake was two feet, and the motor was running at 1000 r.p.m. What was its commercial efficiency if the input was 91.0 amperes at 110 volts?

Solution.—The output can be obtained by substituting in equation (122), which gives

$$\text{h.p.} = \frac{2\pi \times 30 \times 2 \times 1000}{33\,000}$$

$$= \frac{376\,992}{33\,000} = 11.42$$

The output was then 11.42 horse-power or 8519.32 watts. The input was

$$91 \times 110 = 10\,010 \text{ watts}$$

and the efficiency was

$$\frac{8519.32}{10\,010.00} = 85.1$$

Ans. 85.1 per cent.

PROBLEMS ON DIRECT-CURRENT MOTORS

1. Calculate the torque in pound-feet, exerted by the armature of a motor wound with 300 inductors (simplex lap winding, singly re-entrant), and revolving in a four-pole magnetic field, the flux (Φ) per pole being 4 000 000 maxwells and the armature current 200 amperes.

Ans. 281.76 pound-feet.

2. If the speed of the armature in problem (1) is 1200 revolutions per minute, what is the horse-power output of the motor? Ans. 64.3 horse-power.

3. Calculate the counter electromotive force generated for the data given in problem (1) if the speed is 1200 r.p.m.

Ans. 240 volts.

4. Calculate the impressed voltage for the above motor, if the armature resistance is .035 ohms, (I_a) being 200 amperes and (E_c) 240 volts. Ans. 247 volts.

5. The speed of a motor is 1200 r.p.m. when operating under load and 1250 r.p.m. when operating without load, what is its speed regulation in per cent?

Ans. 4.17— per cent.

6. Calculate the output of a motor in horse-power when the input is 100 amperes at 110 volts and the commercial efficiency of the machine is 90 per cent.

Ans. 13.27 horse-power.

7. At what speed must a motor run in order that its output be 50 horse-power, the torque being 263.0 pound-feet?

Ans. 1000 revolutions per minute.

8. What is the average pull on each of the inductors in problem (1) if the inductors are located 8 inches from the center of the armature? Ans. 1.41— pounds.

9. The total armature resistance of a six-pole 250-volt direct-current motor, including brushes, brush contacts, etc., is .012 ohm. The winding on the armature is a simplex singly re-entrant lap winding and composed of 600 inductors. What is the flux (Φ) per pole when the machine runs at 900 r.p.m. and takes a current of 300 amperes?

Ans. 2 738 000 maxwells.

10. In testing a motor by the Prony brake method, the following data were obtained. Calculate the commercial efficiency for this particular load:

(Net) Scale reading (W) = 38.88 pounds
Length lever arm (L) = 3 feet
Speed of armature, 900 revolutions per minute
Impressed voltage, 220 volts
Current input, 75 amperes Ans. 90+ per cent.

CHAPTER XI

ARMATURES FOR DIRECT-CURRENT DYNAMOS

230. Armature.—An electrical conductor, such as a simple loop of wire, moved in a magnetic field, so that there is an e.m.f. induced in it, constitutes a simple armature. An armature composed of a single turn of wire is shown in Fig. 127. The e.m.f. induced in such an armature is unsteady—see section (178)—and in order that a practically steady e.m.f. be induced more turns of wire should be used and these various turns should be so located and connected with respect to each other that the e.m.f. between the brushes remains almost constant.

The armature of a commercial direct-current dynamo consists of three principal parts, namely,

(a) **The armature core** (sections 231 to 233 inclusive).

(b) **The commutator** (sections 234 to 236 inclusive).

(c) **The armature windings** (sections 238 to 251 inclusive).

231. Armature Cores.—The core of an armature serves a double purpose: it supports the armature winding and it conducts the magnetic flux from the face of one pole piece to another.

Since the armature core is moved relative to the magnetic field, it becomes magnetized in alternate directions, which results in a loss due to hysteresis. There will also be a loss, as explained in section (127), due to eddy currents. The hysteresis loss can be reduced to a minimum by using a grade of iron whose hysteretic constant is low, while the eddy-current loss is reduced by building the armature cores of thin soft iron or sheet steel disks insulated from each other by rust, insulating varnish, or paper. The disks are always placed in such a position with respect to the magnetic field that their plane is parallel to the magnetic flux.

Armature cores are of two general types, **smooth cores** and **slotted, or tunneled, cores.** In the smooth core type, the armature windings are placed upon the surface of the cores, while in the slotted, or tunneled, type, they are placed in slots or openings cut in the outer edge of the core stampings. The mechanical and electrical construction of the **slotted,** or tunneled, type is better than that of the smooth core

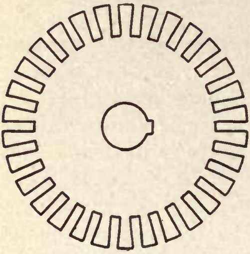


Fig. 180

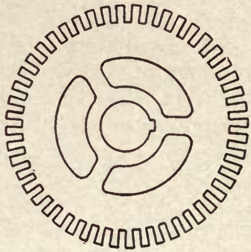


Fig. 181

type, because the length of the air gap in the magnetic circuit is reduced, and the conductors are held rigidly in place, which prevents their moving back and forth and the likelihood of injury to the insulation on them is thus greatly reduced.

232. Armature-Core Stampings.—The stampings used in the construction of armature cores assume a number of differ-

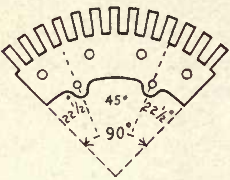


Fig. 182

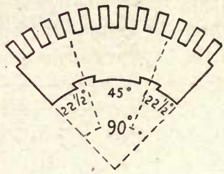


Fig. 183

ent forms, depending upon the size and kind of armature for which they are intended. In the construction of small armature cores the disks are punched in one piece, as shown in Figs. 180 and 181. The disks used in the construction of large cores are made in sections, as shown in Figs. 182 and 183, and these various sections are then mounted upon an auxiliary support called a **spider,** which may assume a number of different forms. A spider upon which the disks

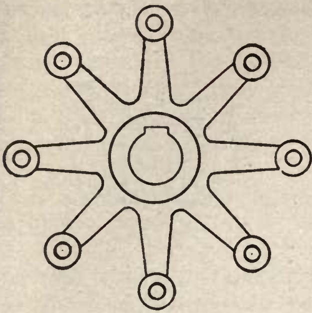


Fig. 184

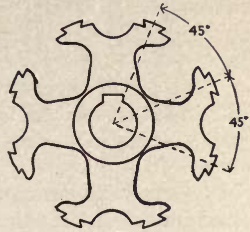


Fig. 185

shown in Fig. 182 can be mounted is shown in Fig. 184. Such a core would usually be used for a ring winding. A spider upon which the disks shown in Fig. 183 can be mounted is shown in Fig. 185. The dovetail notches or extensions on the stampings fit into dovetail extensions or notches on the spider arms. The various laminæ are held together by means of bolts (B) and end plates (P_1) and (P_2), as shown in Fig. 186.

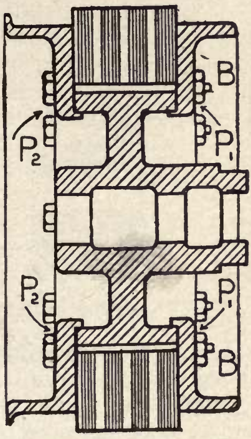


Fig. 186

233. Ventilation.—On account of the heat generated in the armature cores, due to hysteresis and eddy currents in the iron, and the (I_2R) losses in the armature conductors, some means of ventilation must be provided in order to prevent an excessive temperature rise. The means usually employed in ventilating the armature cores, especially in the larger machines is to separate the core disks at certain intervals along the axis of the core. These openings between the disks called **ventilating ducts**, can be made by placing a piece of metal on edge, as shown in Figs. 187 and 188, and fastening them to the disk. These ventilating ducts are usually spaced from 2 to 4 inches apart.

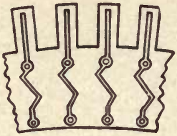


Fig. 187

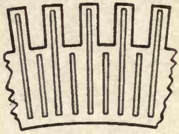


Fig. 188

234. **The Commutator.**—The commutator usually consists of a number of similar wedge-shaped pieces of copper clamped between two rings, as shown in Figs. 189 and 190, and insulated from each other by mica or other insulating material whose wearing qualities are practically the same as that of copper. Amber mica is usually used for this purpose.

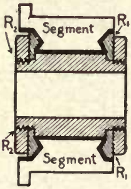


Fig. 189

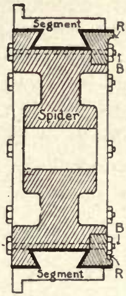


Fig. 190

The commutator shown in Fig. 189 is for a small machine, while the one shown in Fig. 190 is for a large machine.

235. **Commutator Risers.**—The various commutator segments are connected to the armature winding by means of **commutator risers.** These risers consist of pieces of metal that project radially from the end of the commutator toward the surface of the armature. In the case of small machines they are formed as a part of the commutator segment. In large machines a piece of metal is soldered or brazed into a

groove cut in the end of the commutator bar before the commutator is assembled.

236. **Construction of the Commutator.**—In constructing the commutator the segments and insulation are placed inside a heavy clamping ring and the inside of the commutator is turned down to the proper dimension. It is then clamped between its own rings (R_1) and (R_2), Fig. 189, before the first clamping ring is removed. When it is rigidly fastened in place, the outer ring may be removed and the outer surface turned down to the proper dimensions and form.

237. **Brushes and Brush Holders.**—The brushes used on dynamos are usually made from hard blocks of what is known as graphitic carbon. In some special cases, however, metal brushes are used, especially when a very low resistance brush is desired, or they may be a combination of metal and carbon. The carbon brushes have the advantage of wearing well mechanically and they are self-lubricating, giving the commutator a very smooth surface. They also have a higher resistance than the metal, or combination brushes and, as a result, reduce the tendency for sparking to occur at the commutator when the brush bridges two commutator segments connected to an element of the armature winding that may be undergoing commutation. The tendency for sparking at the commutator, due to the cause just mentioned, is not very great in low voltage machines, such as those used in electroplating and, as a result, copper or copper gauze brushes are used, thus reducing the total resistance of the circuit.

Brushes are usually mounted so that they make an angle with the surface of the commutator, although in some cases they are set radial, especially in cases where the direction of rotation of the machine is to change, as in street-car motors.

The brushes are supported in individual holders, and these holders are mounted on arms called **brush-holder** arms, which in turn are mounted on rings that are concentric with the commutator and called **rockers.** The brush holders should be so constructed that the pressure of the brush on the commutator can be adjusted and the electricity be conducted to the brush holders through a path other than that formed by the spring used in holding the brush upon the commutator.

The rockers supporting the brush-holder arms are mounted on the front bearing in small machines, and on projecting arms from the magnetic frame in large machines. The rockers are always so arranged that they can be moved by a lever or a specially arranged hand wheel, which affords a means of adjusting them to their proper position on the commutator. A brush and brush holder are shown in Fig. 191. The brushes are connected to the stationary part of the holder by means of flexible copper conductors.

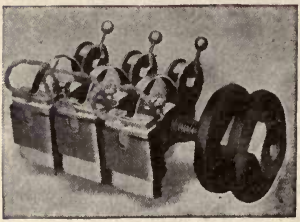


Fig. 191

238. Armature Windings.—Armature windings may be classified according to the manner in which they are placed upon the core, as follows:

(a) **Ring windings.**
(b) **Drum windings.**
(c) **Disk windings.**

(a) In ring windings the conductors are placed upon a **ring-shaped core,** the winding passing through the interior of the ring, as shown in Fig. 192. These windings are sometimes referred to as **helical windings.**

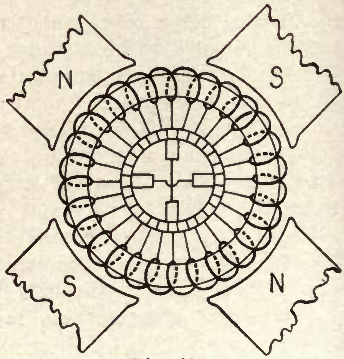


Fig. 192

(b) In drum windings the winding is placed entirely upon the surface of the drum, when smooth cores are used, or in slots or tunnels cut in the surface of the core. Such an armature winding is shown in Fig. 193.

(c) In the disk windings the cores upon which the winding is placed are shorter and larger in diameter in proportion than they are in the case of drum windings. The inductors correspond to the spokes of a wheel and are connected in a manner similar to those in the drum winding. A disk-wound armature is shown in Fig. 194.

In addition to the above classification of armature wind-

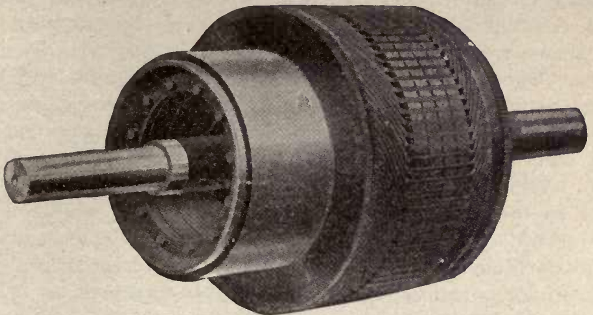


Fig. 193

ings, they may be grouped into two types, depending upon whether the winding constitutes an open or closed circuit, viz,

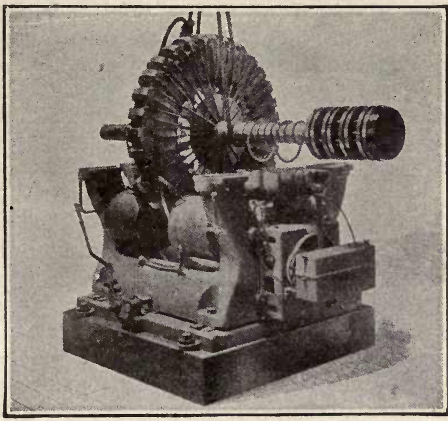


Fig. 194

(a) Closed-coil windings.

(b) Open-coil windings.

(a) The closed-coil windings have all the inductors interconnected, so that the e.m.f.'s induced in them are always effective in producing a current in the external circuit, except when a certain part of the winding is undergoing commutation. This type of winding gives a very steady current and the difficulties due to sparking are considerably less than in the open-coil type.

(b) The open-coil windings have the inductors and commutator segments so arranged that the e.m.f.'s induced in the windings are only effective in producing a current in the external circuit when the coil is undergoing commutation. This type of winding does not give as steady a current as the closed-coil type and considerable trouble is encountered in commutation due to sparking. The open-coil winding is used mostly (in the case of direct-current machines) for constant-current arc-lighting machines.

239. Armature Inductors.—That part of the armature winding in which an e.m.f. is induced is called an armature inductor. The terms conductor and inductor have been used in the same sense up to the present time, but in speaking of armature windings from now on the term armature inductor will be used. Thus, in the case of a ring winding, as shown in Fig. 192, there will be one inductor per turn, it being the outer portion of the turn, as that is the only part of the turn in which there is an e.m.f. induced. In the drum winding, as shown in Fig. 193, there will be two inductors per turn, because both sides of the turn have e.m.f.'s induced in them.

The e.m.f.'s induced in the conductors in the case of the ring winding are all acting in series and in the same direction, the inductors being connected by the part of each turn that passes through the ring. If this return portion of each turn were placed on the outside of the cores, as in the case of a drum winding, it would become an inductor and there would be an e.m.f. induced in it, but the direction of the induced e.m.f. would be such, if the two parts of the coil were under poles of the same polarity, that it would tend to neutralize the e.m.f. in the other portion of the coil or inductor. In order that the e.m.f. in the two parts of an armature coil, in the case of a drum winding, may act in series and in the same direction, they are so placed on the core that the two parts are under poles of opposite polarity.

240. Element of Armature Winding.—The element of an armature winding is that part of the winding which terminates at two consecutive commutator segments, as the winding is being traced out. In a ring winding there may be a commutator segment connected between all the turns, then an element would consist of a single turn and one inductor. The number of inductors and turns per element in the case of a ring winding is the same, and the number of conductors or turns per element will depend upon the relation of the number of commutator segments (K) and the number of inductors (Z). In the drum winding a commutator segment may be connected between all the turns and an element would consist of a single turn, or two inductors. There will always be twice as many inductors per element as there are turns in the case of drum windings.

241. Armature Coil.—In winding armatures a number of turns are usually placed together and insulated as a unit and this unit, called a **coil**, is placed upon the armature core. The method of forming and insulating the coils depends entirely upon the kind of armature they are intended for, their insulation being better and greater care is usually taken in their construction when they are to be used on a high voltage machine. In some cases the winding is placed directly on the armature core.

A coil may correspond to an element of the winding or the number of inductors per coil may be greater or less than the number of inductors per element. Thus, two or more coils may be connected in series to form an element, or taps may be taken off the coil, only part of the coil being used for an element.

242. Number of Commutator Segments.—In the case of a simple ring winding, the maximum number of commutator bars (K) that it is possible to have is the same as the number of turns or inductors on the armature cores. The number of bars may, of course, be less than the number of inductors, as each element may be composed of a number of inductors. In general, if (M) represents the number of turns in each element of the winding and (Z) the total number of inductors, the number of commutator segments will be equal to

$$K = \frac{Z}{M} \qquad (123)$$

The number (M) can have any value so long as (Z) divided by (M) gives a whole number as a quotient.

The maximum number of commutator bars that it is possible to have in a commutator to be used with a simple drum winding is equal to

$$K = \frac{Z}{2M} \qquad (124)$$

In the above equation, (M) represents the number of turns in series in each element of the winding and since there are two inductors per turn for a drum winding, (2M) is the total number of inductors per element. The number (M) can have any value, even or odd, but (2M) will always be even and, since ($K \div 2M$) must give a whole number, as in the previous case, (Z) must be even.

243. Pitch of Winding and Field Step.—It was explained in section (239) that the two inductors composing a single turn in the case of a simple drum winding had to be placed in such a position on the armature that the inductors were under poles of opposite polarity. In the case of a ring winding, as explained in section (239), the inductors can be placed under a pole of the same polarity because they are connected by a conductor that passes through the center of the ring and in which there is practically no induced e.m.f. The field step in the case of a winding is unity when the distance between one inductor and the next in order, in tracing through the winding, corresponds very nearly to the distance between the centers of adjacent unlike poles. The field step then for a simple ring winding is zero and for a simple drum winding is unity. It may be greater than these values for the two windings, but the connections required to join the ends of the inductors would be unnecessarily increased in length, which would mean an increase in the cost of copper required for the winding and an increase in the resistance of the armature.

The pitch of a winding is the distance from one inductor of the winding to the next inductor in order. This distance is usually measured in terms of the number of inductors passed over, or it may be measured in terms of the number of half coils, slots, or distance on the surface of the armature. An example would perhaps show more clearly the exact meaning of the term "pitch." Let the inductors on a certain drum-wound armature be numbered consecutively around the armature starting with number (1). If inductor number (1) is joined at the back end of the armature (end opposite the commutator) to inductor (14), and inductor (14) is joined at the front end of the armature to inductor (27), etc., the pitch of the winding would be the same at both ends and equal to 13. The front pitch is represented by the symbol (Y_f) and the back pitch by symbol (Y_b). These pitches are both positive in sign when they are measured in the same direction around the armature. If, in the above case, inductor (1) be joined to inductor (16) at the back end, and inductor (16) be joined to inductor (3) at the front end, and inductor (3) be joined to inductor (18) at the back end, etc., the front pitch would be negative and the back pitch positive. Their values would be (Y_b) $= 15$ and (Y_f) $= -13$.

The **average pitch** (Y_{av}) in any case is equal to the average of the front and the back pitches regardless of their signs. For the first winding (Y_{av}) would be $[(13 + 13) \div 2] = 13$, and for the second winding (Y_{av}) would be $[(15 + 13) \div 2] = 14$. The resultant pitch (Y_r) of any winding is the algebraic sum of the two pitches. For the first winding (Y_r) would be $(15) + (-13) = 2$.

The **commutator pitch** is the interval between the commutator segments connected to an element of the winding expressed in terms of the number of commutator segments.

244. Types of Ring Windings.—There are two types of ring windings:

(a) Spirally-wound ring windings.

(b) Series-connected wave-wound ring windings.

(a) In the spirally-wound ring armature, the winding forms a closed helix, as shown in Fig. 192. There will be (p) points on the commutator——(p) represents the number of magnet poles——where brushes may be connected to conduct the electricity to and from the armature winding. The proper location of the brushes is shown in the figure and the number of paths (b) through such a winding is equal to the number of poles (p). The current capacity of this winding will be greater than that of a bipolar machine if the same size wire is used in the winding; and the e.m.f.'s will be the same if the field strength, speed, and number of inductors in series are the same in both cases. The e.m.f. equation for such a machine is

$$E = \frac{Z \times \Phi \times p \times r.p.m.}{10^8 \times 60 \times b} \tag{125}$$

Fig. 195

The number of brushes can be made less than the number of poles by permanently connecting the various commutator segments together that are always at the same potential.

(b) In the series-connected ring winding, the various turns are connected in series. In this arrangement there will always be two paths in parallel through the armature, regardless of the number of poles. Armatures wound with this kind of a winding are called **two-circuit,** or **series-wound,** armatures. Only one set of brushes is required, but a maximum of (p ÷ 2) sets can be used.

In calculating the e.m.f. that will be developed in a winding of this kind, equation (125) can be used and (b) will always be equal to 2. The armatures of the machines are usually series wound when their output is to be at a high voltage and low current, while if the output is to be at a low voltage and large current, they are parallel wound.

245. Types of Drum Windings.—Drum windings (closed-coil) are of two kinds:

(a) Lap windings.

(b) Wave windings.

(a) A simple (simplex) **lap** winding is shown in Fig. 195 and a developed form of the same winding is shown in Fig. 196. It will be observed that the front and the back pitches differ in sign, or the winding laps back upon itself. The number of paths (b) in parallel through an armature wound with a simple (simplex) lap winding is equal to the number of poles (p). The number of sets of brushes required in order that all the inductors be effective in producing a current in the external circuit is equal to (p). Lap windings are usually used on armatures whose output is at a low voltage and large current.

(b) A **simple (simplex) wave** winding is shown in Figs. 197 and 198. It will be observed that both the front and the back pitches are of the same sign and the winding advances around the armature in the form of waves. There will be only two paths through an armature wound with a simple (simplex) wave winding regardless of the number of poles. Only two sets of brushes are required for such a winding,

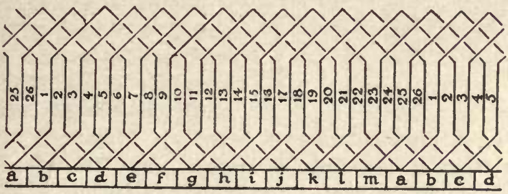


Fig. 196

but as many as (p) sets can be used. Wave windings are usually used on armatures whose output is at a high voltage and low current.

If the front and the back pitches in a wave winding be so chosen that in starting with a commutator segment and passing through an element of the winding in a clockwise direction you arrive at a segment to the right of the one from which you started, the winding is said to be **progressive**; if the segment is to the left of the one from which you started the winding is said to be **retrogressive.**

If the front and back pitches in a wave winding be so chosen that in starting with a given commutator segment and, after passing in a clockwise direction through as many elements of the winding as there are pairs of poles, you arrive at a segment to the right of the one from which you started, the winding is said to be **progressive**; and if the segments be to the left of the one from which you started, the winding is said to be **retrogressive.**

When the average pitch of a winding differs considerably from the number of inductors (Z) divided by the poles (p), the winding is called a **chord winding.**

Fig. 197

246. Multiplex Windings.—Armatures may be wound with two or more independent windings, the inductors and the commutator segments of the two windings being sandwiched between each other, as shown in Fig. 199. A winding composed of two independent windings is called a **duplex winding;** one composed of three independent windings is called a **triplex winding,** etc. The brushes must, of course, be increased in width, if the commutator segments remain the same in breadth when a **multiplex winding** is used, in order that the current may be collected from all the various windings at the same time.

247. Re-Entrancy.—In section (238) it was stated that a winding which closes upon itself is called a closed-circuit winding. Such a winding is also known as a **re-entrant winding,** because it re-enters upon itself. A winding is said to be **singly**

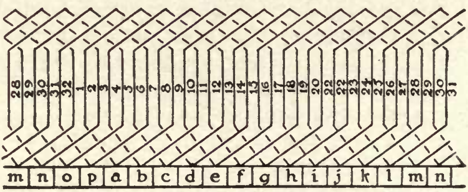


Fig. 198

re-entrant when the entire winding must be traced through before you return to the inductor from which you started. If only one-half of the winding need be traced out before the inductor from which you started is again reached, the winding is said to be **doubly re-entrant.** Likewise only one-third of the winding is passed through in a **triply re-entrant** winding before you return to the conductor from which you started, and so on for multiply re-entrant windings.

The term re-entrancy as used in the remainder of the chapter has a meaning entirely different than that just given, it being used as a factor in determining the number of circuits between positive and negative brushes. In the above definition of re-entrancy, there would be no difference between the multiplicity and the re-entrancy of a winding. A simplex or multiplex winding, however, may be singly or multiply re-entrant, and the re-entrancy in the case of a lap winding is equal to the total number of paths through the armature divided by the product of the number of poles and the multiplicity of the winding, and in the case of the wave winding it is equal to the total number of paths divided by twice the multiplicity of the winding. The winding shown in Fig. 200 is simplex doubly re-entrant, and the one shown in Fig. 199 is duplex singly re-entrant. The number of paths through the winding is the same in both cases.

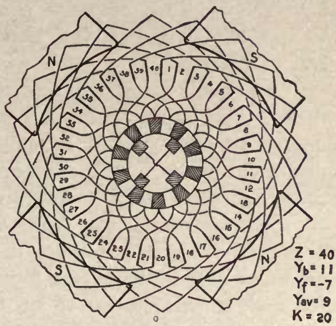


Fig. 199

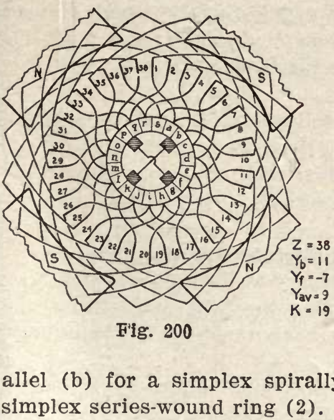


Fig. 200

248. Number of Paths Through Armature Windings.—As stated in section (244), the number of paths in parallel (b) for a simplex spirally-wound ring is (p), and for a simplex series-wound ring (2). When such windings are made multiplex, the number of paths is increased, the number in the second case being equal to the original number multiplied by the multiplicity of the winding. Thus a triplex series-wound ring winding would have (3×2) paths in parallel, and a duplex spirally-wound ring winding would have (2×p) paths in parallel. Winding tables are given in Chapter 20, which show the relation between the multiplicity, the re-entrancy, the number of paths, the number of inductors in series in each path, etc.

A closed-coil drum winding must satisfy the following conditions. No drum winding can have an **odd** number of inductors, for that would be equivalent to not having a whole number of turns. The even-numbered inductors may be regarded as the returns for the odd-numbered inductors, or *vice versâ,* and both the front and back pitches must always be **odd** in simplex windings in order that you pass from an odd to an even numbered inductor at one end of the armature and from an even to an odd numbered inductor at the other end in tracing out the winding.

The front and back pitches should be approximately equal and correspond in value to (Z ÷ p) in order that the inductors connected in series and moving under poles of opposite polarity have their e.m.f.'s additive.

249. Choice of Front and Back Pitch for a Given Number of Inductors.—(A) Lap and wave windings in general.

(a) All the elements or coils composing the winding must be similar, both mechanically and electrically, and must be arranged symmetrically with respect to each other and the armature core.

(b) In a simplex winding each inductor must be encountered only once and the winding must be re-entrant.

(c) If the winding is multiplex, each of the simplex windings composing it must fulfill condition (b).

(B) Choice of front and back pitch for lap windings.

(a) Front and back pitches must be opposite in sign.

(b) The front and back pitches must be numerically unequal, for if they were equal the coil would be short-circuited upon itself.

(c) The front and back pitches must differ by 2 in the case of a simplex lap winding; that is,

$$Y_b + Y_f = \pm 2$$

(d) The front and back pitches differ by 2 **X** in the case of a multiplex winding, (X) being the number of independent simplex windings composing the multiplex winding.

(e) The number of inductors (Z) must be an even number. If the winding is placed on a slotted armature the number of inductors must be a multiple of the number of slots. The number of slots may be even or odd.

(C) Choice of front and back pitches for wave windings.

(a) The front and back pitches must be alike in sign, and odd.

(b) The front and back pitches may be equal, or they may differ by two or any multiple of two. It is customary to make them nearly equal to $(Z \div p)$.

(c) The number of inductors (Z) for a simplex winding should comply with the equation

$$Z = p\,Y_{av} \pm 2$$

(d) And for a multiple winding:

$$Z = p\,Y_{av} \pm 2\,X$$

250. Armature Winding Table.—Tables I, J, and K in Chapter 20 give the values of the various quantities for the different types of armature windings. The symbols used in these tables represent the following quantities:

- Z = the total number of inductors on the armature
- X = the number of independent windings
- b = the total number of paths through the armature
- b_1 = the number of paths in parallel in each winding
- m = the field steps
- y = the resultant pitch
- Y_k = the commutator pitch
- Y_f = the front pitch
- Y_b = the back pitch
- K = the number of commutator segments
- g = the number of inductors per group
- G = the total number of groups
- Y_{av} = the average pitch

Note.—The tables given in Chapter 20 were made up by the use of equations given in "Design of Dynamos" by S. P. Thompson.

251. Equipotential Connections.—The e.m.f.'s generated in the various paths that are connected in parallel in any armature winding will, as a rule, differ in value due to inequalities in winding, location in magnetic field, armature out of center, etc. This difference in e.m.f. in the various paths will result in unequal currents in the different paths through the armature. In order to reduce this unbalanced condition as much as possible the points in the winding that are supposed to be at the same potential are connected by heavy copper leads, called **equipotential connections.**

CHAPTER XII

STORAGE BATTERIES, THEIR APPLICATIONS AND MANAGEMENT

252. The Storage Cell.—A storage cell, secondary cell, or accumulator, as it is variously called, is a voltaic cell in which a chemical action is first produced by an electrical current through the cell from some external source of energy, after which the cell is capable of delivering a current to an external circuit by means of a secondary or reversed chemical action. The process of storing the electrical energy by sending a current through the cell from some external source of energy is called **charging.** When the cell is producing a current in an external circuit or it is supplying energy it is said to be **discharging.**

In charging a storage cell a larger voltage is required between the terminals of the cell than the cell is capable of producing on discharge, on account of the internal resistance of the cell and an action on the surface of the plates similar to polarization in the primary cell. The (IR) drop in the cell opposes the free flow of the electricity through the cell, both on discharge and charge, and the energy the cell is capable of supplying on discharge is less than the energy input to the cell when it is being charged. No storage cell, as a result, can have an efficiency of 100 per cent, the efficiency decreasing with an increase in internal resistance. The greater the internal resistance the greater the variation in the value of the terminal voltage with a change in load.

253. Types of Storage Cells.—Storage cells may be divided into two main groups, according to the kind of materials used in the construction of the plates, viz, **lead storage cells** (sections 254 to 274 inclusive), and **non-lead storage cells** (sections 275 to 278 inclusive).

254. Lead Storage Cells.—In the construction of the lead storage battery, the cathode is made of lead peroxide (PbO_2) and the anode of spongy metallic lead. These two plates, or "grids," as they are called, are immersed in an electrolyte of dilute sulphuric acid. The lead peroxide and spongy lead are called the **active materials** of the cell. They are both converted in lead sulphate ($PbSO_4$), which is insoluble, when the cell is being discharged, and this lead sulphate is reconverted into lead peroxide and spongy lead when the cell is being charged.

The electrode of a storage cell, which is the cathode on discharge, is called the **positive grid** and the other electrode is called the **negative grid.**

255. Action of a Lead Storage Cell While Discharging.—In discharging a lead cell, the electrolyte (H_2SO_4) is split up by the current into hydrogen (H) and sulphion (SO_4). The hydrogen which is liberated at the cathode converts the lead peroxide (PbO_2) into lead oxide (PbO). The lead oxide immediately combines with a part of the electrolyte (H_2SO_4), forming lead sulphate and water. Lead sulphate ($PbSO_4$) is formed at the anode by the sulphion (SO_4), combining with the spongy lead (Pb).

The lead sulphate which is formed during the discharging process is more bulky than the active materials themselves and, as a result, there is an expansion in the plates of the cell. There is also a decrease in the density of the electrolyte on account of the absorption of the sulphion (SO_4) by the active material.

The chemical action taking place in the cell can be easily shown by the equation

Discharging (current from negative to positive grid)

$$\text{Positive grid } PbO_2 + H_2SO_4 + H_2 = 2H_2O + PbSO_4$$

$$\text{Negative grid } Pb + SO_4 = PbSO_4$$

256. Action of Storage Cell While Charging.—In charging a lead storage cell, an action takes place which is just the reverse of that described in section (255). The lead sulphate ($PbSO_4$) on one grid is converted back to lead peroxide (PbO_2), the lead sulphate ($PbSO_4$) on the other grid is converted back to spongy lead (Pb), the density of the electrolyte increases and the volume of the active material decreases. The following equations will serve to show the chemical action that takes place in the cell when it is being charged.

Charging (current from positive to negative grid)

Positive grid $PbSO_4 + 2H_2O + SO_4 = 2H_2SO_4 + PbO_2$
Negative grid $PbSO_4 + H_2 = H_2SO_4 + Pb$

257. Storage Battery Grids.—Two general processes are employed in the manufacture of storage battery grids, viz, **the Planté process and the Faure process.**

258. The Planté Process.—In the Planté process the surface of a lead plate is subjected to the action of a suitable acid which converts the surface of the plate into active material. In the first process the lead plates were exposed to the action of dilute sulphuric acid, and the action was accelerated by making the plates being formed alternately the anode and cathode of the electrolytic cell. The modern process is far superior to the old method, the formation of the active material being brought about in a much shorter time by adding a small quantity of lead dissolving acid, such as acetic or nitric acid, and increasing the area of the plates exposed to the action of the acid, by cutting grooves in their surface.

259. Faure Process.—In the Faure process the active material is manufactured in bulk and introduced by a mechanical process into openings in the lead grids. The original process, and one that is used quite extensively at the present time, consisted in mixing litharge or a mixture of litharge and red lead with dilute sulphuric acid, and placing the paste in suitable supporting frames, the combination forming the grids.

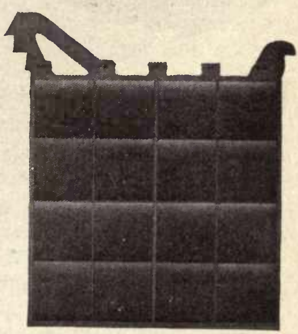


Fig. 201

260. Examples of Planté and Faure Plates.—The grids manufactured by the Gould Storage Battery Company, as shown in Fig. 201, are a good example of the modern Planté plate. Thick plates of lead of the proper dimensions are passed over rapidly revolving rolls which consist of a large number of thin disks separated from each other by thin washers. The action of these disks is such that fins of lead are raised upon the surface of the lead plates. Both surfaces of the plates are subjected to the action of the spinning rolls, but central webs and cross-ribs are left where the plate is in no way changed. The purpose of these central webs and cross-ribs is to add conductivity and strength to the plates.

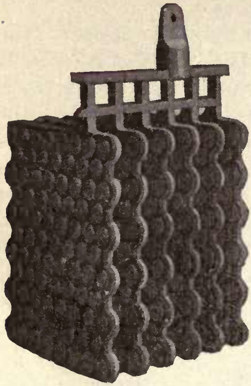


Fig. 202

The positive grid used in the stationary type of storage cell manufactured by the Electric Storage Battery Company, which are often called "chloride" cells, is shown in Fig. 202. A casting is first made of lead-antimony alloy, with numerous holes in it, and small coils of pure lead are placed in these holes. These coils of lead are then converted into active material by the Planté process.

The negative grid used in the stationary storage cell of the Electric Storage Battery Company is shown in Fig. 203. Two plates of pure lead with numerous holes in them are pressed together over a block of active material which squeezes out through the holes. While the plates are still under pressure they are riveted together. In the "exide" cell made by the Electric Storage Battery Company, the grids are cast of a lead-antimony alloy with a large number of small openings in them. The openings in the plates that are to form the positive grids are filled with a paste of red lead and dilute sulphuric acid, and the openings in the plates that are to form the negative grids are filled with a paste of litharge and dilute sulphuric acid.

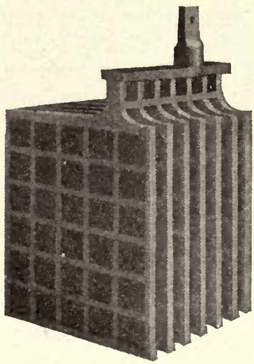


Fig. 203

261. Comparison of Planté and Faure Plates.—The Planté plates are more costly for a given output than the Faure plates. They are more bulky, heavier, and more easily injured by impurities in the electrolyte. They are, however, able to stand a more rapid charging and discharging without injury. They do not lose their active material as easily as the Faure plates. They are in general more durable and dependable than the pasted plates and have longer life. The Faure plates are cheap, light, and occupy a small space. They are not so easily damaged by impurities in the electrolyte; but their efficiency is less than the Planté plates for higher rates of discharge.

262. Capacity of a Storage Cell.—The unit in which the capacity of a storage battery is measured is the **ampere-hour,** and the capacity is usually based upon the eight-hour discharge rate. As an example, a 200-ampere-hour battery would deliver a current of 25 amperes continuously for 8 hours. Theoretically this same battery should deliver a current of 50 amperes for 4 hours, or a current of 12 amperes for 16 hours; but as a matter of fact the ampere-hour capacity of a battery decreases with an increase in the rate of discharge. The change in the capacity of a battery due to a change in the discharge rate is given in Table No. IX. The 8-hour rate is taken as a basis in figuring the output at other rates.

TABLE NO. IX

PERCENTAGE VARIATION OF THE CAPACITY OF A STORAGE BATTERY DUE TO A CHANGE IN THE RATE OF DISCHARGE

Rate in hours	Percentage of capacity at 8-hour rate		
	Plante	Faure	Plante (+) Faure (—)
8	100.0	100.0	100.0
7	99.0	96.0	97.0
6	96.5	92.0	93.5
5	93.0	86.0	89.0
4	88.0	80.0	83.0
3	80.0	72.0	75.0
2	70.0	61.0	65.0
1	55.0	40.0	50.0

263. The Electrolyte.—The electrolyte should be made of sulphuric acid made of sulphur and not from pyrites. Acid made from pyrites contains some iron and the presence of this metal in the electrolyte is injurious to the plates. It is not essential that the electrolyte be chemically pure, but it should not contain any chlorine, nitrates, arsenic, mercury, copper, platinum, nitric or acetic acid. The electrolyte should always be purchased from a very reliable chemical company that will guarantee its being free from impurities which will be injurious to the plates in the storage battery.

The acid may be purchased diluted until the specific gravity is of the desired value for immediate use in the cell. In some cases, however, it may be desirable to purchase the acid and reduce its specific gravity at the point where it is to be used. Only distilled or rain water should be used in diluting the acid and the **acid should always be poured into the water.** There will be considerable heat liberated and the solution should be allowed to cool before a determination of the specific gravity is made as there is quite a change in the specific gravity due to a change in the temperature of the electrolyte. The density of the acid to use will of course depend upon the kind of cell it is to be used in, the ampere-hour capacity of the cell, its rate of discharge and charge, etc. The density that will give the best results for any particular cell is, in the majority of cases, specified by the makers.

264. Density and the Hydrometer.—The density of any substance is the ratio of the weights of equal volumes of the substance and water. Thus, if the specific gravity of a certain quantity of sulphuric acid is 1.25, it means that a certain volume of the acid will weigh 1.25 times as much as the same volume of pure water.


Fig. 204

The hydrometer is an instrument for measuring the density of liquid. It is placed in the liquid and is so constructed that a portion of it projects above the surface of the liquid. The amount projecting will vary with the density of the liquid and a suitable scale attached or marked on the upwardly projecting portion will afford a means of determining the density of the liquid direct from the scale reading. The reading is taken at the surface of the liquid. The outline of a hydrometer is shown in Fig. 204. A small quantity of lead shot in the lower portion gives the instrument the required weight and serves to hold it always in an upright position.

265. Containing Vessel and Separators.—There are a number of different kinds of containing vessels for the plates and electrolyte of a storage cell, and perhaps the most important of these are those made of rubber, glass, and lead-lined wooden tanks. The rubber containing vessel is used in the construction of portable cells because it will stand more abuse than glass and is much lighter. Glass containing vessels are used for stationary cells of moderate capacity. The lead-lined wooden tanks are used for very large cells as they are stronger than either the glass or the rubber and the increase in weight makes no great difference.

When the plates are placed in the containing vessels, they are positive and negative alternately. This results in adjacent plates being of opposite polarity and some means must be provided for separating them. Perforated rubber sheets are used in the smaller cells, rubber sheets and thin sheets of porous wood in medium size cells, and glass rods in the larger cells. The interior of a cell is shown in Fig. 205.

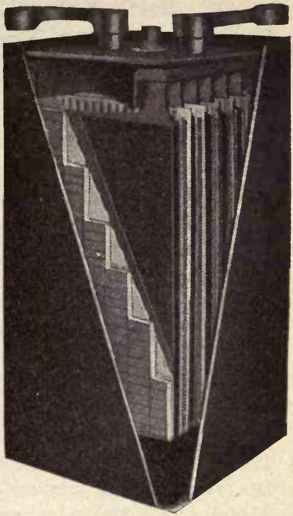


Fig. 205

266. Sulphation.—In the section describing the chemical action of the storage battery, it was mentioned that lead sulphate was formed when the cell was discharged. This lead sulphate is insoluble in sulphuric acid and occupies a larger volume than the pure lead or lead peroxide which forms it, and it is a non-conductor. In discharging a storage battery, it should not be allowed to go beyond a point where a small part of the active material is converted into lead sulphate. If the battery be over discharged there will be an excessive amount of the sulphate formed or as it is termed, an **oversulphation.**

The presence of the excessive amount of sulphate results in the surface of the plates being covered with white crystals and the pores of the plates are closed up due to the increase in volume. The surface of the active material exposed is, as a result, decreased due to the presence of the crystals, and the increase in volume will cause the active material to be loosened from the grid, or it may result in the plate being bent out of shape, which will result, in some cases, in the plates being fractured and the active material falling to the bottom of the cell as sediment. The distortion of the plates is known as **buckling.** A high discharge rate results in a greater expansion than a low rate and the active material is more likely to fall away when the battery is being discharged at a high rate than it is when discharged at a low rate.

267. Battery Troubles and Their Remedies.—The following troubles are perhaps the most important ones encountered in the operation of a storage battery:

(A) Loss of capacity.
(B) Loss of voltage.
(C) Corrosion of electrodes.
(D) Buckling of plates.
(E) Shedding active material.

268. (A) Loss of Capacity.—The loss of capacity may be due to any one or all of the following causes: **(a)** sulphation; **(b)** loss of active material; **(c)** loss of electrolyte; **(d)** sulphate between grid and the active material; and **(e)** contraction of active material on spongy lead plate.

(a) The causes of sulphation have already been discussed but the means of treating sulphated plates will be given here. To remove the sulphate, charge the battery at as high a rate as possible without causing the temperature of the cell to exceed 110° Fahrenheit until the plates gas very freely, then reduce the rate to the normal 8-hour rate and continue until the plates again begin to gas. Then reduce to half the 8-hour rate and continue until the plates gas. Now give the battery a partial discharge and then recharge as just described. This cycle of operations may have to be repeated a number of times before all the sulphate is removed.

(b) Loss of active material is usually due to the plates not being worked under normal conditions; if this is not the case, the plates are poorly designed. This loss is due chiefly to rapid charge and discharge, sulphation, and a long overcharge.

(c) Loss of electrolyte due to evaporation may cause the surface of the liquid to fall below the upper edge of the plates. The remedy is obvious.

(d) In the Faure type of plates, sulphate may form between the active material and the supporting grid, which greatly increases the electrical resistance of the cell and decreases the area of the active material.

(e) The active material on the spongy-lead electrode will contract and such shrinkage will close up the pores and greatly reduce the active surface. There are methods of preventing this contraction in use by several companies. If you think your battery trouble is due to this cause, it would be best for you to get advice from the manufacturers of the battery.

269. **(B) Loss of Voltage.**—The causes of loss in voltage are the same as those resulting in a loss of capacity and the treatment of the cell for the two conditions is identical.

270. **(C) Corrosion of Plates.**—The corrosion of the plates is usually due to the presence of some injurious impurities in the electrolyte and the only remedy is to change the electrolyte.

271. **(D) Buckling of Plates.**—Any condition of operation of the cell which will result in an unequal chemical action over the surface of the plates will result in an unequal expansion of the active material and hence, a tendency for the plate to expand more in some spots than others. These stresses which are set up in the plates relieve themselves by changing the form of the plates. Buckling is usually due to improper design and cannot be overcome except by reconstruction.

272. **(E) Shedding of Active Material.**—When the active material on the plates drops off more rapidly than it should—which is indicated by the rapid accumulation of sediment in the bottom of the cell—the cell should be worked at a low rate of discharge, never being discharged below 1.75 volts and never being charged above 2.4 volts.

273. **Management of a Storage Battery.**—There are a few important rules that one should always bear in mind in the care of a lead storage battery.

(a) Always use a pure electrolyte.

(b) Never allow the surface of the electrolyte to fall below the upper edge of the plates.

(c) Always maintain the specific gravity at the value specified by the manufacturers.

(d) Keep cells well cleaned, never allow sediment to rise until it is in contact with the lower edge of the plates.

(e) Keep all separators in place so that there is no danger of the plates coming in contact with each other and shorting the cell.

(f) Keep cells well insulated by placing them in trays that are supported on insulators.

(g) Inspect all cells occasionally for leaks in the containing vessel and either replace the broken vessel by a new one or repair it immediately.

(h) Always charge the battery as soon as possible after discharge.

(i) Never overcharge the battery or after the negative plates begin to gas, except as stated in section (268).

(j) Never allow the battery to discharge below 1.75 volts at the normal rate of discharge and 1.6 volts when discharging at the 1-hour rate.

(k) Watch the plates for signs of sulphation and if any sulphate appears, treat them immediately as described in section (268).

(l) Always keep the temperature of the battery below 110° Fahrenheit.

(m) Give the battery a prolonged over-charge occasionally until free gassing of the negative plate has continued for one hour.

274. To Put a Cell Out of Service.—When a cell is to be out of service for several months or for an indefinite period, it can be treated as follows and will then need no attention until it is desired to be used again. Fully charge the cell, then discharge it for about two hours at the normal rate. After the cell has been discharged, draw off the electrolyte and fill the vessel with distilled water. Now again discharge the cell at the normal rate until its terminals must be shorted to produce the discharge current. Pour out the water and again fill the cells, allowing them to stand for a day or so when this water should be drawn off and the plates allowed to dry. To put the cell back in service, the electrolyte should be placed in the cell and the cell should be given a prolonged over-charge.

275. Non-Lead Storage Cells.—Almost any primary cell may be made to act more or less as a secondary cell; as, for example, the gravity cell may be charged by passing a current through it opposite to the direction the current passes through the cell on discharge. Quite a number of cells have been devised in which metals other than lead is used for one or both of the plates. Reynier made a cell in which the negative plate was composed of zinc instead of lead, and this zinc was converted into zinc sulphate when the cell was discharging, which dissolved in the electrolyte. The electromotive force of this cell was considerably higher than that of the ordinary lead cell and it was quite a bit lighter, since for the storage of a given amount of energy the weight of zinc required is much less than that of the equivalent lead. This cell, however, is not very satisfactory in operation, since there are trees of zinc formed on the negative plate during the process of charging, and these trees are likely to extend out from the negative plate a sufficient distance to short-circuit the cell. There is also a difference in the density of the electrolyte at the top and the bottom of the cell, which results in the action on the plates not being uniform. This difficulty was overcome to a certain extent by placing the plates in a horizontal instead of in a vertical position. Where the plates are horizontal, however, there is an accumulation of the liberated gases upon the surface of the plates and, as a result, an increase in the internal resistance of the cell.

Waddell and Entz constructed a storage cell in which copper and zinc are used as the plates and the electrolyte is an alkali solution. When the cell is discharged, the positive plate consists of porous copper and on charging, the electrolyte is decomposed, metallic zinc is deposited on the negative plate, the porous copper forming the positive plate is oxidized, and the liquid forming the electrolyte is converted into a solution of caustic potash. The electromotive force of this cell is very low, it being only about .7 volt and, as a result, approximately three times as many cells must be used to give a given voltage as would be required if the lead cells were used. This is a very serious objection to this particular cell or to any other low voltage cell.

276. Edison Storage Battery.—In the Edison battery the active materials are oxides of nickel and iron, respectively, in the positive and the negative electrodes, the electrolyte being a solution of caustic potash in water. The retaining vessels for these cells are made from sheet steel, their walls being corrugated to add strength with a minimum weight. The completed can is nickel-plated, which protects the steel from rust and at the same time adds to the appearance of the cell. There are a number of different types of Edison cells on the market, but they differ only in the number of plates they contain. Each positive plate consists of a grid of nickel-plated steel holding 30 tubes filled with the active material, in two rows of 15 tubes each, as shown in Fig. 206. The tubes are made of very thin sheet steel, perforated and nickel-plated. Each tube is reinforced and protected by small ferrules, eight in number. These ferrules prevent expansion and thereby retain perfect internal contact with the active material at all times. The active material in the tubes is interspersed with thin layers of pure metallic nickel in the form of leaves or flakes. The pure nickel flake that is used is manufactured by a special electrochemical process.

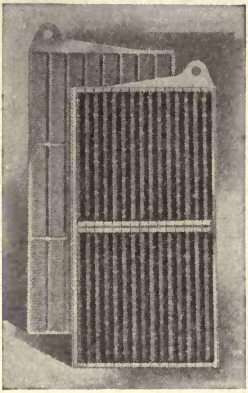


Fig. 206

Each negative plate comprises 24 flat rectangular pockets supported in three horizontal rows in nickel-plated steel grids, as shown in Fig. 207. The pockets are made of thin nickel-plated steel, perforated with fine holes, each pocket being filled with an oxide of iron very similar to what is called iron rust. In the construction of the negative plate each pocket is subjected to a very high pressure, so that it becomes practically integral with the supporting grid.

The positive and the negative plates are hung alternately on two connecting rods, the positive plates being electrically connected to one rod and the negative plates to the other. The plates are properly distanced on these rods by nickel-plated steel spacing washers, and are held firmly in place and contact by nuts screwed on both ends. In assembling the plates a specially shaped lug is placed in the center of each of the connecting rods, as shown in Fig. 207. These rods project upward and are of sufficient length to protrude through openings in the top of the containing can, thus forming the terminals of the cell. There is always one more negative plate in the Edison cell than there are positive, just as there is in the lead cell, which results in both outside plates being negative. Special insulators are used in separating the plates and preventing them from coming into contact with the containing can.

277. Chemistry of the Edison Storage Battery.—Starting with the oxide of iron in the negative, green nickel hydrate in the positive, and potassium hydrate in solution, the first charging of a cell reduces the iron oxide to metallic iron while converting the nickel hydrate to a very high oxide, black in color. On discharge, the metallic iron goes back to iron oxide and the high nickel oxide goes to a lower oxide but not to its original form of green hydrate. On every cycle thereafter, the negative charges to metallic iron and discharges to iron oxide, while the positive charges to a high nickel oxide. Current passing in either direction (charge or discharge) decomposes the potassium hydrate of the electrolyte, and the oxidation and reductions at the electrodes are brought about by the action of its elements. An amount of potassium hydrate equal to that decomposed is always re-formed at one of the electrodes by a secondary chemical reaction, and consequently there is none of it lost and its density remains constant.

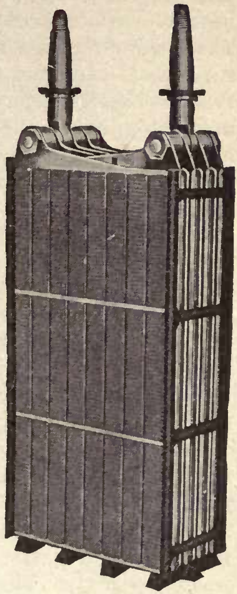


Fig. 207

The eventual result of charging, therefore, is a transference of oxygen from the iron to the nickel electrode, and that of discharging is a transference back again. This is why the "Edison" is sometimes called an **oxygen lift cell.**

When both electrodes become fully charged, the elements of the decomposed potassium hydrate can no longer act on them, but instead they react to produce hydrogen and oxygen—the elements of water which are given off as a gas.

Nickel plates in the positive and mercury in the negative do not take part in the chemical reaction but are used solely to bring the particles of active material into good electrical contact with the conducting support.

278. Care of an Edison Storage Battery.—Edison storage batteries are shipped in a discharged condition, and should be given a long initial charge before being put into service. The duration of this first charge should be about 15 hours at the normal rate, and it is recommended by the company that this overcharge be repeated once every two weeks for the first two months, when the battery is in constant service. If, however, the battery is not in constant service, it should be given a long charge after every 12 complete charges and discharges until five long charges have been put in. This constitutes what might be called the **forming process,** and it is advisable to repeat the long charges about every two months throughout the life of the battery.

In charging an Edison battery, the seven-hour charge at the normal rate is arbitrarily chosen as normal for the reason that a battery will retain good efficiency up to this point. This rate, however, is not fixed and may be varied at will, the highest practical output being reached on a ten-hour charge, which gives a maximum efficiency of about 30 per cent above normal rated output. Overcharging is in no way harmful, provided the temperature is not allowed to exceed 100° Fahrenheit at any time while charging. The cells must be frequently filled when they are overcharged and overcharging means a waste of energy. The evaporation must be replaced with pure distilled water, and under no circumstances use any acid. The solution should never be allowed to go below the tops of the plates, the proper height being one-half inch above the plates. It is always advisable to fill the battery before charge as in the process of charging the liquid is raised to a false level.

The electrolyte—which is a 21 per cent solution of potash (KOH)—in a battery in constant service, being charged and discharged each day, should be renewed once every eight or nine months.

279. Commercial Applications of Storage Batteries.—The following list gives the principal uses to which the storage battery may be placed:

(a) To supply energy to portable electrical apparatus.

(b) As a source of constant potential and current in electrical laboratories.

(c) As a source of energy in telephone and telegraph work.

(d) To supply energy for train-lighting.

(e) To reduce the fluctuations in the load on a generator, by operating the battery and the generator in parallel.

(f) To supply energy during certain hours when the load on a power plant is low and thus allow the generator to be shut down.

(g) To supply energy and aid the generator in carrying the maximum load (peak) which usually lasts only a few hours.

(h) To change from a high to a low voltage by charging the cells in series and discharging them in parallel, or *vice versâ*.

(i) As a means of subdividing the voltage of a main generator, enabling it to supply energy to a multi-voltage system.

(j) To supply energy for electrically driven vehicles and boats.

280. Portable Storage Batteries.—Practically all the battery companies manufacture a portable form of storage cell. These cells are usually constructed so that they will be as light and compact as possible, and mounted in a suitable containing case outside the one holding the electrolyte, which gives ample protection to the cell and affords a means of easily carrying the cell, by providing this outer case with some kind of a handle. The number of cells mounted in each outer containing case may vary depending upon the particular use to which the battery is to be placed.

The great objection to portable storage cells is their great weight and this is almost prohibitive of their general use. Portable cells are used in operating small lighting systems such as occur on automobiles and launches, in operating spark coils for gas engines, in operating small lamps and motors for various special purposes, etc.

281. Storage Batteries in Electrical Laboratories.—The storage battery is a valuable source of energy in electrical laboratories, as the regulation of the voltage and the current can be accomplished by means of the adjustment of a simple rheostat of some kind. The voltage of the battery can be changed by changing the grouping of the cells, a maximum voltage being obtained when they are all connected in series and a minimum voltage when they are all connected in parallel. When a large current is wanted at a low voltage, it can be more easily obtained and at a less expenditure of energy than if the same current were taken from a higher voltage. The connections of a charging and discharging board are shown in Fig. 209.

282. Storage Batteries in Telephone and Telegraph Work.—Storage batteries have come into general use in telephone exchanges since the introduction of what is known as the **common-battery** telephone system. In this system instead of each subscriber having a battery of two or more cells placed in his instrument, these batteries are all combined in one large battery located at the central office, and each subscriber's line is supplied with current from this main or central battery. The storage battery is preferable for this main battery for the following reasons: Lower first cost; smaller space required; lower internal resistance; more constant electromotive force; rapidity of recharge, and low cost of maintenance. Two batteries are usually placed in each exchange so that one can be on charge and held in reserve while the other battery is in use.

In telegraph work the storage battery may be used alone or in combination with small generators in supplying current to operate the telegraph instruments.

283. Storage Batteries for Train Lighting.—The simplest method of lighting a train by electricity is to install a small dynamo on the locomotive, which may be driven by a small steam engine or turbine. With this arrangement there is the objection that the cars must be illuminated by some other means when the locomotive is uncoupled. This has led to the storage-battery system of supplying energy to each car separately even though it be disconnected from the main train. The battery is so connected that it is being charged when connected to the main generator leads, provided the voltage between the generator leads is greater than the terminal voltage of the battery. When the generator voltage drops below a certain point, due to any cause, the battery discharges and the lamps continue to burn just as though the generator were operating. The connections of the battery lamps and the generator are controlled by a specially constructed switch that is automatically operated. In some cases a small generator is mounted on each car and driven by a belt that passes over a pulley on one of the axles. The generator in this system is inoperative when the car is at rest and the battery must necessarily carry the load.

284. Storage Battery and Generator in Parallel.—Often the load a generator is called upon to carry fluctuates in value and in a great many cases it is desired that the voltage between the lines remain as near constant in value as possible. With a fluctuating load there would necessarily be a change in line voltage due to a change in the value of the copper drop unless there was a change in the voltage at the generator terminals that would counteract the copper drop. By connecting a battery in parallel with the generator, as shown in Fig. 208, the battery charges when the load is light and will discharge when the load is of such a value that the voltage between the line wires is less than the battery voltage. As a result, the copper drop in the leads from the generator remains nearer constant in value and there is a smaller fluctuation in the value of the line voltage due to a change in load than there would be if no battery were used.

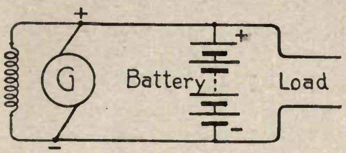


Fig. 208

285. Storage Battery to Supply Energy During Certain Hours.—In a great many generating plants, the energy the generator is called upon to supply during certain periods is so small that it would be poor economy to operate the generator on so small a load. A storage battery can be installed of ample capacity to carry the load during this period and the plant entirely shut down. The output of a generating plant is represented by curve (A), Fig. 210. It will be seen from this curve that the load carried by the generator from about 6 P.M. to 5 A.M. is very small. By installing a storage battery having the required k.w. hours' capacity, the generator can be shut down during part of the night.

286. Storage Batteries to Aid Generators in Carrying the Maximum Load.—Assuming the load on a generating plant is similar to that shown by curve (B) in Fig. 210, sufficient generator capacity must be installed to take care of the maximum load at any time without exceeding the allowable overload capacity of the generators. This would result in a large part of the equipment being practically idle during the greater portion of the day, or a part of the machinery would represent an investment from which there would be proportionally a small income. By installing a storage battery, the

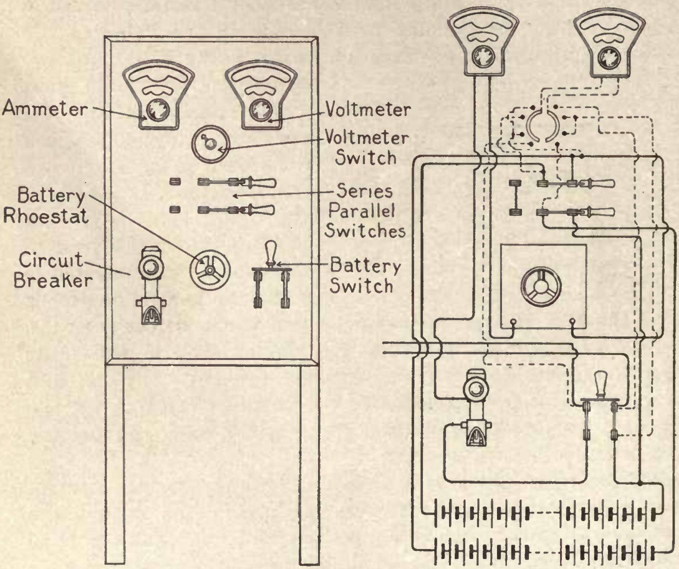


Fig. 209

generator capacity can be reduced, the battery being charged when the load on the plant is light and discharged in parallel with the generators when the load exceeds the capacity of the generators. The shaded portion of the curve in Fig. 210 represents what is called the **peak** of the load.

287. Storage Batteries Used in Changing Voltage.—The line voltage available in a great many cases is either too high or too low for a given purpose and some means must be employed for changing its value. An easy means of doing this is to use a number of storage cells and have them so arranged that they may be readily changed from any connection to another. Thus, if it is desired to reduce the voltage, the cells

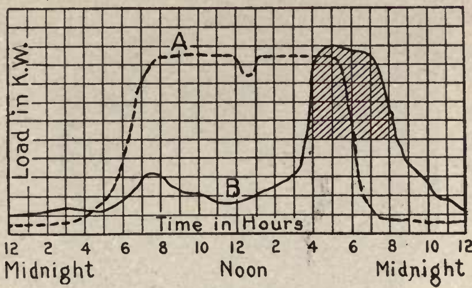


Fig. 210

of a battery may be charged in series and then connected in a number of groups and these groups in turn connected in parallel. If it is desired to raise the voltage, the cells should be charged in parallel and then connected in series for discharge.

288. Storage Batteries Used in Subdividing Voltage of a Generator.—The connections of a battery for dividing the voltage of a generator are shown in Fig. 211. Supposing the generator (G) is a 220-volt machine and it is desired to obtain energy from it at 110 volts. This can be accomplished by connecting the battery (B), which should have a voltage of about 220 volts, across the leads from the main generator and connecting a lead (N) to the center of the battery. With this connection there will be a 110-volt pressure between each outside lead and the lead (N).

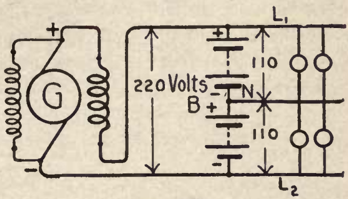


Fig. 211

289. Storage Batteries to Supply Energy for Electrically Driven Vehicles and Boats.—The storage battery is growing in favor as a means of supplying energy to vehicles, such as pleasure automobiles, heavy trucks, and street cars; and it is also quite extensively used in small pleasure boats and submarines. The battery is connected to the motors through

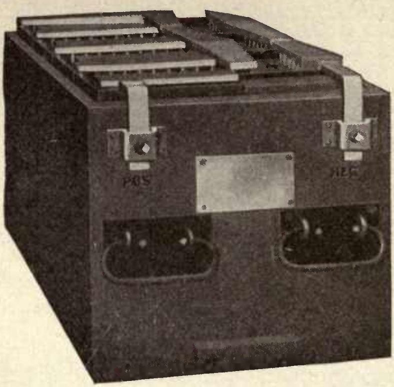


Fig. 212

specially constructed controllers, so arranged that the cells are grouped to give a low impressed voltage on starting and as the controller is advanced to successive positions, the connections of the various cells are changed, all being connected in series when the controller handle is at its final position. A tray of six cells, as used in an electric automobile, is shown in Fig. 212.

CHAPTER XIII

DISTRIBUTION AND OPERATION

290. Systems of Distribution.—The power output of an electrical generator at any instant is equal to the product of the terminal voltage of the machine and the current supplied by the machine. With a change in output there must be a change in the value of this product and necessarily a change in the value of either the current or voltage, or both. When the power output of the generator changes due to a change in the value of the current, the machine is said to be a **constant-voltage machine,** and the method employed in supplying energy to the circuit connected to the machine is called a **constant-voltage, or parallel system** of distribution. If the output of the machine changes due to a change in the terminal voltage, the current remaining constant, the method employed in supplying energy to the circuit connected to the machine is called **constant-current,** or **series system** of distribution.

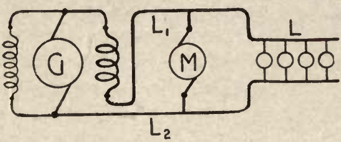


Fig. 213

291. Constant-Voltage Distribution.—In the constant-voltage, or parallel system of distribution, the various devices that are being supplied with energy are connected in parallel across the two lines leading to the terminals of the generator. A motor (M) and a number of lamps (L) are shown connected in parallel to the terminals of the generator (G), Fig. 213. With a change in the number of lamps or motors connected, there will be a change in the value of the total resistance between the two leads (L_1) and (L_2) and, as a result, a change in the value of the current output of the machine. Thus, for example, if the generator is connected to ten incandescent lamps each having a hot resistance of 220 ohms, there will be a total resistance of (220 ÷ 10) or 22 ohms between the leads, and if the voltage of the machine is 110 volts, there will be a current of 5 amperes supplied by the machine. Now if 5 of the lamps are disconnected, the resistance between the leads will be increased as the number of paths in parallel has been decreased, and it will be equal to (220 ÷ 5) or 44 ohms. The current supplied by the generator in this case will be 2.5 amperes, the voltage remaining constant. When more than ten lamps are connected, the combined resistance will be less than the resistance of the ten and, as a result, the current supplied by the generator will increase, which results in an increase in the power output, it being equal to (E × I).

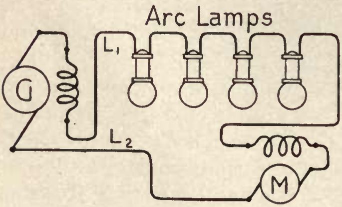


Fig. 214

292. Constant-Current Distribution.—In the constant-current, or series system of distribution, the various devices that are being supplied with energy are connected in series to the terminals of the generator. A number of arc lamps and a motor (M) are shown connected in series in Fig. 214, and the combination connected to the generator (G). If there is a change in the number of lamps or motors connected in such a circuit there will be a change in the value of the resistance of the circuit, and since the construction of the generator (G) is such that it supplies a constant current, there must be a change in the terminal voltage of the machine with a change in load. Thus, if there are ten arc lamps connected in series and there is a drop of 90 volts over each lamp, the terminal voltage of the machine must be (10×90) or 900 volts, neglecting the drop in the line wires. If five of these lamps be disconnected from the line, the circuit still being closed, the voltage required at the terminals of the machine will be (5×90) or 450 volts. The current in the circuit is the same in each case. The output of the machine in the second case then would be only one-half what it was when the ten lamps were in operation as the voltage has been reduced one-half, the current remaining constant.

293. Series-Parallel System of Distribution.—The series-parallel system of distribution is a combination of the series and parallel systems. A number of similar lamps may be connected in series and the combination then connected to the supply leads, as shown in Fig. 215.

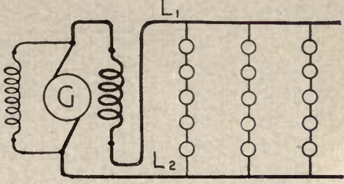


Fig. 215

The same current exists in each lamp of a given set and the drop in potential over the various lamps that may be connected in series will be proportional to their respective resistances. This system is usually used where it is desired to operate a number of lamps or motors from a line whose voltage is several times that required to operate a single lamp or motor. A good example of such an arrangement is the wiring in a street car where five similar 110-volt lamps are connected in series and the group then connected to the 550-volt source of supply, as shown in Fig. 215. If one of the lamps in any group should burn out or for some reason be removed from its socket, thus opening up the circuit, the remaining lamps of that group would also be extinguished.

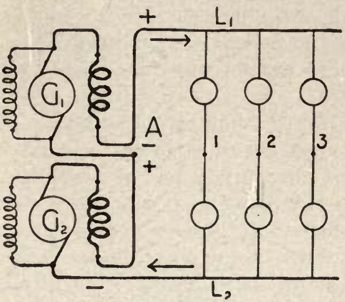


Fig. 216

294. Edison Three-Wire System of Distribution.—Two 110-volt generators, (G_1) and (G_2), are shown connected in series and supplying current to a number of groups of incandescent lamps, Fig. 216. Each group of lamps consists of two 110-volt lamps connected in series. If the two lamps of any group have the same resistance there will be the same drop in potential over each, since they both carry the same current, the drop being equal to the product of the resistance between the points considered and the current in the resistance. All of the points numbered (1), (2), (3), etc., will be at the same potential, since the drop over each of the upper lamps is the same and equal to the drop over each of the lower lamps. If these various points be connected by a conductor there will be no change in the division of the current through the various branches or lamps. The conductor connecting the points (1), (2), and (3) may be extended back and connected between the two generators, as shown in Fig. 217, provided the terminal voltage of the generators is the same, the point (A) between them will be at the same potential as the points (1), (2), and (3), and connecting all of these various points together by the lead (N), which is called the **neutral wire,** will produce no change in the division of the line current through the various branches of the load. Such an arrangement as that shown in Fig. 217, is called the **Edison three-wire system** of distribution.

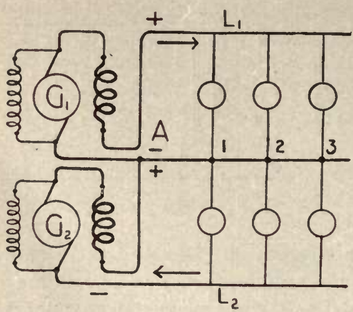


Fig. 217

There will be no current in the neutral wire when the number of lamps in the upper set is the same as the number of lamps in the lower set and the current in the leads (L_1) and (L_2) will be the same in value and in the direction indicated by the arrows in the figure. If the number of lamps in the lower group be less than the number in the upper group, there will, as a result, be a current in the neutral lead and the direction of this current will be toward the generators, or toward the left, when the polarity of the machines is the same as that shown in the figure. When the number of lamps in the upper group is less than the number in the lower group, the current in the neutral lead will be from the generators or toward the right when the polarity of the machines is the same as that indicated in the figure. The current in the neutral lead will always be equal to the difference in the value of the current in the two outside leads

(L_1) and (L_2) and its direction will be just opposite to that of the current in the outside lead that is greatest in value. When there is no current in the neutral lead, the load is said to be **balanced** and when there is a current in the neutral lead it is said to be **unbalanced.**

The neutral lead in no case will carry a current greater in value than either of the outside leads and, as a result, it need not be greater in cross-sectional area than the outside leads. Each outside wire in the Edison three-wire system need be only one-fourth as large in cross-sectional area to supply the same number of lamps with the same per cent voltage drop as would be required in the simple 110-volt system. Only one-fourth as much copper would be required in the three-wire system as would be required in the 110-volt system if no neutral lead was used, or each outside lead would represent one-eighth of the total copper required in the 110-volt system. Since the neutral lead is usually made equal in area to the outside leads, there will be three leads, each representing in weight one-eighth of the copper required for the 110-volt system, or the total copper required for the three-wire system is three-eighths of that required for the 110-volt system.

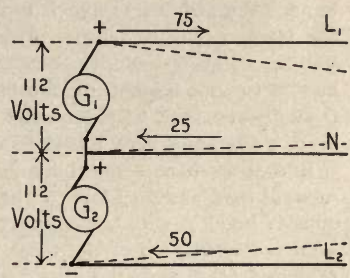


Fig. 218

If no neutral lead were used, it would be impossible to operate one lamp alone since there are two in series; but with the neutral lead, the number of lamps that may be turned on or off in either the upper or the lower groups is entirely independent of the number of lamps turned on in the other group.

295. Drop in Potential in the Neutral Wire.—If the current taken by the upper group of lamps in Fig. 217 be 75 amperes and the current taken by the lower group be 50 amperes, there will be a current of 25 amperes in the neutral lead and the direction of these currents will be that shown by the arrows in Fig. 218. Since the current in the neutral lead is toward the generators, the end connected to the load must be at a higher potential than the end connected to the generators. The load end of the upper lead (L_1) is at a lower potential than the generator end and the load end of the lower lead (L_2) is at a higher potential than the generator end. The drop in potential in these various leads is represented by the dotted lines in Fig. 218, the potential falling off along each lead in the direction of the current. Assuming the voltage of each of the generators is 112 volts and that this voltage remains constant regardless of the load, then the voltage over the upper group of lamps will be equal to 112 minus the algebraic sum of the drops in the upper lead (L_1) and the neutral; while the voltage over the lower group of lamps will be equal to 112 minus the algebraic sum of the drop in the lower lead (L_2) and the drop in the neutral. The drop in the neutral causes a decrease in the voltage over the upper group of lamps and it tends to increase the voltage over the lower group of lamps. The voltage over the smaller load will be greater than the terminal voltage of the machine connected to that load when the current in the neutral is greater than the current in the ouside lead connected to the smaller load, if the neutral and outside leads have the same resistance.

If a three-wire system be unbalanced and the fuse in the neutral lead should blow or the neutral should be opened, the outside leads remaining connected to the generators, there will be a redistribution of the total voltage, between the two leads (L_1) and (L_2), over the upper and lower groups of lamps. The drops over the two groups would bear the same relation to each other as exists between the resistances of the two groups, that is, the group containing the smaller number of lamps or having the larger resistance will have the larger drop over it. For example, if there be ten 220-ohm lamps connected in parallel and forming one group and only one 220-ohm lamp in the other group, the resistances of the two groups would be in the ratio of 22 to 220. This would result in the voltage over the single lamp being equal to $^{220}/_{242}$ of the total voltage between the outside leads when the neutral lead was open. If the total voltage between the outside leads is, say 220 volts, then the voltage over the single lamp will be 200 volts. This voltage is in excess of the value the lamp will stand and, as a result, the lamp filament will be destroyed.

296. Three-Wire Generators.—In the operation of the Edison three-wire system as described in sections (294) and (295), two generators are required, giving rise to an additional expense for machines as compared to the system using a single generator; and on this account a special type of machine has been devised which is known as a three-wire generator.

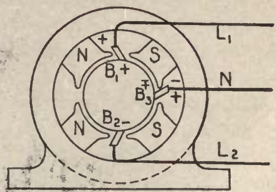


Fig. 219

The total voltage of any direct-current generator can be divided into two parts by placing a brush midway between the negative and the positive brushes of the machine. The coils short-circuited by this additional brush would be in a strong magnetic field in the ordinary machine and, as a result, there would be considerable trouble encountered in properly commutating the current. This additional brush, however, can be connected to a coil that is located in a weak magnetic field and the commutation greatly improved by the arrangement shown in Fig. 219, which consists of a four-pole field-magnet frame wound for a bipolar machine, there being two adjacent north poles and two adjacent south poles. The brushes (B_1)

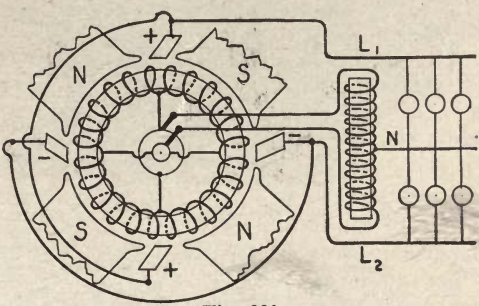


Fig. 220

and (B_2) represent the main brushes of the machine and the brush (B_3) is the one to which the neutral lead is connected. The brush (B_3) is negative with respect to the brush (B_1) and positive with respect to the brush (B_2). The magnetic flux from the two north poles or into the two south poles is not equal on account of armature reaction which crowds the flux into the forward pole. This results in the voltage between the neutral brush and one main brush being greater in value than the voltage between the neutral brush and the other main brush.

Another form of three-wire generator is shown diagrammatically in Fig. 220. The armature winding is divided into

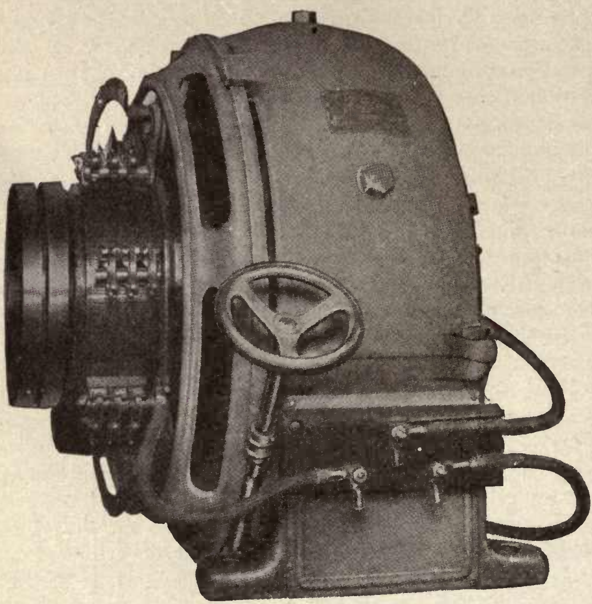


Fig. 221

the same number of parts as there are magnetic poles on the machine. The alternate division points of the armature winding are connected to one slip ring and the remaining division points to a second slip ring. A coil of low resistance and high inductance, called a **reactor**, is connected to two brushes that make continuous contact with the two slip rings, and a tap, which is taken off from the center of this coil, forms the neutral connection.

The number of slip rings may be reduced to one by placing the reactor inside of the armature and allowing it to revolve with the armature, the middle point being connected to the slip ring. Three-wire generators may be flat or over-compounded just as an ordinary generator to compensate for armature and line drops. A machine manufactured by the General Electric Company and provided with two slip rings is shown in Fig. 221.

297. **Dynamotors.**—The dynamotor is a machine having one magnetic field and two armature windings. It is a combination of generator and motor. Each of the armature windings is usually supplied with a separate commutator, the electrical connections of the two windings being independent. Either of these windings may be used as a generator or a motor. The relation of the terminal voltage of the generator side and the impressed voltage on the motor side will depend upon the relation between the number of turns in the two armature windings. If the number of inductors in the winding of the generator armature winding is one-fourth the number of inductors in the motor armature winding, then the voltage of the generator will be practically one-fourth the voltage impressed upon the motor armature. The current output of the generator, however, will be practically four times the current taken by the motor. This relation of current and voltage in the generator and the motor armatures results in there being practically the same number of ampere-turns in each armature winding when the machine is in operation, and since the current in the generator armature winding will be in the opposite direction around the armature core to what it is in the motor armature winding, there will be practically no armature reaction, the two magnetizing effects neutralizing each other.

The dynamotor in the direct-current circuit corresponds to the transformer in the alternating-current circuit, however, it is not nearly so efficient as the transformer.

A dynamotor manufactured by the Crocker Wheeler Company is shown in Fig. 222.

298. **Dynamotor as an Equalizer.**—The dynamotor is often used to equalize the difference in potential between the outside leads in a three-wire system when one side of the system is carrying a larger load than the other. When the dyna-

mometer is thus used, it is called an **equalizer**; the windings on the armatures are the same and the machine can be connected to the line as shown in Fig. 223. When the two sides of the system are balanced there will be no current in the neutral lead (N) and a small current will pass through the two armature windings of the dynamotor in series, both armatures acting as motors. If one side

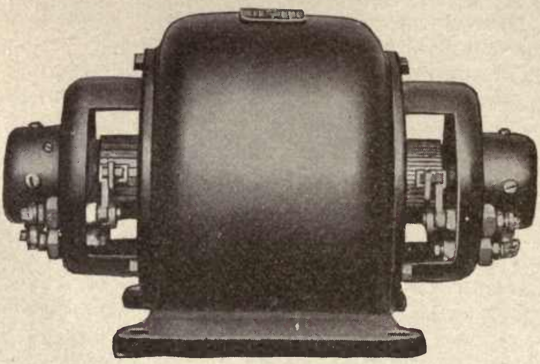


Fig. 222

of the system is carrying a larger load than the other, there will be a greater drop in the leads connected to it and, as a result, a lower voltage will exist over the larger load than exists over the smaller load. The armature winding of the balancer connected to the higher voltage will act as a motor and drive the other armature winding which will act as a generator, and the pressure of this generator will tend to raise the voltage of the more heavily loaded side. When one of the windings changes from a motor to a generator, the current in it reverses in direction. The direction of the currents in an unbalanced three-wire system that is being supplied with energy from a main generator (G) is shown in Fig. 223. The upper commutator of the balancer is connected to the generator winding of the dynamotor and is supplying current to the upper or larger load, and the lower commutator is connected to the motor winding of the dynamotor and is taking current from the lightly loaded side.

299. Motor-Generators, or Balancers.—A motor-generator in its simplest form consists of a motor mechanically connected to a generator. The number of generators connected to any motor is not limited to a single machine, but it may be any number. Thus, a motor may be electrically connected to a source of energy and be operated as any ordinary motor, its output being consumed in driving a number of generators of the same or unequal voltages. These various generators can in turn be connected and supply energy to a multi-voltage system, as shown in Fig. 224.

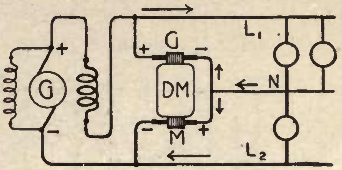


Fig. 223

A motor-generator is quite often used in connection with a three-wire system, the motor and the generator being similar machines and rigidly connected together. The combination, when so used, is called a balancer and its operation is practically the same as the dynamotor previously described. The connection of a balancer composed of two simple shunt generators to a three-wire system is shown in Fig. 225. The two machines composing the balancer have their field connections interchanged, that is, the field of one machine is connected to the terminals of the other. With this arrangement of connections, the voltage regulation is greatly improved, and is further improved by compounding the two machines forming the balancer and connecting them as shown in Fig. 226.

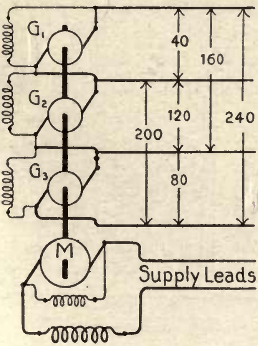


Fig. 224

300. Boosters.—When electrical energy is being distributed from a central station over long leads, there is a drop in voltage due to the resistance of the leads and, as a result, the voltage at the receiving end of the line is less than it is at the transmitting end. This loss in voltage can be compensated for by connecting in series with the line a machine called a

booster, whose action in the circuit is to produce an electrical pressure which acts in series with the main generator pressure. When the electrical pressure of the booster acts in opposition to the voltage of the main generator, it is called a **negative booster.** The booster may be driven by a motor connected to the same line the booster is connected to, or to any other line, or it may be engine-driven. There are a number of different forms of boosters but only two will be mentioned here, the **series** and the **shunt.** The connection of a series booster in a line is shown in Fig. 227. The booster (B) is driven by a compound motor (M) connected as shown in the figure. The booster itself is nothing more than a series generator in which the iron of the magnetic circuit will not be worked above the knee of the curve when the maximum current which the feeder is to carry passes through the series winding of the booster. When the magnetic circuit of the machine is worked at such a flux density, the relation between the terminal voltage of the machine and the load current is practically a straight line. Now by properly winding the machine, its terminal voltage may be made to increase or decrease with a change in current in the feeder just a sufficient amount to exactly compensate for the loss in voltage due to copper drop.

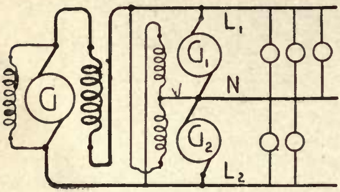


Fig. 225

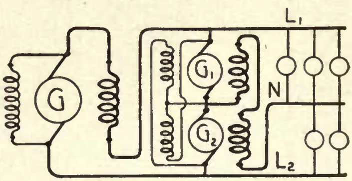


Fig. 226

In charging a storage battery, the voltage of the line from which current is to be taken in charging the battery may in some cases be less than is required to give the battery a full charge. In such a case a small shunt-wound generator (B) may be connected in series with the battery, as shown in Fig. 228. The voltage of this generator will act in series with that of the line giving a resultant voltage sufficient to charge the battery. A shunt generator when so used is called a shunt booster and it may be either motor- or engine-driven.

301. Operation of Generators and Motors for Combined Output.—The load generating stations are called upon to carry is, as a rule, not constant in value throughout the twenty-four hours of the day. If one large generating unit were installed in a station supplying a varying load, the efficiency of the plant would vary between very wide limits on account of the efficiency of a generator varying with the load it is carrying. A generator is usually designed so that it will have the maximum efficiency at its rated full load, it decreasing in value with either an increase or decrease in load. Now in order that the generating equipment in a central station be operated at its maximum efficiency, it should at all times be carrying a load something near its full capacity. In modern central stations this is accomplished by using a number of generators, instead of a single machine, their combined capacity being sufficient to carry the full load of the station and so arranged that they may all be connected to the load at the same time. The number of generators in operation may be changed as the load on the station changes and in this way each machine will operate on a load corresponding to, or near, its maximum efficiency.

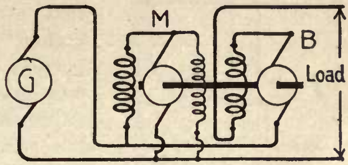


Fig. 227

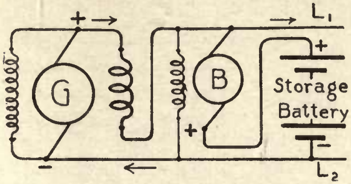


Fig. 228

For a similar reason to that mentioned above, motors are connected so that their outputs may be added, the number of motors in operation depending upon the load.

302. Shunt Generators Connected for Combined Output.—Two simple constant-voltage shunt generators (G_1) and (G_2) are shown connected in parallel, in Fig. 229, to two heavy leads (L_1) and (L_2) called **bus-bars.** The regulating rheostats (R_1) and (R_2) in the field circuits should be adjusted so that the total load connected to the bus-bars is properly divided between the two generators. If the voltage regulation of the two machines is not maintained, no serious damage will result except one machine will not carry its portion of the load, the machine of higher voltage carrying the greater portion of the load. The voltage of one machine may drop to such a value that it will change to a motor but still no serious damage will result as the shunt motor rotates in the same direction as a shunt generator, the connections of the field windings and armature leads remaining unchanged.

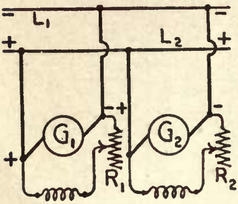


Fig. 229

Two or more shunt generators may be operated in series, as shown in Fig. 224, and supply energy to a multi-voltage system or they may supply energy to a single voltage system, they being connected in series so as to increase the total voltage between the leads.

303. Series Generators Connected for Combined Output.—Two series generators (G_1) and (G_2) are shown connected in parallel to the bus-bars (L_1) and (L_2), Fig. 230. The two machines will operate satisfactorily in parallel so long as their voltages remain the same. If, however, the voltage of one machine falls a small amount due to any cause, such as a decrease in speed of its prime mover, there will be a decrease in current supplied by it and, as a result, a decrease in its field excitation, which results in a further decrease in its voltage. This unbalanced condition continues to grow until the lower voltage machine is converted into a motor, and since the direction of rotation of a series generator is opposite to what it is when used as a motor, the results may be very serious to one or both machines.

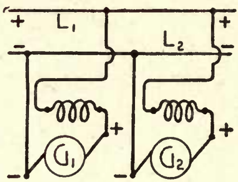


Fig. 230

The above difficulty in operating two series-wound generators in parallel can be overcome to a certain extent by allowing the armature current of one machine to pass through the field of the other. With this arrangement, a decrease in armature current of one machine causes a decrease in voltage of the other machine and, as a result, the first machine must carry its proper share of the load.

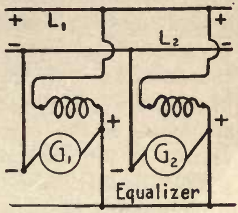


Fig. 231

The current in the various field windings may be made independent of the voltage of the different machines by connecting the junctions of the series windings and brushes by a low resistance lead, called an **equalizer**, as shown in Fig. 231. The polarity of the points connected by the equalizer should all be the same. When this connection is made, the current in the various series windings is practically the same provided they have the same resistance. It is impractical to operate series generators in parallel and, as a result, it is never done.

Series generators are operated in series in practice in direct-current, high voltage power transmission. The generators and their fields are all connected in series. Such systems are used in Europe and in the majority of cases they are constant-current systems, the current being maintained constant in value by special regulating devices which change both the speed of the prime movers and the position of the brushes.

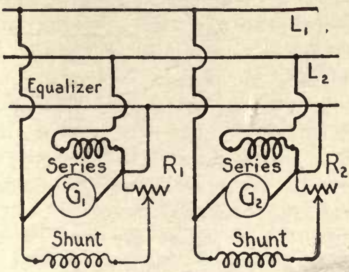


Fig. 232

304. Compound Generators in Parallel.—Compound generators may be operated in parallel very satisfactorily, the connections being made as shown in Fig. 232. It is not necessary that the capacity of the machines connected in parallel be the same but they must have the same terminal voltage at all loads and the resistance of their series fields must be to each other inversely as their capacities for the same degree of compounding in order that the total load be divided in proportion to their respective capacities as the load changes in value. When it is desired to operate two machines having different degrees of compounding, the series field of the machine of higher compounding should be shunted with a resistance, or sufficient turns in the series windings disconnected, so that its compounding will correspond to that of the machine with which it is to operate. A resistance may be connected in parallel with the series winding of one of the machines, if the currents in the series windings are not inversely as the capacities of the two machines.

305. Operation of Shunt Motors in Series and Parallel.—Any number of shunt motors will operate satisfactorily in parallel across a constant pressure, and each motor may be connected to a separate load or to the same load.

When a number of shunt motors are operated in series across a constant-pressure line, they must be rigidly connected together. If they were not rigidly connected together and the load was removed from one of the motors, it would race and rob the remaining motors of their proper share of the total voltage. It is not practical for this reason to operate shunt motors in series unless they be rigidly connected together.

306. Operation of Series Motors in Series and Parallel.—Any number of series motors may be operated in series on constant-current circuits and their operation is independent of the load any of the motors may be carrying. Any motor may be overloaded until it stops without interfering with the other motors connected to the same line, since the current in the circuit remains constant in value at all times. Series motors will operate satisfactorily in series on constant-voltage circuits provided they are rigidly connected together. An example is to be found in starting a street car when the motors are connected in series groups of two each. The speed of each motor is the same in this case, provided none of the wheels slip, and the voltage over each will be practically the same. If, however, the wheels to which one of the motors is geared slip, this motor will speed up and rob the other motor of its proper share of the line voltage and, as a result, the motor having the lower voltage impressed upon it will have its starting torque lowered.

Any number of series motors may be operated in parallel from a constant-voltage line provided their loads are not disconnected, which would result in the motor racing and no doubt destroying itself.

307. Operation of Compound Motors.—Compound motors are operated from constant-voltage lines in every case and each has its own load. The speed regulation of the compound-wound motor, when the series- and shunt-field windings are differentially connected, is better than any other type of direct-current motor.

308. Switchboard.—A switchboard is a board, of insulating material usually, upon which the indicating instruments and the switches used in connecting various electrical circuits are located. It is customary to divide a switchboard up into sections called **panels**. If a switchboard be used in connecting a number of machines to a certain load, it will be divided into what are called **generator panels** and **feeder panels**. All of the switches and instruments associated with each generator being mounted on the generator panels, and the instruments and switches associated with the feeder circuits being mounted on the feeder panels. The equipment most commonly found on a direct-current switchboard consists of voltmeters, ammeters, wattmeters, ground detectors, circuit breakers, fuses, rheostats, and switches. All of the above equipment has been described with the exception of circuit breakers, rheostats, ground detectors, and switches. These devices will be discussed in the following sections.

309. Circuit Breakers.—A circuit breaker is a switch that may be closed against the action of gravity or a spring and held in the closed position by means of a suitable latch, which in turn is controlled by one or more solenoids. A solenoid may be connected so that its winding will carry all or a definite part of the total current the contacts of the circuit breaker carry and its armature may be so adjusted that it will be drawn up and trip the latch when the current exceeds a certain value. Such a circuit breaker is called an **overload** circuit breaker.

A solenoid may be so constructed that it will trip the latch of the circuit breaker when the current in the circuit is reversed. Such a circuit breaker is called a **reverse-current** circuit breaker.

A circuit breaker in which the latch is tripped when the current falls below a certain value is called an **under-load** circuit breaker.

A fourth form of circuit breaker is one having the solenoid controlling the latch connected directly across the line and so arranged that the breaker is opened automatically when the voltage drops below a certain value. This form of circuit breaker is called a **no-voltage** circuit breaker. Various combinations of the above forms of circuit breakers may be made which will meet practically all requirements. An over-load and no-voltage circuit breaker combined is shown in Fig. 233.

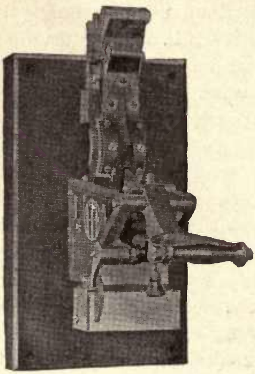


Fig. 233

310. Rheostat.—A rheostat is a resistance whose value may be varied. There are numerous forms of rheostats, their construction in a measure being determined by the particular use to which they are to be placed. A form of rheostat used in regulating the shunt-field current of generators is shown in Fig. 234. This consists of a number of small coils of wire connected in series and their junctions joined to a number of contact buttons over which a metal arm passes. One terminal of the rheostat is the arm that moves over the contact buttons and the other terminal is one of the end coils. The variation in current that may be produced by such a rheostat will depend upon the relation between the resistance of the circuit in which the rheostat is connected and its own total resistance. Such rheostats, as a rule, have rather a small current-carrying capacity.

A rheostat composed of a number of carbon plates mounted side by side is shown in Fig. 235. The resistance of this rheostat is changed by varying the pressure between the various plates of carbon between the end plates, by means of a small handle shown in the figure. The resistance of this rheostat is, as a rule, rather low, but its current-carrying capacity is quite large. It operates very satisfactorily in low voltage circuits and the variations in its resistance can be made very gradual.

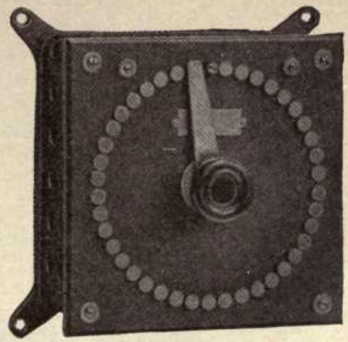


Fig. 234

Rheostats are usually controlled from the switchboards when used in adjusting the field current of machines and the control is accomplished by a small handle on the face of the board, the rheostat being usually mounted back of the board.

311. Ground Detectors.—A ground detector is an instrument used in measuring the insulation resistance between any line connected to the switchboard and ground. It is really a special form of series voltmeter marked in some cases to read directly in ohms.

312. Switches.—Switches are devices that are connected in

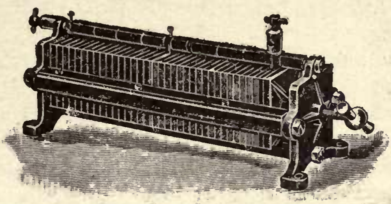


Fig. 235

a circuit to facilitate its being closed or opened. They may be single-pole, double-pole, etc., depending upon the number of circuits that are interrupted when the switch is opened. A double-pole double-throw switch is shown in Fig. 236. This switch is so constructed that the circuits are connected to it back of the board upon which it is mounted. The size of the jaws and blades of a switch will depend upon the value of the current the switch is designed to carry, and the distance between the various parts that are connected to the different leads will depend upon the voltage.

313. Instructions for Starting a Generator or Motor.—In starting a machine make sure the commutator is perfectly clean. Examine the brushes carefully to see that they are all making good contact with the commutator and that they are in their proper position, which should be indicated by a mark on the rocker arm supporting them. If there happens to be no such mark, their position must be adjusted after the machine is in operation, it being indicated by a maximum voltage in the case of a generator and a minimum speed in

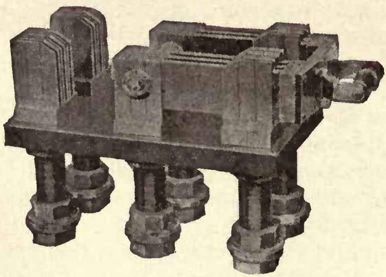
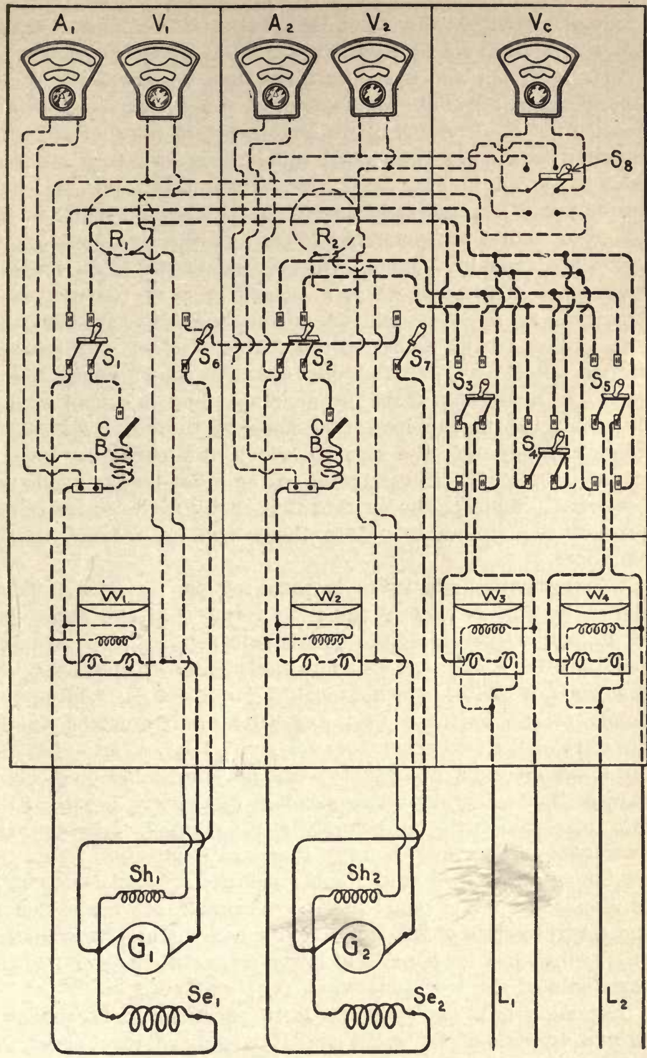


Fig. 236

the case of a motor. They are, however, usually advanced a little beyond this position in a generator and back of it in a motor in order to reduce the tendency for sparking. Examine all connections and see that all screws and bolts are tight. Fill the oil cups and see that they are supplying oil to the parts they are supposed to lubricate.

If the machine is being started for the first time, make sure that it turns over freely and that the armature is properly balanced and that it is centrally located in the magnetic field. After it has been thus inspected, the machine should be started up and its speed increased gradually when possible, with the switches all left open in the case of a generator. If the machine is being started for the first time, it should be run for a number of hours without load and the load then



A1
V1
A2
V2
Vc
S8
R1
R2
S1
S6
S2
S7
S3
S5
S4
C
B
C
B
W1
W2
W3
W4
Sh1
Sh2
G1
G2
Se1
Se2
L1
L2

Fig. 237

gradually applied, the attendant being in readiness at all times to disconnect or stop it if anything should go wrong.

314. Starting and Stopping Compound Generators that are Operating in Parallel.—A diagram of the wiring of a switchboard used in connecting two generators in parallel and to a common load or in connecting either generator to a separate load is shown in Fig. 237. The left-hand panel is the generator panel for, say generator (G_1); the middle panel is the generator panel for generator (G_2); and the right-hand panel is the feeder or load panel. On each generator panel there is mounted a wattmeter (W), a circuit breaker (CB), a main generator switch, an equalizer switch, a field-regulating rheostat (shown in the figure by the dotted circles), a voltmeter, and an ammeter. The ammeter shunt is shown connected in series with the lead from the generator and it should always be connected in the lead that goes to the terminal of the generator opposite the one to which the equalizer lead is connected. If it were connected in the other lead it would not necessarily indicate the current that really exists in the armature of the generator unless there was no current in the equalizer.

The following apparatus is mounted on the feeder panel shown in Fig. 237. Two lines (L_1) and (L_2) are connected to the central points of the double-pole double-throw switches (S_3) and (S_5), one lead of each line passing through the current coils of the two wattmeters (W_3) and (W_4). The outside points of the switches (S_3) and (S_5) are connected to the bus-bars of the two generators (G_1) and (G_2). The upper and the lower contacts of the switch (S_4) are connected to the bus-bars of the two generators and when this switch is closed the two machines will be connected in parallel, provided the terminals of the switch (S_4) that are connected when the switch is closed are of the same polarity. A voltmeter (V_c) is mounted on this panel and its terminals are connected to the central points of the small double-pole double-throw switch (S_8), which has its upper and lower contacts connected to the terminals of the two generators (G_1) and (G_2).

Assuming now one machine is in operation and connected to one or both of the loads and it is desired to connect the idle machine in parallel with the one already in operation. The two loads can be connected to one machine by closing the switches (S_3), (S_4), (S_5), and the proper generator switch. Bring the generator up to speed, close the equalizer switches (S_6) and (S_7), and adjust its shunt-field current to such a value that its terminal voltage is a little in excess of that between the bus-bar to which the machine is to be connected. This can be determined by noting the indications of the two voltmeters (V_1) and (V_2), respectively, or the voltmeter (V_c) may be thrown from one circuit to the other, by operating the switch (S_8) and its indication noted when it is connected to the two circuits. Using a single voltmeter eliminates the possibility of an error due to the two separate voltmeters not indicating the same, even though they be connected to the same pressure. When the voltage of the incoming machine has been adjusted to the proper value, the main switch may be closed and the field current adjusted to such a value that the load is divided between the two machines in proportion to their capacities. You should always be **absolutely** sure that the points of the last switch you close in connecting the machines in parallel is of the proper polarity, positive to positive and negative to negative, before the switch is closed. If the indications of the voltmeters depend upon the direction of the current in their windings, and you are sure there has been no change in the connections back of the board or at the machines, you can then close the paralleling switch when all of the voltmeters read in the proper direction.

When it is desired to disconnect a machine from the line, its voltage is lowered by reducing its shunt-field current and, as a result, it fails to carry its proper share of the load. The main generator switch should be opened when the current output of the generator has decreased to almost zero value. The equalizer switch may then be opened and the machine shut down.

CHAPTER XIV

DISEASES OF DIRECT-CURRENT DYNAMOS

315. Sparking at the Brushes Due to Fault of the Brushes.—

(1) Brushes not set diametrically opposite.

(R1a) Should have been properly set at first while at rest by counting bars, by measurement, or by use of reference marks on the commutator.

(R1b) Can be done if necessary while running by bringing the brushes on one side to the least sparking point by moving the rocker arm and then adjusting the brushes on the other side to the least sparking point by moving the rocker arm and then brush holder and then clamping.

(2) Brushes not set in neutral point.

(R2a) Move the rocker arm slowly back and foıth until the sparking stops. See (R58e).

(3) Brushes not properly trimmed.

(R3a) Brushes should be always kept properly trimmed and set. If sparking begins from this cause and dynamo cannot be shut down, bend back the brushes and cut off loose and ragged wires if metal brushes are used. Retrim as soon as possible after run is over. If there are two or more brushes in each set, they may be changed one at a time for new and properly trimmed ones during the run on any low voltage machine. See number (38). To trim, clean them from oil or dirt with benzine, soda, or potash, then file or grind to a

Note.—The list of dynamo diseases given in this chapter was taken from a large chart, suitable for framing, that is published by the Guarantee Electric Company, Chicago.

standard jig and reset carefully as at (R1a), (R1b). See (R38a) and (R38b).

(4) Brushes not in line.

(R4a) Adjust each brush of a given set until they are all in line and square with the same commutator bar, bearing evenly for their entire width, unless purposely staggered. See (R13a).

(5) Brushes not in good contact.

(R5a) Clean the commutator of all dirt, oil or grit, so that brushes touch.

(R5b) Adjust pressure by tension screws and springs until light, firm, yet even contact is made. Pressure should be about 1.25 pounds per square inch. See number (38).

316. Sparking at the Brushes Due to Fault of the Commutator or Magnetic Field.—

(6) Commutator rough, worn in grooves or ridges.

(7) Commutator not round.

(R6a and R7a) Grind down the commutator with fine sand paper (never emery in any form) laid in stock curved to fit the commutator. Polish with a soft, clean cloth.

(R6a and R7b) If too bad to grind down, turn off with a special tool and rest while turning slowly in the bearings, or remove the armature from bearings and turn off with light cuts in lathe.

Note.—Armature should have from 1/16″ to 1/8″ end motion so as to distribute wear evenly and prevent wearing in ruts or ridges. Brushes may be shifted sideways occasionally to assist in distribution of the wear. See number (31).

(8) One or more high commutator bars.

(R8a) Set the high bar down carefully with a mallet or block of wood, being careful not to bend, bruise or injure the bar and then tighten the clamping rings. If this does not remedy the fault, file, grind or turn the high bar down to the level of the other bars. The high bar may cause the brushes to jump or vibrate so as to "sing." See number (38).

(9) One or more low commutator bars.

(R9a) Grind the remainder of the commutator down to a true surface so as to remove low spots.

Note.—The insulation between the segments may be high, due to its not wearing as fast as the metal of the segments. Insulation should be turned down to level of segments to remedy this fault.

(10) Weak magnetic field.

(A) Broken circuit in field.

(R10a) Solder or repair broken connection. Rewind if the brake is inside of the winding.

(B) Short-circuit of the coils.

(R10b) Repair if external and rewind if internal.

(C) Dynamo not properly wound or without proper amount of iron.

(R10c) No remedy but to rebuild.

317. Sparking at the Brushes Caused by an Excessive Current in the Armature Due to an Overload.—

(11) Generator. **(A)** Too many lamps on the circuit (constant-potential system).

(B) Ground and leak from short-circuit on the line.

(C) Dead short-circuit on the line.

Motor. **(D)** Excessive voltage on a constant-potential circuit.

(E) Excessive amperage on a constant-current circuit.

(F) Friction. See section (321).

(G) Too great a load on the pulley. See section (321).

(R11a) Reduce the number of lamps and thus diminish the current called for.

(R11b) Test out, locate the ground and repair.

(R11c) Dead short-circuit will or should blow the safety fuse. Shut down the dynamo, locate and repair the fault. Put in new fuse before starting again. Fuse should not be inserted until the fault is corrected, as it will blow again on starting up the machine.

(R11d) Use the proper value of current for a motor and no other.

(R11e) Make sure you have the proper rheostat or controlling switch.

(R11f) Reduce the load to the proper amount for rating of the motors.

(R11g) Remedy any cause of trouble from undue friction. See section (321).

318. Sparking at the Brushes Due to Fault of the Armature.—

(12) Short-circuited coil in the armature.

(R12a) Look for copper dust, solder, or other cause for metallic contact between commutator bars and remove.

(R12b) See that the clamping rings are properly insulated from commutator bars, and from carbonized oil and copper dust or dirt which may form a short-circuit.

(R12c) Test for internal short-circuit or cross-connection; if found, reinsulate the conductor, change the connection, or rewind armature to correct.

(R12d) Examine the insulation of the brush holders for the fault. Dirt, oil, or copper dust may form a short-circuit from brush holder to rocker arm, and thus short-circuit the machine.

(13) Broken circuit in the armature.

(R13a) Bridge the break temporarily by staggering the brushes till the run is finished, then test out and repair the fault. This is only a temporary make-shift to try to stop the bar sparking during a run when dynamo cannot be shut down.

(R13b) If the dynamo can be shut down, look for broken or loose connection to the bar and repair.

(R13c) If the coil is broken inside, rewinding is the only sure remedy. The break may be bridged temporarily by hammering the disconnected bar until it makes contact across the mica to the next bar of the commutator. This remedy is of doubtful value if done. The bars must be repaired and insulation replaced again after fault is corrected.

(R13d) Solder the commutator lugs together or bridge across them with piece of heavy wire and thus cut out the broken coil. Be careful not to short-circuit a good coil in soldering, and thus cause sparking from a short-circuited coil, as in number (12).

(14) Cross-connection in the armature.

(R14a) Cross-connections may have the same effect as a short-circuit and they are to be treated as such. See number (12). Each coil should show a complete circuit with no connection to any other coils.

319. Heating of the Armature.—

(15) Overloaded or not centrally located between the poles.

(16) Short-circuit. See numbers (11), (12), (13), and (14).

(17) Broken circuit.

(18) Cross-connection.

(19) Moisture in the armature coils.

(R19a) Dry out the coils by slow heat, which may be done by sending a current through the armature regulated not to exceed the proper value. If not so bad as to cause a short-circuit, cross-connection, or too much heat, the moisture may be dried out by the heat of its own current while running.

(20) Eddy currents in the armature core.

(R20a) The iron of the core may be hotter than the coils after a short run due to a faulty armature core, which should be finely laminated and the laminæ insulated. No remedy but to rebuild.

(21) Friction.

(R21a) Hot bars and journals may affect the temperature of the armature. See section (321).

320. Heating of the Field Coils.—

(22) An excessive current in the field circuit.

(R22a) **Shunt machine.** Decrease the voltage at the terminals by reducing the speed, or increasing the resistance of the field coils by winding on more wire, or rewind them with finer wire, or put a resistance in series with the field.

(R22b) **Series machine.** Shunt a portion of the current, or otherwise decrease the current in the field windings, or take off one or more layers of wire, or rewind the fields with a coarser wire.

Note.—An excessive current may be due to a short-circuit or from moisture in the coils acting as a short-circuit. See number (24).

(23) Eddy currents in the pole pieces.

(R23a) The pole pieces may be hotter than the field coils after a short run due to faulty construction or to a fluctuating current in the latter; regulate and steady the current.

(24) Moisture in the field coils.

(R24a) The coils show a resistance lower than normal, which may be caused by a short-circuit or contact with the iron of the dynamo. Dry out the coils as in number (19). See note under (R22b).

321. **Heating of the Bearings.**—

(25) Not enough or poor quality of oil.

(R25a) Supply plenty of good clean oil and see that it feeds properly. Oil should be best quality mineral oil, filtered clean and free from grit.

Note.—Be careful not to flood the bearings so as to force oil upon the commutator, or into the insulation of the brush holders, as it will gradually char and gather copper dust and form a short-circuit. See (R12b) and (R12d).

(R25b) Vaseline, cylinder oil, or other heavy lubricant may be used if ordinary oil fails to remedy the hot box. Use till run is over, then clean up and adjust the bearings.

(26) Dirt, grit, or other foreign matter in the bearings.

(R26a) Wash out the grit by flooding the bearings with clean oil until run is over. Be careful, however, about flooding the commutator or brush holders. See note under (R25a).

(R26b) Remove the cap and clean the journals and bearings, then replace the cap and lubricate well.

(R26c) After the run is over (or if shut-down is made), remove the bearings completely, cool off naturally, and polish everything free from grit, and set up again.

(27) Rough journals or bearings.

(R27a) Smooth and polish in a lathe, removing all cuts, burs, scratches, and tool marks, then make new bearings (of babbitt or other metal) to properly fit.

(28) Journals too tight for bearings.

(R28a) Slacken the bolts in the cap, put in packing pieces till run is over, then fit to smooth bearing and easy rotation by hand (if the machine is small).

(R28b) Turn down smooth and repolish the journal, or ream or scrape the bearings until they fit properly.

(29) Bent or sprung shaft.

(R29a) Bend or turn the shaft true by careful springing or turning in lathe.

(30) Bearings out of line.

(R30a) Loosen the base of the bearings and shift them until the armature turns freely by hand with belt off and it is at the same time in the center of the polar space. Remount, bolt, and dowel-pin holes, and fit new dowels to allow new position to be kept when bolts are drawn up tight. If shaft need be raised or lowered, then pack up or trim down the foot of the bearing to allow the proper setting.

(31) End pressure of the pulley hub or shaft collars against the bearings.

(R31a) See that the foundation is level and that the armature moves freely with a small amount of end motion.

(R31b) If there is no end motion, then turn off the shoulders on the shaft or file or trim off the ends of the bearings until the necessary end motion is obtained.

(R31c) Then line up the shaft, pulley, and belt so that no end thrust is maintained on the shaft, but the armature has free end play while in motion.

(32) Too great a load or strain on the belt.

(R32a) Reduce the load so that the belt may be slackened and yet not slip. Avoid vertical belts if possible. (Vibration and flapping of belt causes lamps to flicker.)

(R32b) Use larger pulleys, wider and longer belts. Run with slack side on top to increase the adhesion and pull of belt without excessive tightening. Belt should be tightened just enough to drive the full load smoothly without vibration or flapping.

(33) Armature being not centrally located between the poles.

(R33a) Bearing may be worn out, letting the armature move out of center and should be replaced. See number (30).

(R33b) Center the armature in the polar space and adjust the bearings to the new position. See number (30).

(R33c) File out the polar space to give an equal clearance all around the armature.

(R33d) Spring the pole away from the armature and secure it in place. This will be a difficult if not an impossible job in large and rigid machines.

322. **Noise.**—

(34) The armature or pulley out of balance.

(R34a) The armature and pulley should have been properly balanced when made. Their construction may, however, be somewhat improved by mounting them on knife edges and adding weight to the light side until balanced.

(35) The armature strikes or rubs against the pole pieces.

(R35a) Bend or press down and secure any projecting wires. Secure rigidly with proper tie bands of strong wire.

(R35b) File out the pole pieces where armature strikes. See numbers (30) and (33) for possible remedies.

(36) The collars or shoulders on the shaft, hub, or web of pulley strike or rattle against the bearing.

(R36a) The bearing may be worn out and too loose and therefore rattle, new bearing needed. See numbers (30) and (33).

(37) Loose screws, bolts, or connections.

(R37a) Tighten up all the screws, bolts, and connections to firm bearing and keep them so by daily attention. The jar and movement of dynamos tends to work screwed connections loose when not held by check nuts.

(38) Singing or hissing of the brushes. See numbers (3), (4), and (5).

(R38a) Apply a little mineral oil or better yet vaseline or hold a piece of stearic acid (adamantine) candle to the commutator and then wipe off. Just a faint trace of oil or grease is all that is needed.

(R38b) Lengthen or shorten the brushes in the holder until firm yet gentle pressure is maintained free from any hum or vibration. See numbers (3), (6), (7), (8), (9), and (31).

(39) Flapping or pounding of the belts, joints, or lacing.

(R39a) Use an endless belt. If a laced belt must be used, have square joints properly laced.

(40) Slipping of the belt due to an overload.

(R40a) Tighten the belt or reduce the load. See number (32).

(41) Humming of the armature lugs or teeth as they pass the pole pieces.

(R41a) Slope the ends of the pole pieces so that the armature teeth do not pass the edges all at once.

(R41b) Decrease the magnetism of the fields or increase the magnetic capacity of the teeth.

323. Speed Too High.—

(42) The engine fails to regulate under a varying load.

(R42a) Adjust the governor to the proper regulation if possible; if not, get a better engine. The engine should regulate closely from "no load" to "full load" with the proper steam supply.

(43) Series motor takes too much current for a given load and the motor runs away. (Load on the series motor is too small.)

(A) Series motor on a constant-current circuit.

(R43a) Put in a shunt and regulate until the proper current is obtained.

(R43b) Use the proper regulator for controlling the magnetism of the field for a varying load.

(B) Series motor on a constant-potential circuit.

(R44c) Put in a resistance to cut down the current.

(R44d) Use the proper regulator or controlling switch.

(R44e) Change to an automatic speed-regulating motor.

(44) Shunt motor.

(A) Regulator or field rheostat not properly set.

(B) Voltage too high.

(R44a) Adjust the regulator or field rheostat to control the speed.

(R44b) Use the proper voltage and the proper rheostat.

324. Speed Too Low.—

(45) Same as number (42).

(R45a) Same as (R42).

(46) Overloaded.

(R46a) See (R11a) to (R11g).

(47) Short-circuit in the armature.

(R47a) See (R12a) to (R12d).

(48) Striking or rubbing of the armature on pole pieces.

(R48a) See (R35a) and (R35b).

(49) Friction.

(R49a) See section (321).

(50) Weak magnetic field.

(R50a) See (R10a), (R10b) and (R10c).

325. Motor Stops.—

(51) Too great an overload. See (D), (E), (F), and (G) under number (11).

(R51a) Open the switch, locate the trouble, and remove. Keep the switch open and the arm of the rheostat in the position "off" while locating and repairing trouble. Then close the switch and move the arm gradually to the position "on" to see if everything is correct. With a series motor, no great harm will result from motor stopping or failing to start. If it is a shunt motor on a constant-potential circuit, the armature may and probably will burn out or the fuse blow.

(52) Very excessive friction.

(R52a) Same as (R51a). See section (321).

(53) Circuit open.

(A) Safety fuse melted.

(B) Broke wire or connection.

(C) Brushes not in contact.

(D) Switch open.

(E) Current fails or is shut off from the station.

(R53a) Open the switch, locate and repair the trouble, and then put in the fuse. See (R11c).

(R53b) Open the switch, locate and repair the trouble. See (13).

(R53c) Open the switch to repair the fault. See number (3).

(R53d) Close the switch, but before doing so see that the starting resistance is in circuit.

(R53e) Open the switch, return the starting lever to the position "off," wait for the current, testing from time to time by closing the switch and moving the starting lever to the first closed-circuit position.

(54) Complete short-circuit of the field.

(R54a) Test for the fault and repair if possible. Inspect the insulation of the binding posts and brush holders. Poor insulation, oil, dirt, or copper dust may cause a short-circuit. See number (12).

(55) Complete short-circuit of armature.

(R55a) Same as (R54a).

(56) Complete short-circuit of switch.

(R56a) Same as (R54a).

326. Motor Runs Backward or Against the Brushes.—

(57) Wrong connections within the motor.

(R57a) Connect up properly, referring to the proper diagram. If proper diagram is not to be had, try reversing the connections to the brush holders. Other changes may be made until proper connections are found for rotation desired, then connect up permanently.

327. Dynamo Fails to Generate.—

(58) Reversed residual magnetism.

(A) Reversed current in the field coils.

(R58a) Send a current from another machine or from a battery through the field coils in the proper direction to correct the fault. Polarity may be tested by a compass needle. If the connections of the windings are not known, try one and test; if not correct, reverse connections, try again, and test.

(B) Reversed connections.

(R58b) Connect up properly for rotation desired, referring to the proper diagram of the connections. See that connections for series coils (in compound dynamo) are properly made as well as those for the shunt coils. See number (57).

(C) Earth's magnetism.

(R58c) Same as (R58a).

(D) Proximity of another dynamo.

(R58d) Same as (R58a).

(E) Brushes not in the proper position.

(R58e) Shift the brushes until evidence of an improvement is given. The position of the brushes for best generating power should be clearly understood, and is generally at or near the neutral point.

(59) Too weak residual magnetism.

(R59a) Same as (R58a).

(60) Short-circuit in the machine.

(R60a) See numbers (12), (54), (55) and (56).

(61) Short-circuit in the external circuit.

(R61a) Lamp socket or other part of the line short-circuited or grounded may prevent building up of shunt or compound machines. Locate and remedy the fault before closing switch. See numbers (54), (55), and (56).

(62) Field coils opposed to each other.

(R62a) Reverse the connections of one of the field coils and test. Compass should show pole pieces of opposite polarity. If, after such a trial, dynamo does not build up, try (R58a). If the polarity does not then come up in proper direction, cross the field connections or remagnetize them in the opposite direction. See number (58A).

(63) Open circuit.

(A) Broken wire.

(B) Faulty connections.

(C) Brushes not in contact.

(D) Safety fuse melted or broken.

(E) Switch open.

(F) External circuit open.

(R63a) Locate and repair brake. See number (13).

(R63b) See (R58b).

(R63c) See (R5a) and (R5b).

(R63d) See (R53a).

(R63e) Close the field switch.

(R63f) Test out and repair with the dynamo switch open until the repairs are completed.

(64) Too great a load on the dynamo.

(R64a) Reduce the load to pilot lamps alone (shunt or compound machine). After dynamo comes up to full voltage, as shown by pilot lamps, or voltmeter, close the other circuits in succession and regulate the voltage at the same time. See (R11a).

(65) Too much resistance in the field regulator or field rheostat.

(R65a) Gradually turn the regulating switch to cut out the resistance and watch the pilot lamp or voltmeter when the dynamo comes up to voltage, regulate, etc.

328. **General Suggestions and Precautions.**—Never use ice or water to cool off the bearings, as it may get into the armature and ruin it, unless it has been made waterproof as in the case of street-car motors.

Never shut down because of hot box until remedies for troubles (25), (26), (28), and (32) have been tried and proved useless. If absolutely necessary to shut down, get the belt off as soon as possible. Do not allow shaft to "stick" in stopping. Get the boxes or bearings out and cool them off naturally as soon as possible and not in water, as this may ruin them. Then scrape, fit, polish, clean the shaft, and test for free turning by hand before belting up and starting again.

Cleanliness about a dynamo or motor is imperative. Dirt, oil, or copper dust may prove a source of great annoyance or damage. Small tools, bolts, or pieces of iron must be kept away from a dynamo as they may be drawn into or fall upon armature and ruin it. It is always best not to allow loose articles of any kind to be placed upon any portion of a dynamo.

Brass or copper oil cans are best to use as they are non-magnetic.

All the connections must be large, clean, and firm. Look over and tighten the loose connections, screws or bolts, daily.

Always keep copper brushes raised from the commutator when the dynamo is at rest. Poor, cheap oil is poor economy. Use none but the best of mineral oils. All new oils should always be filtered before using.

Keep cotton waste off the commutator. Use canvas or cloth to wipe the commutator.

A piece of pine makes a good burnisher to use on the commutator to keep it clean and smooth.

CHAPTER XV

ELECTRIC LIGHTING

329. The Electric Lamp.—The electric lamp in its broadest sense consists of a part of an electric circuit heated to incandescence, together with special regulating and controlling devices. Electric lamps may be conveniently classified under three heads, viz,

(a) **Arc lamps** (sections 330 to 333, inclusive).
(b) **Glow lamps** (sections 334 to 339, inclusive).
(c) **Vapor lamps** (sections 340 to 344, inclusive).

330. The Carbon Arc Lamp.—If the ends of two carbon rods that are connected to some source of electrical energy be touched together and then drawn apart, there will be an electric arc formed between them. This arc consists of a column of very hot vapor which serves to conduct the electricity from the end of one rod to the other. The terminals of the two rods will be wasted away as the arc continues to burn, the two rods, however, are not consumed at the same rate always. If the arc be formed by a direct current, the ends of the carbons assume a form similar to that shown in Fig. 238, the end of the positive becoming concave, and the end of the negative pointed. The carbon rod forming the positive terminal of the arc is consumed approximately twice as fast as the rod forming the negative terminal. The cup or concave portion of the positive carbon is called the **crater;** it is extremely hot and the greater part of the light the arc emits comes from this crater. The point of the negative carbon is not nearly so hot as the crater of the positive carbon, and it does not emit nearly so much light. As a result of this difference in light emitted by the positive and the negative terminals of the direct-current arc, the positive carbon will be placed above the negative so that the light will be cast downward, except in special cases; in the case of searchlights and projecting lanterns, the arc is arranged as shown in Fig. 239. If the electric arc be formed by an alternating current, the ends of both carbons are heated about the same, the upper carbon being perhaps a little hotter than the lower, due to the upward movement of the heated vapor. As a result of the heating of the ends of the two carbons being approximately equal, the light emitted from them will be approximately the same. The two carbons of an alternat-

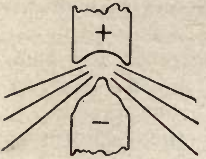


Fig. 238

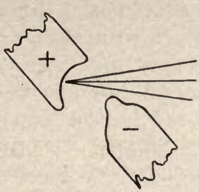


Fig. 239

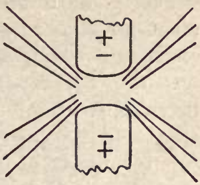


Fig. 240

ing current are wasted away approximately the same, the upper one being consumed a little faster than the lower one. An alternating-current arc is shown in Fig. 240. The light emitted by the alternating-current arc lamp is not steady, but pulsates in value with the change in the value of the alternating current, there being two pulsations of the light for each cycle of the current.

A direct-current arc makes practically no noise when it is operating properly, while the alternating-current arc makes a loud humming noise on account of the continuous contraction and expansion of the heated vapor, due to the variation in the value of the current, and the lamp mechanism often vibrates, due to reversals in magnetism.

A carbon arc lamp consists of two carbon rods, which have their distance apart controlled by a suitable mechanism that is operated by solenoids, or by hand.

331. Regulation of Arc Lamps on Constant-Voltage and Constant-Current Circuit.—If an electric arc be connected directly to a constant-voltage line, it will be impossible to maintain the arc unless a resistance be connected in series with the arc for the following reason. Assuming the arc is operating satisfactorily on a constant-voltage line and that the current decreases in value, due to an increase in length of the arc, caused by the ends of the carbon being consumed, this decrease in current will cause a decrease in the size of the arc unless an additional voltage be applied at the terminals of the arc, but the required increase in voltage is not available since the arc is operating on a constant-voltage circuit and, as a result, the lamp would go out almost instantly, or before the regulating mechanism has a chance to act and bring the carbons nearer together. When the circuit is once broken at the arc, the ends of the carbons must be placed in contact with each other and then drawn apart to re-establish the arc.

If the current producing the arc is increased in value, there will be an increase in the size of the arc or a decrease in its resistance and the constant voltage applied to the terminals of the arc would be more than sufficient to produce the desired current and, as a result, the current would continue to increase in value and would become excessive almost instantly, or before the regulating mechanism has time to operate and thus separate the carbons.

By placing a resistance in series with the arc, an increase in current will cause an increase in drop over this resistance and a decrease in current will cause a decrease in drop. If the resistance is large enough in value, the change in the drop over the resistance will more than balance the variation in the drop over the arc caused by a change in the current, and the operation of the arc will be quite stable. A resistance used for the purpose just described is called a **ballast.** The ballast for alternating-current arc lamps is usually a **reactance coil,** instead of a resistance, the reactance coil being formed by winding a coil on a laminated iron core.

When arc lamps are operated on constant-current circuits, no ballast is required, as the current remains constant regardless of the position of the carbons, it being governed by the generator, transformer, or regulator. The drop in potential over the arc, however, must be regulated in a series lamp by means of a solenoid which controls the distance between the carbons.

332. Multiple Arc Lamps.—Multiple arc lamps require only one solenoid for their operation. When the lamp is first started, there is a large current in the circuit, the solenoid is energized and draws the carbons apart until the decrease in current due to the increase in resistance of the arc weakens the solenoid to such an extent that it no longer acts to separate the carbons. If the current decreases in value, the solenoid is weakened, which allows the ends of the carbons to approach each other and the current is restored to its original value, or if the current increases in value, the solenoid acts to separate further the ends of the carbons and thus prevent an excessive increase in current.

The circuit of a multiple direct-current arc lamp is shown in Fig. 241. The circuit is composed of the ballast or steadying resistance (R), the two regulating solenoids (S_1) and (S_2), and the arc (A) between the ends of the carbons. The steadying resistance and the solenoids are so constructed that the number of turns in circuit can be varied by changing a connection from one tap to another on the various coils. The armature (B), controlled by the solenoids, actuates the upper carbon, the lower being stationary. The upper carbon is connected to the positive terminal of the circuit.

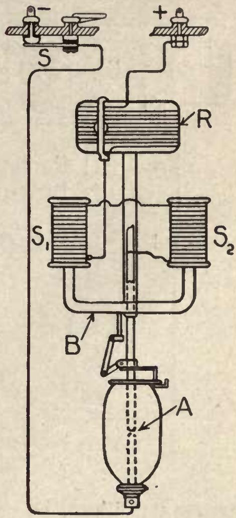


Fig. 241

333. Series Arc Lamps.—In this type of arc lamp no ballast or reactance is required in series with the arc since the lamps are connected in series and operate on a constant-current circuit. The series lamp does not regulate automatically, as the multiple lamp does, and a second solenoid whose winding is connected in parallel with the arc is required. The mechanical action of this second solenoid is just opposite that of the solenoid connected in series with the arc. The diagram of a series arc lamp is shown in Fig. 242. When the lamp is first connected in the circuit, the two terminals are connected by means of three paths—one through the starting resistance (SR), and the cut-out (CO); a second through the series coil (C), adjusting resistance (AR) and arc in series; and the third through the winding of the coil (DC), which is called the **differential shunt** on account of its winding being in shunt with the arc and its action differential with respect to the series coil. The two terminals of the lamp may be connected directly together by closing the switch (S) which is usually located in the top of the lamp.

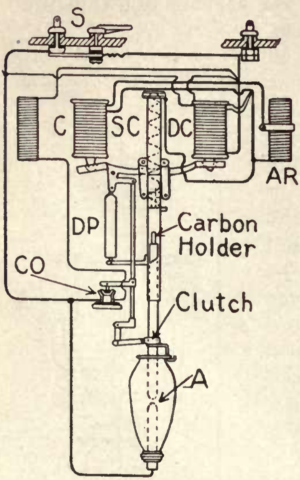


Fig. 242

The operation of this lamp, which is typical of all series arc lamps, is as follows: The series solenoid is energized as soon as the lamp is connected in circuit, and the action of this solenoid will draw the ends of the carbons apart, starting the arc and opening the cut-out (CO). As the carbons are drawn apart, the arc voltage increases and the current in the shunt solenoid (DC) increases, and its action tends to bring the carbons together, but it does not overcome the action of the series coil (SC), which tends to separate the carbons. As a result of these two solenoids acting at the same time, the arc is adjusted so that it takes a definite current, and a definite voltage exists across it. When the carbons are consumed, the shunt solenoid brings them nearer together, as its current has increased, due to the increase in voltage over the arc, and the current in the series coil remains approximately constant. This action continues until the cut-out (CO) is closed and the current is shunted through it. The shunt solenoid (DC) is short-circuited by the cut-out closing and there is no current in the series solenoid (SC), the upper carbon is released and the two come together. When the end of the two carbons come together, the current is re-established in the series solenoid and the lamp again picks up. If the carbons be entirely consumed, the cut-out remains closed and the circuit of which the lamp is a part is not opened, even though the lamp is not operating. A dash pot (DP) dampens the movement of the armature of the solenoids, which greatly improves the operation of the lamp. In some types of series arc lamps the shunt and series windings are both placed on the same spool instead of on two different ones, as shown in Fig. 242.

334. **Glow Lamp.**—In all glow lamps the light is emitted from a solid electrical conductor that is heated by an electrical current to such a temperature that it emits light. The lamps included under this head are the ordinary carbon-filament lamps, the different metal-filament lamps, such as tungsten and tantalum, and the Nernst lamp.

335. **Carbon-Filament Lamp.**—The common carbon-filament incandescent lamp consists of a fine filament of carbon mounted in a highly exhausted glass bulb, which may assume a number of different forms, depending upon the particular use of the lamp. The carbon filament is connected to the external circuit by means of two short pieces of platinum that are embedded in the glass. Platinum is used for making these connections on account of it being capable of withstanding a high temperature and it contracts and expands due to changes in temperature the same as glass, which is quite an advantage in maintaining the vacuum in the bulb containing the filament.

The method usually employed in the manufacture of the carbon filament is as follows: Some of the fibrous substances such as cotton are thoroughly cleansed and then dissolved in a solution of zinc chloride by constant stirring, forming a thick fluid which is freed from lumps by filtering and from bubbles by heating almost to the boiling point under pressure. This fluid is then "squirted" through a small hole and allowed to pass into an alcohol bath, which immediately hardens the gelatinous rod which can then be thoroughly washed in water. This thread has the appearance of celluloid, it is fairly tough, and may be cut into lengths and bent on formers into any shape desired. They are then packed in charcoal and carbonized in a furnace, after which they are mounted on the platinum wires that are to form the terminals and heated electrically by a current to a high temperature in a vapor of hydrocarbon. The hydrocarbon vapor is decomposed by the hot filament, which results in a deposit of carbon on the filament. This deposit will be greatest at the hotest points in the filament, which will be at the points of highest resistance or smallest cross-section and, as a result, the filament is made more uniform in cross-section, and its resistance slightly lowered, due to the increase in area. The above process is called **flashing.** The completed filament is placed in a glass bulb, which is exhausted by means of special pumps and sealed. A mounting suitable to screw into a lamp socket is then mounted on the bulb and the terminals of the filament connected to the two parts of the mounting, which make electrical contact with the two terminals of the line when the lamp is screwed into the socket.

The resistance of a carbon filament when working under normal conditions is approximately half what it is at ordinary temperatures.

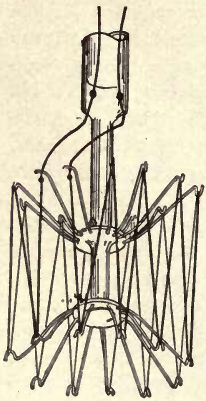


Fig. 243

336. Metalized Carbon-Filament or Gem Lamp.—The filaments used in the so-called metalized carbon-filament lamps are carbon filaments that have been subjected to an enormously high temperature, both before and after flashing, by means of a specially constructed electric furnace. The term "metalized" is used on account of the filaments acquiring a positive temperature coefficient when subjected to very high temperatures.

337. Tantalum Lamp.—The tantalum lamp was invented by Dr. Bolton—chemist for Siemens and Halske—who discovered the peculiarities of tantalum and the methods of obtaining the pure metal. Tantalum is obtained by special processes from the ores tantalite and columbite, the tantalite being found principally in Australia and the columbite in New England. Filaments of the desired size are drawn from the pure ductile tantalum. The melting temperature of tantalum is approximately 2800° centigrade and its resistance increases with a rise in temperature. The tensile strength of tantalum is very high when cold, but when heated it becomes soft and after the filament has been burning a few hours it becomes very brittle, which is the great disadvantage of this kind of a filament. The filament of a tantalum lamp to operate on a 110-volt circuit is a great deal longer than the carbon filament, and special means must be provided for mounting those long filaments, such as shown in Fig. 243.

The tantalum lamp gives a much whiter light than the carbon-filament lamp on account of the high temperature at which it operates. The life of a tantalum lamp is a great deal less on an alternating-current circuit than it is on a direct-current circuit and its life on an alternating-current circuit depends upon the frequency.

338. Tungsten Lamp.—The latest form of metallic-filament lamp placed on the market is the tungsten lamp. It has only been commercially used for about three years, but even in that short time it has attained the highest position in the field of incandescent lighting.

Tungsten is not a rare metal, having been used for a number of years in the manufacture of tool steel and armor plate. Owing to the fact that as hitherto produced the metal was very hard and brittle, it has not until recently been obtained in a ductile form and consequently was not drawn into wire as was tantalum. It has a very high melting point —about 3050°C.—which allows the lamps to be operated at the relatively high efficiency of 1.25 w.p.c. and even higher. This makes the light emitted very much nearer a pure white than any other incandescent lamp which has yet come into commercial use.

There are four methods of forming the tungsten filament, but the one in most general use in this country is the Auer, or paste, process. This process starts with a pure tungstic acid, obtained from some one of the various tungsten ores, such as wolframite or scheelite. Tungstic acid is a yellow powder, which must undergo several processes of purification and reduction before it is finally reduced to the pure metal. This metal is used in the form of a fine black powder, which is mixed with a binding material in order to form a putty-like mass that can be squirted through a very small die, even as small as one-thousandths of an inch. A die is very expensive, being made from a diamond, through which a hole is drilled with a fine flexible steel needle. Its life is very short on account of the wear which the hard metal gives the diamond and the enormous pressure of 30000 pounds per square inch, under which the filament is formed. Thus only enough filaments for 1500 lamps can be formed before the die is so badly worn that it must be rebored for the next larger size filament, an operation which costs almost as much as a new die.

The filament while being squirted is looped back and forth on a card, which, when filled, is laid aside to allow the filament time to dry. After drying, the filaments are cut into loops, which resemble in shape the finished filaments. These loops are placed in a tube furnace and baked at a cherry red heat in an atmosphere of gas which contains no oxygen. After baking for some time the more volatile constituents of the binder are found to have been driven off and the filaments are ready to be "formed." They are now connected into an electrical circuit by means of clips and are gradually heated in an atmosphere of inert gas, until incandescence is reached, when the remaining binding material is volatilized, leaving the pure metal filament. This last process causes the filament to shrink somewhat, which, however, has been allowed for in the previous operations.

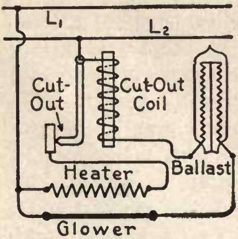


Fig. 244

The formed filament is now mounted on the center support and the two ends are welded to the supporting wires in an atmosphere of forming gas. After sealing the mount into the tubulated bulb, the lamp follows practically the same process of exhaustion as the tantalum lamp.

There has been recently discovered a means whereby tungsten is rendered ductile, and wire-drawn filaments are the result. Tungsten wire has a tensile strength varying from 400 000 to 600 000 pounds per square inch, a value three to four times that attained by tantalum wire. This wire can be bent into any form and consequently can be mounted in such a manner as to be more capable of withstanding shocks than was possible with a filament made by the paste process.

339. Nernst Lamp.—The filament or glower of a Nernst lamp consists of a small rod of porcelain-like material composed of the oxides of zirconium and yttrium. This rod is a good insulator at ordinary temperatures, but becomes a very good conductor at a low red heat, and its resistance decreases very rapidly as the temperature rises. If such a glower is to be used some means must be provided for heating it until it will become a conductor in starting the lamp, and a ballast resistance must be connected in series with the glower to prevent the current becoming excessive after the glower has started to conduct. A diagram of a single glower lamp is shown in Fig. 244. When the lamp is first connected to the line, the circuit is completed through the heater coil and cut-out. As the temperature of the glower is raised, due to the action of the heater, its resistance is lowered, which permits the electricity to pass through the glower, ballast, and cut-out coil all in series. After a short time this current will reach a value, due to decrease in the resistance of the glower, sufficient to operate the cut-out and thus disconnect the heater, and the glower will become incandescent. The ballast is composed of fine iron wire placed inside of an exhausted glass tube to prevent the iron oxidizing when it is heated. This ballast increases in resistance with an increase in temperature, due to an increase in current and, as a result, automatically tends to maintain the current constant. A Nernst lamp is shown complete in Fig. 245.

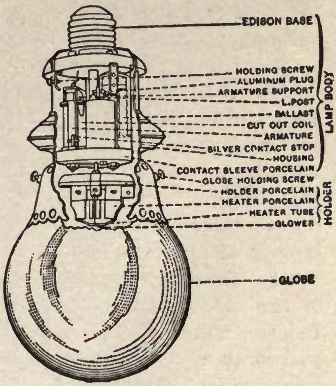


Fig. 245

340. Vapor Lamp.—In the different forms of vapor lamp the light is emitted from an incandescent or luminescent column of vapor that conducts the electricity. The lamps included under this head are the flaming-arc lamps, mercury-vapor lamps, and the Moore tube.

341. Flaming Arc.—In the carbon arc lamp the greater part of the light is emitted from the ends of the intensely heated carbons, the arc itself emitting only a pale violet light. If the carbons between which the arc is formed be impregnated with metallic salts, or rods of metal, or metal oxide be used instead of carbon, an arc will be formed which is highly charged with metal vapor. The light emitted by such an arc comes mostly from the incandescent particles in the metal vapor, very little coming from the terminals of the rods forming the arc. Arc lamps employing impregnated carbons or metal rods instead of carbons to form the arc are known as flaming arcs.

One of the materials most commonly used in combination with carbon is calcium, which gives the light emitted by the arc a highly brilliant yellow color. Carbons impregnated with stroncium give a red light, and those impregnated with titanium or barium give a white light. There are many different forms of electrodes for the flaming arc lamps, consisting of different metals and combinations.

342. Bremer Flaming-Arc Lamp.—The Bremer lamp is one of the oldest and is the most efficient of the different flaming arc lamps on the market. The carbons in this lamp are placed parallel or slightly inclined to each other, instead of being placed in the same plane with their axes coinciding, which results in a larger arc being formed between them. This arrangement of the carbons gives the lamp an additional advantage over the other arrangement, since there is no lower carbon in the path of maximum illumination. In the construction of the lamp, a magnet is provided which creates a magnetic field that acts on the arc and deflects it downward, thus preventing its climbing up the carbons, and at the same time giving a longer and larger arc and a better distribution.

343. Mercury-Vapor Lamp.—The mercury-vapor lamp consists of a highly exhausted glass tube with two platinum wires sealed in its ends. One of these wires is connected inside the tube to a piece of iron or graphite that forms the anode and the other is connected to a pool of mercury that forms the cathode. In starting such a lamp a high electromotive force or a special starting device is required, but after the lamp is once started a current of several amperes can be easily maintained by a pressure of from 30 to 100 volts. The mercury vapor in the tube gives off a bright light that is deficient in the longer wave-lengths, or red. The lack of the longer wave-lengths results in an unpleasant distortion of color.

The lamp may be started by tilting the tube, it being normally at an angle to the horizontal, which allows the mercury to extend from one end to the other and complete the circuit, and the circuit is maintained through the mercury vapor when the metallic mercury circuit is broken by the tube being allowed to return to its normal position. A spark may be caused to pass through the tube, due to the action of an induction or kick coil which ruptures the medium and starts the lamp. A third means of starting is to place an auxiliary positive electrode near the negative electrode to be used in starting and the connection is then transferred to the other positive electrode after the lamp is started.

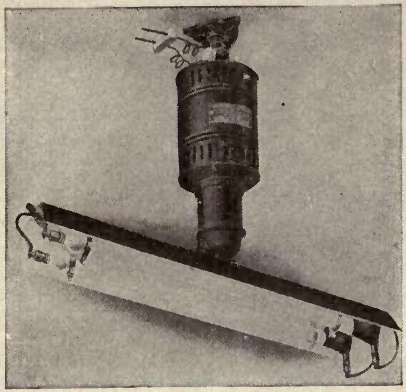


Fig. 246

The lamp is operated on alternating current by connecting the negative electrode of the lamp to the middle point of a transformer winding and having two positive electrodes located at the same end of the tube and connected to the two ends of the transformer winding. A mercury-vapor lamp is shown complete in Fig. 246.

344. Moore Tube.—The Moore tube resembles the mercury-vapor lamp in that it consists of a conducting vapor enclosed in a glass tube and the light is emitted from incandescent particles in the vapor stream. The tube from which the light is emitted may be of any length up to about 200 feet, of any desired form, and its diameter may be as large as 1¾ inches. Two graphite electrodes are sealed in the ends of this tube, which is filled with air, carbon dioxide, nitrogen, or other suitable gas. The secondary winding of a

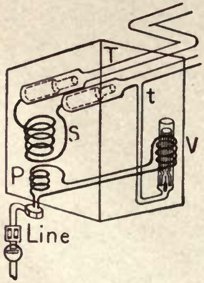


Fig. 247

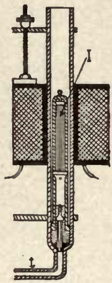


Fig. 248

transformer is connected to the graphite terminals in the ends of the tube, the primary winding being connected to the source of power, as shown in Fig. 247. The vacuum in the tube becomes more and more perfect, which decreases the efficiency of the lamp, and some means must be provided for regulating the vacuum, which is done as follows: A separate tube (t) projects downward from the main one, as shown in Fig. 247, and is connected with what is called a **feeder valve.** This feeder valve, shown more in detail in Fig. 248, consists of a solenoid connected in series with the primary winding of the transformer. The iron plunger (I) is fastened in a glass displacement tube and it is raised or lowered, due to a change in the current in the solenoid. In the end of the tube (t) there is cemented a carbon plug with a very small opening in it, which is normally covered with mercury. If the displacing tube be moved up, due to the action of the solenoid, the mercury recedes, uncovering the opening in the carbon plug and allowing a small amount of gas to enter the tube.

With an increase in vacuum there is a decrease in resistance and an increase in current in the secondary winding of the transformer, and also a corresponding increase in current in the primary winding. This increase in current causes the feeder valve to operate and the vacuum is restored to normal by admitting gas. The secondary voltage required will depend upon the length of the main tube.

345. **Units of Illumination.**—The luminous intensity of a source of light is measured by comparing it with a source of unit intensity, and the unity commonly employed for measuring luminous intensity is the **candle-power.** The unit of candle-power is equal to 1.111 hefner units.

The **Hefner lamp,** so-called from its inventor, is a specially constructed lamp that burns pure amyl acetate. The wick and the tube holding the wick are of definite dimensions and in using the lamp the wick is adjusted so that the flame is a prescribed height. The intensity of a beam of light in a horizontal plane from such a lamp is called a **hefner unit** or a **hefner.**

The **illumination** or the amount of light falling on an object is measured in a unit called the **foot-candle.** A foot-candle is the normal illumination produced by one unit of candle-power at a distance of one foot.

The **mean horizontal** intensity is the average intensity in all directions in a horizontal plane that passes through the source of light. In the case of incandescent lamps this plane is taken perpendicular to the axis of the lamp.

The **mean spherical** candle-power is the average candle-power taken in all directions around the source of light.

346. **Photometry.**—The measurement of light emitted by a lamp is called photometry. This is always accomplished by comparing the beam of light from a given lamp with the beam of light from a standard lamp, and the device used for making this comparison is called a **photometer.** The intensity in different directions can be measured by placing the lamp in different positions with respect to the photometer.

Lighting measurements are all based upon the law of inverse squares, which can be explained by reference to Fig. 249. A source of light is shown at (L) and four rays of light (R_1), (R_2), (R_3), and (R_4) are shown emanating from (L) and forming a pyramid. Three cross-sections through this pyramid and perpendicular to its axis are shown at (A), (B), and (C). These three cross-sections and the light (L) are all equally spaced and, as a result, the cross-section (B) is four times that of (A), and (C) is nine times that of (A), etc., or the cross-sections between the four rays increase as the square of the distance the cross-sections are from the source of light. Since the same total number of rays pass through each area, the intensity per unit of area varies in-

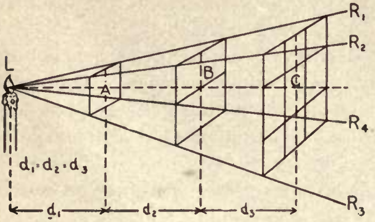


Fig. 249

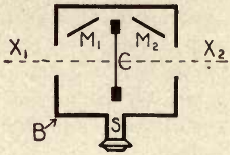


Fig. 250

versely as the square of the distance from the source of light.

The **Bunsen photometer** is one of the oldest and simplest forms of photometers and also one of the most efficient means of comparing the intensities of different sources of light. The construction of this photometer can best be explained by reference to Fig. 250. A sheet of white paper, the center portion of which is made transparent by being treated with paraffin or some other similar substance, is mounted inside a box (B), as shown in the figure. This sheet of paper is called the **screen** (C) of the photometer.

The two sides of this screen are viewed simultaneously through the sight piece (S) by the aid of the two mirrors (M_1) and (M_2) which are so mounted that they make an angle of about 140 degrees with each other and equal angles with the plane of the screen. The light falling on either side of this screen is not all reflected, a part passing through the translucent spot in the center. When the illumination on both sides of the screen is the same, an equal amount of light is transmitted through the screen in both directions, and if the lights on the two sides are of the same hue the spot in the center and the remainder of the screen should appear of the same color.

The photometer is used as follows: Two lamps, whose intensities are to be compared, are located a known distance apart on what is known as the **photometer bench.** The box (B), Fig. 250, is placed between the two lamps so that its axis (X_1X_2) coincides with the line connecting the centers of the two sources of light and so arranged that it can be moved along this line. It is then moved until the two parts of the screen have the same appearance. When this balance is obtained, the distance the center of each source of light is from the screen is determined and the relation of the intensities is calculated by applying the law of inverse squares given above. If the candle-power of one lamp is known, the candle-power of the other one can be easily determined, as follows:

Let (S_s) represent the candle-power of the standard lamp.

Let (S_x) represent the candle-power of the lamp being tested.

Let (D_s) represent the distance the screen is from the standard lamp.

Let (D_x) represent the distance the screen is from the lamp being tested.

Then
$$\frac{S_x}{S_s} = \frac{D_s2}{D_x2}$$

and
$$S_x = \frac{D_s2}{D_x2} S_s \qquad (126)$$

347. The Specific Consumption of Lamps.—The specific consumption of a lamp in practice is always specified by giving the watts consumed in the lamp per spherical candle-power of light emitted. The specific consumption of different types of lamps is given in Table X.

TABLE NO. X.

APPROXIMATE SPECIFIC CONSUMPTION OF DIFFERENT TYPE LAMPS

Type of Lamp—	Watts per Mean Spherical Candle-Power	Remarks
Direct-current series	1.0	
Direct-current multiple	2.4	
Alternating-current series	1.7	No outer globe
Alternating-current multiple	2.5	No outer globe
D. C. Bremer flaming arc	.196	48 volts over arc
A. C. Bremer flaming arc	.226	48 volts over arc
Carbon-filament lamps	3.0 to 3.5	
Tantalum lamps	1.8 to 2.2	
Tantalum lamps	1.8	Direct current.
Tungsten	1.25	
Nernst	2.95	Six glower.
Nernst	3.92	Single glower
Mercury-vapor	.48*	See note (A)
Moore tube	1.7*	See note (B)

Note (A): The candle-power is measured perpendicular to the axis of the tube.

Note (B): This value corresponds to a vacuum in the tube of approximately .10 millimeters of mercury.

348. Distribution Curves.—The distribution of light from a source through any plane and in different directions can be represented graphically, and such a graphical representation is called a distribution curve. The distribution curve, about a four-candle-power lamp in a vertical plane, is shown in Fig. 251. The intensity in different directions being proportional to the distance, the curve is from the center. The form of the filament, bulb, shades, and reflectors all have an influence in determining the shape of the distribution curve.

349. Calculation of Illumination.—If a 16-candle-power lamp (L) be placed 8 feet from the plane (A), as shown in Fig. 252, the illumination per unit area on the plane (A) at the point (B) would be equal to $(16 \div 8^2) = \frac{1}{4}$ foot-candle, since the intensity varies inversely as the square of the distance. In general, to get the illumination at any given

*Watts per candle-power.

point, the candle-power in the direction measured must be divided by the square of the distance from the light to the point illuminated.

When the surface illuminated is not at right angles to the light, the values of illumination obtained above must be multiplied by a reduction factor, which takes into account the angle at which the rays of light strike the surface. Thus,

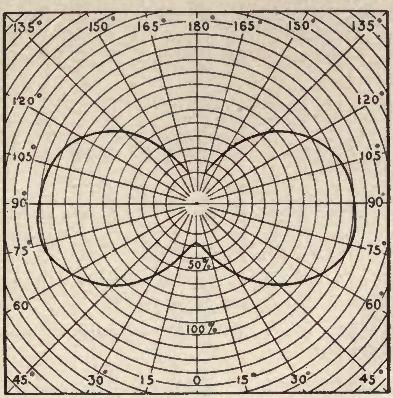


Fig. 251

if a lamp (V) be placed 8 feet above the horizontal plane (H), as shown in Fig. 253, and it is desired to determine the illumination at the point (B), 6 feet from the vertical line through the lamp, you should proceed as follows: The distance (l) the point (B) is from the lamp is equal to

$$l = \sqrt{v^2 + h^2}$$

The value of (l) in Fig. 253 is equal to

$$l = \sqrt{8^2 + 6^2} = 10$$

Assuming the intensity of the light from the lamp (L) along the line (l) is 20 candle-power, then the illumination on a surface (P) at the point (B) perpendicular to the line (l) would be equal to

$$\text{Illumination} = \frac{20}{10^2} = \frac{1}{5} \text{ foot-candle}$$

TABLE NO. XI

CONSTANTS TO BE USED IN CALCULATING THE ILLUMINATION OF A HORIZONTAL PLANE BELOW A LAMP

Height of Lamp in Feet above Plane Illuminated	Horizontal Distance in Feet from Point Directly Under Lamp to Point Where Intensity of Illumination Is Desired										
	0	2	4	6	8	10	12	14	16	18	20
2...	.250	.0883	.02240	.00790	.00355	.001907	.001109	.000722	.000473	.000341	.000242
4...	.0625	.0447	.02206	.01064	.00560	.003220	.001975	.001436	.0008875	.000631	.000476
6...	.02775	.02365	.01600	.00980	.00602	.003802	.002485	.001689	.001207	.000876	.000654
8...	.01563	.01428	.01119	.008015	.00552	.003815	.002665	.001913	.001402	.001050	.000865
10...	.010	.009417	.007997	.00630	.004757	.003530	.002623	.001960	.001490	.001149	.000897
12...	.006945	.00665	.00592	.00496	.00400	.003120	.002450	.001900	.001506	.001181	.000950
14...	.005105	.004905	.00453	.00397	.003335	.002745	.002220	.001801	.001455	.001178	.000965
16...	.00391	.003818	.003567	.003202	.002795	.002383	.002001	.001665	.001380	.001142	.000954
18...	.00309	.003030	.002875	.002648	.002353	.002060	.001781	.001517	.001288	.001090	.000927
20...	.00250	.002460	.002355	.002197	.002000	.001786	.001575	.001375	.001189	.001025	.000883
22..	.002065	.002047	.001963	.001852	.001711	.001553	.001398	.001240	.001088	.000955	.000835
24...	.001736	.001715	.001662	.001582	.001480	.001365	.001240	.001118	.001000	.000890	.000785
26...	.00148	.001465	.001428	.001369	.001290	.001200	.001108	.001008	.000915	.000821	.000736
28...	.001276	.001265	.001225	.001190	.001132	.001062	.000991	.000911	.000834	.000758	.000686
30...	.001111	.001105	.001080	.001045	.001002	.000947	.000889	.000826	.000765	.000700	.000640

The illumination of 1/5 foot-candle on the surface (P) is to be distributed over a larger area when the horizontal plane is considered. The ratio of the illumination per unit of area on the horizontal plane to the illumination per unit area on the plane (P) is equal to the inverse ratio between a unit area in the plane (P) and the projection of this unit area on the horizontal plane. This ratio is equal to the cosine of

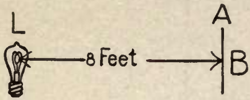


Fig. 252

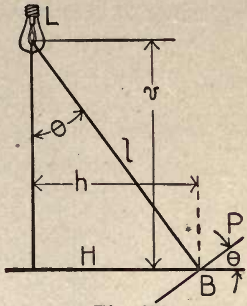


Fig. 253

the angle between the plane (P) and the horizontal plane, which is the same as the angle between (l) and a vertical line through the lamp. The constants by which the intensity in candle-power along the line (l) must be multiplied to obtain the illumination on the horizontal for different values of (h) and (v) are given in Table No. XI. The illumination on the horizontal plane for the above example would be equal to

$$20 \times .008\,015 = .1603 \text{ foot-candle}$$

When the source of light consists of a number of lamps, the illumination for each lamp can be determined and the resultant illumination obtained by addition.

TABLE NO. XII

REQUIRED ILLUMINATION FOR VARIOUS CLASSES OF SERVICE

Class of Service	Intensity of Illumination in Foot-Candles
General illumination of residences	1 to 2
Reading	1 to 3
Auditoriums and theaters	1 to 4
Churches	2 to 4
Bookkeeping and clerical work	3 to 5
General illumination of stores	2 to 5
Engraving and drafting	5 to 10
Street lighting by electricity	.05 to .06

The illumination required for various classes of service is given in Table No. XII.

350. Shades, Reflectors, and Diffusers.—Often the distribution from a source of light is undesirable and the intrinsic brilliancy of the source may be too great for the best effect

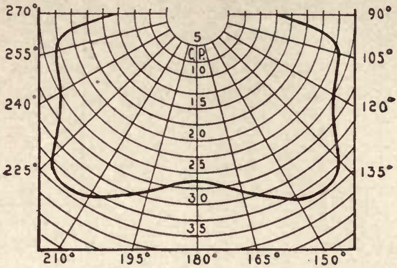


Fig. 254

or greatest comfort, which results in the use of shades, reflectors and diffusers. A **shade** is used to modify the light and is placed between the source and the eye. It may act as a reflector or diffuser. A **reflector** serves to re-direct the light and thus change the distribution, and it may act as a shade in certain directions. A **diffuser** is intended to decrease the intrinsic brilliancy and to reduce the glare, and in so doing act as a shade or reflector. The arc lamp is usually enclosed in two globes when used for interior lighting, in order to reduce the intrinsic brilliancy. The change in shape of the distribution curve, shown in Fig. 251, due to the use of a holoplane reflector, is shown in Fig. 254. The reflector and lamp are shown in Fig. 255.

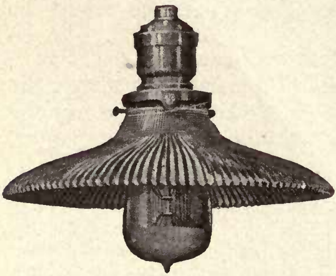


Fig. 255

351. The Effect Different Colored Walls Have Upon the General Illumination.—In rooms not larger than approximately 15 feet by 15 feet, the color of the walls will have considerable effect upon the general illumination when the lamps are used without shades or reflectors. The effective illumination in rooms with different colored walls is obtained by multiplying the illumination given directly by the lamp by the factor given in Table No. XIII.

TABLE NO. XIII

FACTORS FOR OBTAINING EFFECTIVE ILLUMINATION

Color Wall	Illumination Factor
White paper	3.3
Orange paper	2.0
Yellow paper	1.67
Yellow painted wall	1.67
Pink paper (light)	1.56
Green paper (emerald)	1.22
Brown paper (dark)	1.15
Blue-green paper	1.14
Chocolate paper (deep)	1.04

CHAPTER XVI

ELECTRIC WIRING

352. Wiring in General.—The term "electric wiring" is usually considered to mean the proper placing of electrical conductors to form a complete metallic circuit for conducting the electrical energy to and from the points where it is generated and consumed. The above use of the term, however, is rather narrow and it should include in addition to the proper placing of the electrical conductors, the calculation of the proper size of conductors to meet given requirements; the selection of the proper materials; a consideration of the proper location of the service mains, meters, outlets for lamps, panel boards, switches, controlling devices, etc., and a thorough understanding of the requirements of the inspection department under whose jurisdiction the work is being done.

353. Factors Determining the Size of Conductors.—The problem in electric wiring is the transmission of a certain amount of energy from one point to another, and it is usually desired that this transmission be effected with a minimum loss and at the same time keep the initial cost within a reasonable value.

The drop in electrical pressure between any two points connected by an electrical conductor is equal to the product of the current in the conductor connecting the two points and the resistance of the conductor, or volts drop equals $(R \times I)$. This drop in pressure in volts multiplied by the current in amperes gives the value of the power loss in watts in the conductor, or power loss in watts equals $(R \times I)$ times (I), which equals (I^2R). The current in a conductor forming part of the circuit connecting a given load to its source of energy is fixed by the voltage of the generator and the resistance of the load. Since the value of the current in the expression for the power loss in a conductor is to be fixed for any given voltage, the only way to reduce the loss is to reduce the value of the resistance (R).

The resistance of a conductor composed of a given material and at a constant temperature varies directly as the length and inversely as the cross-sectional area. The length of a conductor connecting a load and generator is usually determined by the distance between them (in some cases the conductor may be a great deal longer than this distance on account of its not following a direct path), and, as a result, the resistance can be reduced only by an increase in the cross-section of the conductor. An increase in cross-section, the length remaining constant, means a like increase in weight, and hence an increase in cost. The loss in the conductors in any circuit may be made very small by an increase in their cross-sections, but, as pointed out above, the cost of the conductors is increasing at the same time the loss is decreasing. In practice, a reasonable loss, usually expressed in per cent, is allowed and the size of the conductor required to carry the current is figured from this value.

Neglecting the loss in the conductors, there is another important factor to consider in the determination of the proper size of conductors to use, and that is the allowable rise in temperature of the conductor caused by the loss in it. The rise in temperature due to a given loss will depend upon the rate at which the heat generated in the conductor is radiated, which in turn will depend upon its insulation and mechanical protection. The allowable current-carrying capacity for different size copper wires has been established by the Underwriters, and Table G, Chapter 20, gives a complete set of these values. It must be understood that the percentage drop in voltage is not taken into account in this table.

In some cases the size of the conductor is determined by the mechanical requirements; it, however, should never be smaller than the size determined by the electrical requirements.

354. Choice of Material to Use as a Conductor.—From the standpoint of loss in the line, the choice of a material to use as a conductor is governed by its resistance. In order that the loss be small, the specific resistance must be low. This, however, does not mean that the materials of lowest specific resistance will be used, as their cost may be a great deal more than that of some material having a higher specific resistance. If the specific resistance of a material which we shall call (A) is twice that of a material which we shall call (B), and the cost of the material (A) per unit volume is just one-half that of material (B), then the cost of the two conductors, one each of the (A) and (B) materials, of the same length and having the same resistance, will be the same. As far as the loss in the conductors and the initial cost are concerned, there would be no choice in the above case. The conductor composed of material (A) would be larger than the one composed of material (B), and more material would be required to insulate it; a larger conduit would be required to accommodate it if it be placed in a conduit; and it would be bulkier and more than likely harder to handle. The tensile strength of one material might be such that it would not meet the mechanical requirements although it fulfills the electrical requirements. Thus a long span across a stream would be made of steel wire on account of its high tensile strength and not for electrical reasons. The material that seems to meet best all the requirements for a conductor, except in special cases, is copper, and for this reason copper is usually used. The supply of copper and its cost are also in its favor as compared to silver, which is electrically better.

355. Calculation of the Resistance of a Conductor.—The resistance of any conductor (neglecting changes in temperature) can be determined if its dimensions and the value of the specific resistance of the material composing it are known. The equation used in making this calculation is

$$R = \frac{Kl}{d^2} \qquad (127)$$

In the above equation (K) represents the mil-foot resistance, or it is the resistance of a portion of the conductor one foot in length and having a circular cross-section one-thousandth of one inch in diameter; (l) is the length of the conductor in feet; and (d) is the diameter of the conductor in mils (the mil is equal to the one-thousandth part of one inch).

Example.—Calculate the resistance of a conductor, composed of commercial copper having a mil-foot resistance of

(10.8), 500 feet in length, and having a diameter of 325. mils. (This corresponds to a No. 0, B. & S. gauge wire).

Solution.—Substituting in equation (127), the values of (K), (l) and (d) given in the problem, gives

$$R = \frac{10.8 \times 500}{325 \times 325} = .05112$$

Ans. .05112 ohm.

If the length of a circuit is given, the value of (l) to substitute in equation (127) is equal to twice the length of the circuit; or if the length of the circuit be represented by the letter (L) the value of (l) is equal to (2L).

356. Calculation of Size of Conductor When Allowable Drop and Current Are Given.—If the drop in potential (E), in volts, that is to occur in any circuit when there is a definite current in the circuit, and the current of (I) amperes are both given, the resistance of the circuit in ohms is equal to

$$R = \frac{E}{I} \qquad (128)$$

Knowing the resistance of the circuit and its length, the size of the conductors required can be determined by substituting in the following equation:

$$d^2 = \frac{I \times K \times 2L}{E} \qquad (129)$$

Since from equation (128)

$$R = \frac{E}{I}$$

and from equation (127)

$$R = \frac{K \times 2L}{d^2}$$

we have

$$\frac{E}{I} = \frac{K \times 2L}{d^2}$$

or

$$E\,d^2 = I \times K \times 2L$$

and

$$d^2 = \frac{I \times K \times 2L}{E}$$

Example.—The voltage at the terminals of a generator is 112 volts, and it is desired to transmit 50 amperes over a circuit 450 feet in length with a drop in voltage not to exceed two per cent. What size of conductor is required if it be composed of copper having a mil-foot resistance of 10.8?

Solution.—The drop in voltage (E) is equal to two per cent of 112, or

$$E = .02 \times 112 = 2.24 \text{ volts}$$

Substituting the value of (E) just obtained, and the value of (I), (L), and (K) in equation (129), gives

$$d^2 = \frac{50 \times 10.8 \times 2 \times 450}{2.24}$$

Solving this equation, gives

$$d^2 = 215\ 170$$

and

$$d = 464 \text{ mils}$$

Referring to a table giving the diameters of different size wire you will find a No. 0000 B. & S. gauge is the size having a diameter practically the same as the value just obtained. In case the value of (d) obtained is less than the diameter of a No. 14 wire, the No. 14 wire should always be used, or in no case use a wire smaller than No. 14, B. & S. gauge, except in the wiring of fixtures.

Tables L, M, and N, Chapter 20, give the proper size conductors to use on 50-, 110-, and 220-volt circuits, when the distance to the center of distribution and the current the conductor is to carry are given, the loss in each case being two per cent. The following example will illustrate the use of the tables:

Example.—A current of 100 amperes is to be supplied to a number of incandescent lamps from a generator whose terminal voltage is 220 volts with a loss not to exceed two per cent. What size conductor should be used when the generator and lamps are 200 feet apart?

Solution.—Referring to Table N, Chapter 20, and passing along the horizontal line corresponding to 100 amperes until you strike the vertical column headed 200, which corresponds to the distance to the center of distribution, you will find that a No. 0 B. & S. gauge wire is the proper size to use.

In some cases the percentage loss to be allowed in the line may be different from that given in the tables, and the size wire can be determined as follows: The percentage loss allowed should be divided by two, giving a constant which we shall call (C). Then determine the size wire required by means of the tables, on the assumption that the loss is two per cent, divide the circular-mil area of the wire thus obtained by the constant (C), and look up the size of wire having a circular-mil area corresponding to or next larger than this result.

Example.—It is desired to transmit 100 amperes from a 220-volt generator a distance of 200 feet with an allowable loss of five per cent. What size wire should be used?

Solution.—The constant (C) is equal to 5 divided by 2, or

$$C = 5 \div 2 = 2.5$$

Referring to Table N, Chapter 20, we find that a No. 00 B. & S. gauge wire would be required if the loss were only two per cent. The circular-mil area of a No. 00 B. & S. gauge wire is, from Table C, equal to 133 100, and this value divided by (C), or 2.5, gives the circular-mil area of the wire to be used.

$$\text{Circular-mil area} = 133\,100 \div 2.5 = 53\,240$$
$$\text{diameter} = 230.7 \text{ mils}$$

A No. 3 B. & S. gauge wire has a diameter of 229.4 mils, so that it should be used.

357. **Motor Wiring Formula.**—The size of wire required to supply energy to a direct-current motor can be calculated as follows: Assuming the horse-power, efficiency, and the voltage of the motor are given, the current that must be supplied when the motor is operating under full load can be determined by substituting in the following equation:

$$I = \frac{\text{h.p.} \times 746}{E} \times \frac{100}{F} \qquad (130)$$

In the above equation (h.p.) represents the horse-power of the motor, (E) the voltage the motor is designed to operate on, (F) the efficiency of the motor in per cent, and (746) is the number of watts per horse-power. Having determined the value of the current (I), the size of wire required can be determined as in section (356). The size of conductor used should be such as to allow for a 25 per cent overload on the motor, the current in the conductor not exceeding the values given in Table G, Chapter 20.

Example.—A 50-horse-power direct-current motor is to be supplied with current from a 220-volt generator over a line 250 feet in length and having such a resistance that the drop in voltage shall not exceed 4 per cent. What size wire should be used, the efficiency of the motor being 90 per cent?

Solution.—Substituting directly in equation (130) gives

$$I = \frac{50 \times 746}{220} \times \frac{100}{90} = 188. + \text{amperes}$$

When the motor is carrying a 25 per cent overload the current in the leads will be equal to 1.25 times 188, or

$$\text{Overload current} = 1.25 \times 188 = 235 \text{ amperes}$$

Since the maximum value of current given in Table N, Chapter 20, is less than 235 amperes, the size wire can be calculated as follows: The size of wire required to carry 235 amperes with a 4 per cent drop will be the same as the size of wire required to carry 117.5 amperes with a 2 per cent drop. Referring to Table N, we find, that with a current of 120 amperes and a distance of 250 feet, a No. 000 B. & S. gauge wire is required. Referring to Table G, we find that No. 000 B. & S. gauge wire cannot be used to carry 235 amperes except when insulations other than rubber are used. The size of wire required, if it is insulated with rubber, would be a 300 000 circular-mil cable.

358. Methods of Wiring and Rules Governing Same.—The rules and requirements governing the proper installation of electrical conductors and the kind of material that must be used vary in different localities. In the majority of cases the rules and requirements of the National Board of Fire Underwriters as published in the National Electric Code are followed. In some municipalities there are certain ordinances in force, or the power company may have certain requirements that must be met before they will supply electrical energy. The National Electric Code should, however, be followed at all times unless there are other requirements in force.

There is a supplement to the National Electric Code that contains a complete list of all the fittings that are approved by the Underwriters, and in no case should fittings be used that do not appear in this supplement unless by special permission.

There are several methods of wiring that are approved by the National Board of Fire Underwriters, viz.:

(a) **Open, or exposed, work.**
(b) **Moulding work.**
(c) **Concealed "knob and tube" work.**
(d) **Interior conduit and armored cable work.**

359. Open, or Exposed, Work.—This method of wiring is perhaps the cheapest of any of the methods given, and it is at the same time one of the safest and best methods when properly installed. It is used a great deal in mills, factories, etc., where the appearance of the wires on the ceiling or walls is of no great importance. The wires used in this method of wiring may be either rubber covered or provided with slow-burning weatherproof insulation. Rubber insulation should always be used when the wire is in a damp place, such as a cellar, and either weatherproof or rubber insulation may be used to protect it against corrosive vapors. When installed in dry places and for voltages below 300, the wires should always be rigidly supported on non-absorptive, non-combustible insulators that separate them 2½ inches from each other and ½ inch from the surface over which they pass. For voltages from 300 to 500, the wires should be separated 4 inches from each other and 1 inch from the surface over which they pass. If the wiring is in a damp place, the wires should always be at least 1 inch from the surface over which they pass, even if the voltage be below 300 volts, the other distances being the same as above. The wires should always be protected by porcelain tubes or short pieces of flexible tubing when they pass over pipes or other material, as shown in Fig. 256. It is usually best to place the wires above the pipes rather than under them. The wires, when they run vertically on the walls, should be protected by a suitable boxing or run in a pipe, as shown in Fig. 257. There should be a clearance of at least 1 inch around the wires when they are placed inside the box, which should be closed at the top, and the holes in the top of the box where the wires enter should be bushed with porcelain tubes. If the wires be placed inside a pipe, they should each be encased in a piece of flexible

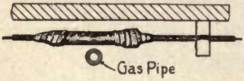


Fig. 256

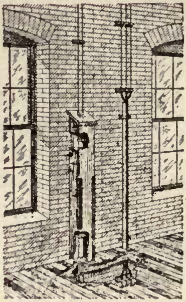


Fig. 257

tubing that will extend from the insulator below the end of the pipe to the first one above it. Porcelain tubes should always be used when the wires pass through walls and floors. These tubes should be long enough to reach all the way through the wall or floor, except in special cases, when a piece of pipe may be used with a long porcelain bushing put into it from each end and cemented in place.

360. Moulding Work.—In this class of work the wires are placed in grooved pieces of wood that are provided with a wooden cap that is fastened to the body of the moulding after the wires have been put in place. The dimensions of this moulding are governed by the requirements of the Underwriters, and the number of grooves is usually two or three, depending upon whether it is to be used on a two- or three-wire system. The capping can be made to correspond in design and color to the other woodwork in a building or room, which makes it less conspicuous.

Moulding work is extensively used alone and in combination with other classes of work, there being numerous fittings on the market that can be used in changing from one system to the other. It cannot be used in damp places, or in rooms where it will be subjected to fumes, or in concealed work or elevator shafts. Approved rubber covered wire should be used when it is placed in moulding. The same precautions should be taken in protecting the wires in this class of work where they pass through floors and ceilings as were mentioned for open, or exposed, work. A device known as a **kicking box**, Fig. 258, is usually used in protecting the wires at the points where they enter or emerge from the floor.

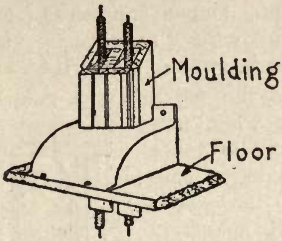


Fig. 258


Fig. 259

Metal mouldings, such as those shown in Fig. 259, are used quite extensively at the present time, on circuits requiring not more than 600 watts and where there is a difference in potential not to exceed 300 volts. Special fittings must be used with this kind of moulding so that it is continuous both mechanically and electrically. The moulding should be grounded, or the rules governing its installation are practically the same as those governing the installation of conduit work.

361. Concealed "Knob and Tube" Work.—Concealed "knob and tube" work is fast disappearing on account of the great danger of fire due to short-circuits between the wires that are placed in the walls and floors. This class of wiring is quite cheap and it is extensively used in frame buildings in localities where the Inspection Departments will permit. The wires for this class of work must have an approved rubber insulation and be supported by means of knobs or tubes on the joist and studding. When the wires are run in a direction perpendicular to the direction in which the joists run, holes are drilled in the joists and porcelain tubes, with a shoulder on one end, are driven into these holes, through which the wires are passed, as shown in Fig. 260. The knobs should support the wires at least 1 inch from the surface over which they run; these knobs should not be farther apart than 4½ feet and the wires fastened to them in an approved manner. Split knobs are usually used for this class of work, as the wires are no longer approved by the underwriters. The various wires should be at least 5 inches apart at all times when supported on the knobs, and it is best to have the wires run on separate joist or studding when possible, as shown in Fig. 261. Porcelain tubes should always be used where the wires pass through walls and ceilings, and the knobs should be so located that there is no strain on the tubes. Each wire must be encased in a piece of flexible tube at all outlets, switches, distributing centers, etc., and this piece of tubing should be of sufficient length to extend from the last insulator and project at least 1 inch beyond the outlet, as shown in Fig. 260. When wires cross pipes or other wires, they should be insulated by means of porcelain tubes or pieces of flexible tubing, as shown in Fig. 256.

Fig. 260

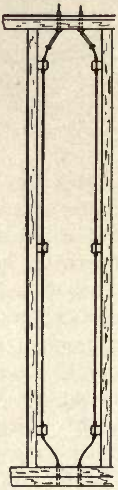


Fig. 261

362. Interior Conduit and Armored Cable Work.—Armor cable consists of rubber-covered wire that is protected from mechanical injury by two layers of flexible steel armor, which also serves to protect the wire to a certain extent from dampness, Fig. 262. A lead covering is often placed between the insulation on the wire and the steel armor, which protects the enclosed conductors from dampness. Leaded armor cables can be used for all classes of work, and the unleaded cable can also be used for all classes where it is not exposed to dampness. Leaded cables may be buried in the walls or floors, but reasonable care must be exercised in installing the unleaded cable to protect it from being exposed to moisture. Special fittings are on the market for connecting the ends of the armor to metal outlet boxes. The armor should be cut away 6 or 7 inches from the end of the wires so that switches, fixtures, etc., may be properly connected.

In new work, holes are drilled in the joists and studding and the cable is pulled into place, it being fastened by means of special straps of metal. Armored cable is used quite extensively in the wiring of old buildings, as it can be put into different places regardless of its coming in contact with pipes, etc.

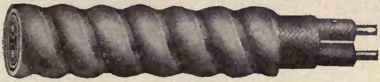


Fig. 262

In conduit work approved rubber-covered wire must be used and it is drawn into a system of iron piping that is installed and connected to all outlet and cut-out boxes before the wires are put in place. The conduit must never have an inside diameter of less than .625 inch and in installing it no bends or elbows should have a radius less than 3.5 inches, nor should there be more than the equivalent of four quarter bends from outlet to outlet. The conduits should be cleaned out before the wires are drawn in and it is often advisable to blow a small quantity of soapstone into them, which will reduce the friction of the wire on the surface of the pipe to a minimum. This system of wiring is the safest, most satisfactory, and in the long run no doubt the most economical method of installing wires.

363. Service Wires.—When the electrical energy is supplied from a source outside the building, certain precautions must be taken in bringing the wires into the building. When the wires are overhead and are taken into the building above the basement, they must be provided with drip loops and pass through insulating tubes in the wall that slope so their outside end is lower than the inside end. Such an arrangement is shown in Fig. 263. When the wires are brought into the basement from an outside service that is overhead, they should be placed in a metal conduit with its outside end bent over and provided with a suitable fitting, thus forming a drip loop, as shown in Fig. 264. When the outside wires are underground and are brought into the basement, they should be placed in metal or porcelain tubes that are tightly sealed afterwards. The leads pass directly to the cut-out, then to the main switch, both of which should be enclosed in a suitable cabinet, and from the switch to the meter, and

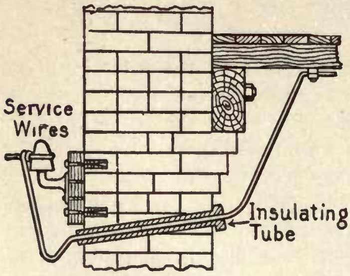


Fig. 263

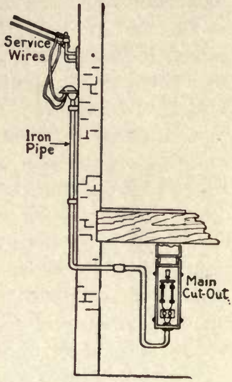


Fig. 264

then to the main distributing center. A three-branch distributing center for a three-wire system is shown in Fig. 265. The gaps in the various leads are for fuses.

364. Location of Outlets, Switches, and Distributing Board.—The various distributing boards from which the branch circuits emanate should always be located as near the center of the load as possible, so that the circuits will be practically the same length. These boards are mounted in either metal boxes or wooden boxes with fireproof lining, depending upon the kind of work. Each branch circuit is provided with a double-pole switch and properly fused. A three-wire distributing board is shown in Fig. 266 and a two-wire board in Fig. 267. A main switch and fuses are placed in the leads connecting the board to the source of energy.

The switches in the various branch circuits outside the distributing board should be located in such positions that they will be convenient to operate. They should, as a rule, in light wiring be placed near a door and on the side nearest the door handle.

The location of the outlets will depend upon the location of the lamps, kind of lamps—arc or incandescent—location of motors, etc. A chart of the standard symbols for wiring plans, as adopted and recommended by the National Electrical Contractors' Association of the United States, is given in Chapter 20.

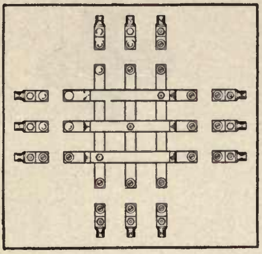


Fig. 265

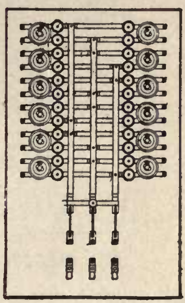


Fig. 266

365. Installing Arc Lamps and Fixtures.—Arc lamps should be insulated from inflammable material, and at all times surrounded with a glass globe surrounding the arc and securely fastened in place. Approved rubber-covered wire should be used and it should be supported on porcelain or glass insulators in constant-current systems that hold the wire at least 1 inch above the surface over which the wire passes, and these wires should never be nearer each other than 8 inches, except in cut-out boxes and in the lamps.

Fixtures, when supported from the gas piping or from any grounded metal work of the building, must be insulated from such metal by an approved insulating joint placed as near the walls or ceiling as possible. The cross-section of an insulating joint is shown in Fig. 268.

366. Electric Heaters.—All electric heaters must be protected by cut-out and controlled by indicating switches. These switches should be double pole except when the device controlled does not require more than 660 watts. Heaters must always be in plain sight unless special permission be given by the Inspection Department having jurisdiction. Stationary heaters, such as radiators, ranges, plate warmers, etc., must be placed in safe locations, isolated from inflammable materials, and always treated as sources of heat.

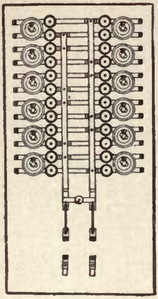


Fig. 267

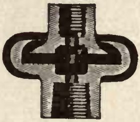


Fig. 268

367. Electric Generators and Motors.—All generators and motors should be located in dry places. They should never be installed in places where a hazardous process is carried on, in dusty places, or in places where they are exposed to inflammable gases or flying of combustible materials.

Generators and motors should always be insulated from the surrounding floor on wooden bases. When it is impossible to insulate them for any reason, the Inspection Department having jurisdiction may permit the omission of the insulating frame, in which case the frame should be permanently and effectively grounded.

368. Electrical Inspection.—No attempt has been made in this chapter to give all the details that must be observed in the proper installation of electrical conductors, it being left to the engineer in charge, who should have a copy of both the National Electric Code and its supplement, which contains a list of approved fittings and materials. The Inspection Department under whose jurisdiction the work is being done should be consulted freely, as it will often save time and trouble in cases where doubtful work has been suspected, and the inspector requires the floors to be taken up or the plaster knocked off in certain places to satisfy himself that the work was properly done.

CHAPTER XVII

THE ALTERNATING-CURRENT CIRCUIT

369. Definition of an Alternating Electromotive Force or Current.—An alternating electromotive force or current is one that changes in value, and reverses in direction at certain regular intervals. Such an electromotive force would be induced in a loop of wire that was resolved in a magnetic field, as shown in Fig. 126. An alternating current would exist in a closed circuit connected to the terminals of such a coil by means of two brushes and slip-rings, as shown in Fig. 127.

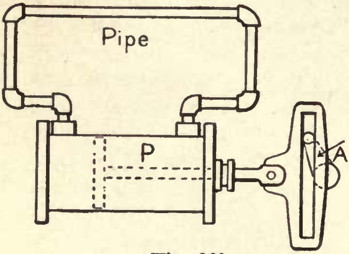


Fig. 269

370. Hydraulic Analogy of an Alterating Current.—The alternating current in an electric circuit can be compared to the flow of water in a closed pipe connected to a cylinder in which there is an oscillating piston operating, as shown in Fig. 269. If the arm (A) be moved at a constant angular velocity there will be a flow of water through the pipe similar to that represented by the curve in Fig. 270. The length of the horizontal line (AB) corresponding to the time of one complete revolution of the arm (A), and the length of the ordinate of the curve, or vertical distance from a point on the line (AB) to the curve, at any instant, represents the rate at which the water or liquid is passing a given cross-section of the pipe, or the current in the pipe.

371. Cycle—Frequency—Alternation—Period—Synchronism—Phase Displacement.—When an alternating pressure or current has passed through a complete set of positive and negative values, starting from any value and again returning to that value in the same direction, the pressure or current has completed what is called a **cycle**. A complete cycle is shown by curve (E) in Fig. 271, which represents an alternating electromotive force. The e.m.f. is zero at (A), increases to a maximum positive value at (C), decreases to zero at (D) and reverses in direction, increasing to a maximum negative value at (E), and then decreases to zero at (B), which completes the cycle, it passing through a similar set of values in the next equal interval of time.

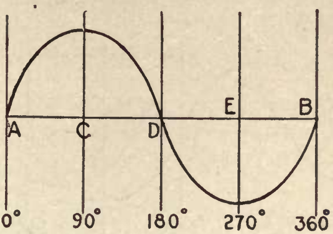


Fig. 270

The number of cycles the pressure or current passes through in one second is called the **frequency**. Thus a 60-cycle electromotive force or current would be one that passed through a complete set of positive and negative values 60 times per second.

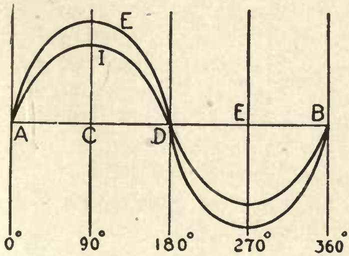


Fig. 271

An **alternation** is half a cycle, and corresponds to a complete set of positive or negative values of e.m.f. or current. There will be just twice as many alternations in a given time as there are cycles, or a frequency of 60 cycles would mean 120 alternations per second.

The **period** of an e.m.f. or current is the time in seconds required to complete one cycle. Thus the period of a 60-cycle e.m.f. or current would be $\frac{1}{60}$ of a second and of a 25-cycle e.m.f. or current $\frac{1}{25}$ of a second.

Two electromotive forces or currents are said to be in **synchronism** when they have the same frequency.

Any number of e.m.f.'s or currents are said to be in **phase** when they pass through corresponding values of their respective cycles at the same time. Thus the current (I), and the e.m.f. (E), Fig. 271, are in phase because they both pass through corresponding values of their cycles at the same time.

Any number of e.m.f.'s or currents are said to be **displaced in phase** when they do not pass through corresponding values of their respective cycles at the same time. Thus the current (I) and the e.m.f. (E), Fig. 272, are displaced in phase, and this phase displacement may be measured in degrees by determining the difference in the degrees represented by the two points where the curves cross the horizontal line (AB). The total length of the line (AB) corresponds to 360 degrees, and if the distance between the two points where the curves (E) and (I) cross the horizontal line is ⅛ of the length of the line (AB), the e.m.f. and current represented by these two curves are displaced in phase by ⅛ of 360 degrees, or 45 degrees. The current lags the e.m.f., because the current curve is shown as crossing the horizontal line (AB), as you pass along the line from left to right, after the e.m.f. curve.

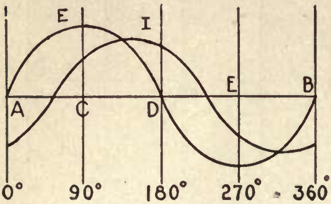


Fig. 272

This phase displacement may be expressed in time as well as degrees. Thus the time interval between when the current and e.m.f. are zero, as shown in Fig. 272, is ⅛ of a period or (1 ÷ 8 × frequency) of a second. The displacement in practice is usually measured in degrees rather than time.

372. Chemical and Heating Effects of an Alternating Current.—It was mentioned in Chapter VIII that the chemical effect of an alternating current was zero. This is due to the fact that the current exists in the circuit in one direction for the same time that it exists in the opposite direction and as a result of this reversal in direction there will be a chemical action taking place first in one direction and then in the opposite direction, and the resultant chemical action will be zero.

The power expended in heating a conductor at any instant is equal to the product of the resistance of the conductor and the square of the current in the conductor. In an alternating-current circuit the current is constantly changing in value and, as a result, the power expended in heating the conductors is changing in value, it at any instant being equal to the product of the resistance and the square of the current at that particular instant. In order to obtain the total heating effect of an alternating current, it is necessary to add up all of the instantaneous heating effects. The heating effect of a current is independent of the direction of the current in the circuit.

373. Sine Wave E.M.F. or Current.—If a simple loop of wire be revolved at a constant rate in a uniform magnetic field, there will be an induced e.m.f set up in the coil, which will reverse in direction and change in value as the coil rotates. The value of the induced e.m.f. will vary as the direction of motion of the coil changes with respect to the magnetic field, it being a maximum when the two sides of the loop move perpendicular to the magnetic field and zero when the two sides of the loop move parallel to the magnetic

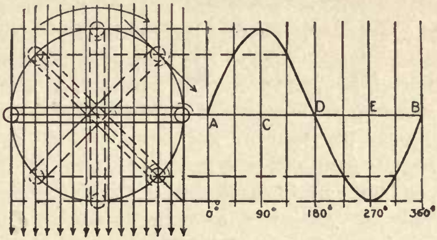


Fig. 273

field. The e.m.f. induced in the coil for positions between those just mentioned will bear a definite relation to the maximum e.m.f., and this relation can be determined as follows: The rate at which the two sides of the loop are moving perpendicular to the field decreases in value from a vertical position and becomes zero for a horizontal position of the coil when the field is vertical, as shown in Fig. 273. The movement of the coil at any instant can be resolved into two parts, one parallel to the magnetic field and the other perpendicular to the magnetic field. It is the part that is perpendicular to the magnetic field that results in an e.m.f. being induced in the coil, and this part is proportional to the sine of the angle the path of the two sides of the coil make with the magnetic field. The sine of this angle will vary as the projection of the coil on the vertical plane. If the projection when the coil is in a perpendicular position be taken as representing the maximum e.m.f., the e.m.f. for other positions will correspond to the projection of the coil upon the vertical plane for those positions. Let a complete revolution be represented by the horizontal line (AB), it corresponding to 360 degrees, then the relation of the e.m.f.'s for various angular positions can be laid off on ordinates drawn vertically through points on the line (AB), which correspond to the angular displacement of the coil from a position perpendicular to the field. The values for the 45° positions are the only ones shown in the figure; the remaining ones, however, are determined in the same way. Such a curve is called a **sine curve,** since its ordinates vary as the sine of the angle represented by the point on the line (AB) through which the ordinate passes. An e.m.f. or current whose value varies as the ordinate of a sine curve is called a **sine e.m.f. or current.** The following calculations are all based on a sine curve. The e.m.f. and current curves met with in practice are very seldom sine curves, but approach a sine curve quite often.

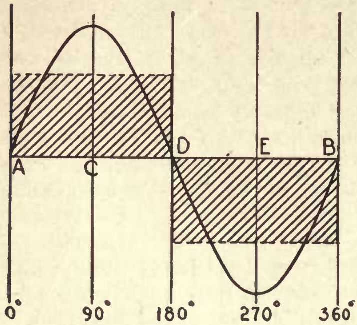


Fig. 274

374. Maximum, Average, and Effective Values of E.M.F. and Current.—The maximum value of an alternating e.m.f. or current is the value represented by the ordinate of the e.m.f. or current curve having the greatest length. Thus in Fig. 274 the maximum e.m.f. occurs at 90° and 270°, it being opposite in direction for the two positions but having the same value.

The average value of an alternating e.m.f. or current is equal to the average of all of the instantaneous e.m.f.'s or currents for a complete alternation, starting with zero value and returning to zero value. For a true sine wave the average e.m.f. and current are always .636 times their maximum value. This relation is determined by finding the area of a positive or negative loop of the e.m.f. or current curve and dividing this area by the distance between the two points where the curve crosses the horizontal line. The rectangles, shown by the shaded portions in Fig. 274, have each the same area as one loop of the sine curve, and the altitude of this rectangle is .636 times the maximum ordinate of the sine curve.

The **effective value** of an alternating current is numerically equal to a steady direct current that will produce the same heating effect in a given time as is produced by the changing alternating current. If a conductor has a resistance of (R) ohms and there is an alternating current in the conductor, the power expended in heating the conductor at any instant is equal to the value of the current at that instant squared, times the resistance in which the current exists. Adding up all of these instantaneous heating effects for a certain time gives the total heating effect. This resultant or total heating effect could be produced by a steady direct current as well as by an alternating current. Now the value of the steady direct current required to produce the same heating effect as is produced by the alternating current corresponds in value to the effective alternating current

$$I^2R = \text{average } i^2R,$$

or

$$I^2 = \text{average } i^2$$

and

$$I = \sqrt{\text{average } i^2}$$

Note—Small letters are used to represent instantaneous values.

For a sine wave the square root of the average of the instantaneous values squared is equal to .707 times the maximum current.

Average value = .636 maximum value
Effective value = .707 maximum value
Effective value = 1.11 average value

The effective value divided by the average value is equal to 1.11, which is called the **form factor** of the wave. The above relations hold true for sine waves only.

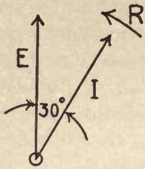


Fig. 275

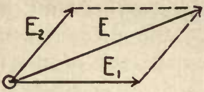


Fig. 276

375. Vector Representation of Alternating E.M.F.'s and Currents.—A vector quantity is one having both direction and magnitude; it may be represented by a line, called a vector, drawn in a definite direction corresponding to the direction of the quantity it represents and having a length corresponding to the value of the vector quantity to a suitable scale. Thus a current of 10 amperes and an e.m.f. of 10 volts, displaced in phase by 30 degrees, would be represented as shown in Fig. 275.

These vectors can be thought of as rotating, and one revolution corresponds to 360 degrees. The counter-clockwise direction of rotation is taken as positive. In representing alternating e.m.f.'s and current by vectors, the effective values are the ones usually used.

376. Addition and Subtraction of Vectors.—Two vectors are added in the same way as two forces are added in determining the resultant force. The two vectors (E_1) and (E_2), shown in Fig. 276, are added by completing the parallelogram, as shown by the dotted lines, and drawing the diagonal gives the resultant (E). Its direction is that indicated by the arrowhead.

Two vectors are subtracted by reversing one and adding them. Thus if it is desired to know the value of ($E_1 - E_2$), shown in Fig. 276, the vector (E_2) is reversed in direction and then added to the vector (E_1); the direction of the vector (E), representing the difference, is shown in the figure by the arrow head.

377. Factors Determining the Value of an Alternating Current.—The current in a circuit upon which there is a steady direct voltage impressed is equal to the value of the impressed voltage in volts divided by the total resistance in ohms. In an alternating-current circuit upon which there is a constant effective pressure impressed, the value of the effective current is determined not by the resistance alone but by the combined effects of the resistance, inductance, and capacity, if they all be present in the circuit. If there is no inductance or capacity in the circuit, then the same law holds for the alternating-current circuit as is true for the direct-current circuit. The current in the alternating-current circuit will be equal to the impressed voltage divided by the resistance of the circuit

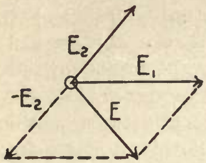


Fig. 277

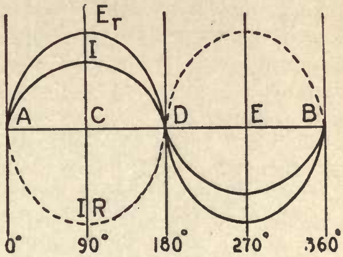


Fig. 278

when the effects of the inductance and capacity are exactly equal, they acting in opposition to each other, as will be explained later.

378. E.M.F.'s Required to Overcome Resistance.—The e.m.f. at any instant required to overcome the resistance of a circuit is equal to the product of the current at that instant and the resistance of the circuit, or (IR). If there be an alternating current, as represented by the curve (I) in Fig. 278, in a circuit, the e.m.f. at any instant required to produce this current is equal to (IR) and varies directly as the current or passes through corresponding values at the same time. The current and e.m.f. will, as a result, be in phase, and the curve (E_r) represents the impressed e.m.f. required to produce the current (I).

379. Hydraulic Analogy of Inductance.—If the electric current in an alternating-current circuit be represented by a fluid that flows through a pipe, as shown in Fig. 279, due to the alternating pressure that is created by the pump (P), then an inductance in such a circuit can be represented by a fluid motor (M) similar to that shown in the figure. When such a motor is connected in the circuit, considerable time will be required for the current of liquid to reach a maximum steady value if a constant pressure be applied to the circuit by the pump, on account of the inertia of the wheel (W) that is attached to the fluid motor. After the pressure has been applied to the motor for some time, the motor will have reached a speed such that it offers practically no resistance to the flow of the liquid through it. If, however, there be a change in the pressure produced by the pump, there will be a tendency for the current of liquid to change in value, and the action of the fluid motor will always be such as to tend to prevent a change in the current—that is, if the current tends to increase in value due to an increase in pump pressure, the motor will oppose this increase, and if the current tends to decrease in value, due to a decrease in pump pressure, the motor will tend to prevent this decrease. The action of the motor at all times is such as to tend to prevent any change in the value of the current in the circuit of which it is a part.

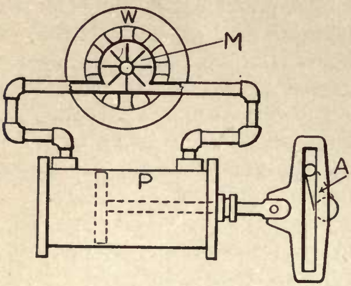


Fig. 279

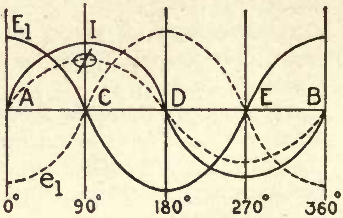


Fig. 280

The motor in the hydraulic problem just discussed corresponds in action to the inductance of an alternating-current circuit in which there is an alternating current. In the hydraulic problem, if an alternating pressure be applied to the motor instead of a direct pressure, its direction of rotation will change twice per cycle of the impressed pressure. The direction of rotation, however, will not change at the same instant the pressure produced by the pump changes on account of the inertia possessed by the moving parts of the fluid motor. The motor will continue to rotate in a given direction for some time after the pressure has been reversed in direction. The velocity of the paddle wheel of the motor determines the value of the current of liquid through it, and the direction of rotation of the paddle wheel determines the direction of the current. Since the velocity of the fluid motor is not a maximum when the pressure of the pump is a maximum, it reaching a maximum velocity in a given direction after the pressure produced by the pump has reached its maximum value in the same direction, and the velocity of the motor is zero after the pressure of the pump is zero, the current of liquid in the circuit must lag the pressure.

380. Phase Relation of E.M.F. to Overcome Inductance and the Current in an Alternating-Current Circuit.—Assume there is a circuit containing inductance alone, and that there is a current in this circuit represented by the curve (I), Fig. 280. The magnetic field created by the current at any time will depend upon its instantaneous value. Thus the magnetic field or lines of force associated with the current will be a maximum when the current is a maximum, will decrease or increase in value with a decrease or increase in the value of the current, and will reverse in direction at the same time the current reverses in direction. Since the above relation exists between the current in the circuit and the magnetic flux produced by the current, a second curve (Φ) may be drawn, as shown in Fig. 280, whose ordinate at any instant will represent to a suitable scale the magnetic flux at that instant. With a change in the magnetic flux associated with the circuit, there will be an induced e.m.f. set up in the circuit, which at any instant is proportional to the rate at which the flux is changing with respect to the circuit, or the rate at which the conductor forming the circuit is cutting the lines of force. By investigating curve (Φ) it is seen that the flux is changing at its greatest rate when it is zero in value and is changing at a minimum rate when it is at its maximum value; or the induced e.m.f. in the circuit is zero at the points (C) and (E) and is a maximum at the points (A), (D), and (B).

The value of the induced e.m.f. at any other time during the cycle will depend upon the rate at which the flux is changing in value, and its direction will, according to Lenz's Law, always be such as to oppose a change in the value of the current in the circuit. Thus, if the current be increasing in value in the positive direction, as it is between the points (A) and (C), the induced e.m.f. acts in such a direction as to oppose this change in the current, or it acts in the negative direction. If the current be decreasing in value in the positive direction, the induced e.m.f. opposes this decrease, or it acts in the positive direction. The curve (e_1) represents the e.m.f. induced in the circuit. If the circuit has no resistance (a theoretical condition), the only e.m.f. required to produce the current (I) in the circuit would be one that would overcome the e.m.f. (e_1). Such an e.m.f. would be represented by the curve (E_1), whose ordinates are at each instant equal to those of (e_1) but opposite in sign, or (E_1) acts opposite to (e_1), and will produce the current (I). From the relation of the curve (I) and (E_1) in the figure, it is seen that the current and impressed e.m.f. in an inductive circuit are displaced in phase by 90° and that the current lags the e.m.f.

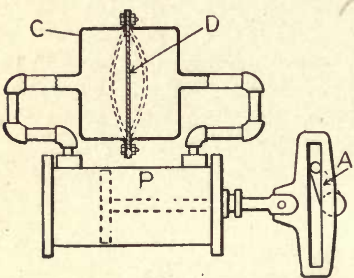


Fig. 281

381. Hydraulic Analogy of Capacity.—The hydraulic analogy of a condenser is shown in Fig. 281. A flexible rubber diaphragm (D) is stretched across a specially constructed chamber (C) which is connected to a pump (P), as shown in the figure, that produces an alternating pressure. When the diaphragm (D) is in its normal position, it offers no opposition to the flow of the liquid through the pipe in either direction. As soon, however, as the diaphragm is displaced from its neutral position, it sets up a reaction which opposes the flow of the liquid, and this reaction will increase in value as the diaphragm is displaced more and more, finally reaching a value equal to the pressure, causing the liquid to flow through the pipe, and when the reaction becomes equal to the acting pressure there will be no current. If, now, the current be reversed in direction, the diaphragm will return to its normal position, and while it is returning, it will act in the same direction as the current. When the diaphragm has reached its normal position and it is forced to the opposite side, it will immediately react upon the current and tend to stop it, and this reaction will finally reach such a value that there will be no current in the circuit. It is seen, then, that the diaphragm acts with the current one-half of the time and in opposition to it one-half of the time. The reaction of the diaphragm corresponds to the electrical pressure at the terminals of a condenser connected in an alternating-current circuit, and it has a maximum value when the current is zero and a zero value when the current is a maximum.

382. Phase Relation of the E.M.F. to Overcome the Effect of Capacity and the Current in an Alternating-Current Circuit. —The current in a circuit containing capacity alone may be represented by a curve such as (I), Fig. 282. The flow of liquid through the chamber (C), Fig. 281, could be represented by such a curve, and since the reaction of the diaphragm corresponds to the e.m.f. at the terminals of the condenser, the phase relation of the e.m.f. and the current can be determined by an investigation of Fig. 281, carrying the operation through a complete cycle. The position of the diaphragm must be normal when the current is a maximum, say at the point (C), Fig. 282, as it produces no opposition to the flow of liquid. As the diaphragm is extended to either side, its reaction increases and it opposes the flow of liquid, or if the current is in the positive direction, the action of the diaphragm is negative. If the current reverses in direction when it has reached a zero value and starts to increase in value in the negative direction, the diaphragm will act with the current or they will both be negative. When the diaphragm has reached its normal position, its reaction is zero

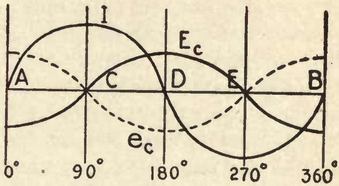


Fig. 282

and the current is a maximum, and at this point the reaction of the diaphragm changes sign and the current starts to decrease in value in the negative direction. While the current is decreasing in value in the negative direction, the reaction of the diaphragm is increasing in value in the positive direction. The current again reverses in direction after reaching zero value and starts to increase in the positive direction, the reaction of the diaphragm decreasing in value in the positive direction, which completes the cycle. The curve (e_c), Fig. 282, represents the reaction of the diaphragm, or the electrical pressure at the terminals of a condenser connected in an alternating-current circuit carrying a current (I). Since the curve (e_c) represents the reaction in the circuit, the e.m.f. required to overcome this reaction must be equal in value and opposite in direction to it at each instant. The curve (E_c) then represents the e.m.f. required to overcome the effect of the capacity in a circuit and produce the current (I). It is seen by an inspection of the curves that the current (I) leads the impressed e.m.f. (E_c) by 90 degrees.

383. E.M.F. Required to Overcome Combined Effects of Resistance, Inductance, and Capacity.—By comparing the curves (E_l) and (E_c) in Figs. 280 and 282, it is seen that they are displaced in phase by 180 degrees, or the e.m.f.'s they represent act just opposite to each other. If now inductance and capacity be present in a circuit at the same time, the electrical pressures required to overcome their effects would tend to neutralize. When the effects of inductance and capacity are equal, the two e.m.f.'s exactly neutralize, and the only e.m.f. required would be that to overcome the resistance of the circuit. The current and impressed e.m.f. in such a circuit would be in phase. If, however, the e.m.f.'s required to overcome the effects of inductance and capacity are not equal, they will not exactly neutralize and there will be a resultant e.m.f. in the circuit to overcome, which has a value at any instant equal to the difference between the e.m.f.'s to overcome the effects of inductance and capacity. The e.m.f.'s required to overcome the effects of resistance, inductance, and capacity, and thus produce the current (I), are shown in Fig. 283. The e.m.f. required to overcome the effect of inductance in this case is greater than that required to overcome the effect of capacity, and they will not exactly neutralize each other. The curve (R) represents their combined value. This resultant pressure represented by the curve (R) must now be combined with the e.m.f. to overcome the resistance (E_r) in order to obtain the impressed pressure required to produce the current (I). These two curves can be combined by adding their ordinates for various points along the horizontal line (AB), the algebraic sum of their ordinates at any point being the ordinate of the resultant curve (E), which represents the total pressure that must be impressed upon the circuit to produce the current (I). When the pressure required to overcome the effect of the inductance is greater than the pressure required to overcome the effect of the capacity, the current lags the impressed pressure, as shown in Fig. 283. If the pressure required to overcome the effect of the capacity is greater than that to overcome the effect of the inductance, the current in the circuit will lead the impressed pressure.

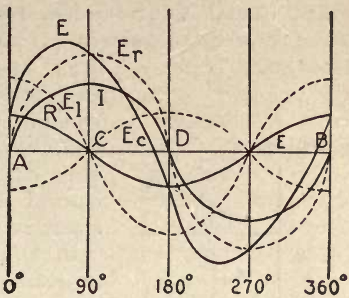


Fig. 283

384. Numerical Values of E.M.F. Required to Overcome Resistance, Inductance, and Capacity.—If the current in a circuit changes in value according to the sine law, and (I) be taken as the effective value of the current in the circuit, the pressures required to overcome the effect of the inductance and capacity can be determined by means of the equations

$$E_l = 2 \times \pi \times f \times L \times I \qquad (131)$$

$$E_c = \frac{I}{2 \times \pi \times f \times C} \qquad (132)$$

In the above equations (f) represents the frequency in cycles per second, $\pi = 3.1416$, (L) is the inductance of the circuit in henrys, (C) is the capacity in farads, and (I) is the effective current in amperes. (E_l) and (E_c) represent the effective e.m.f.'s required to overcome the effects of the inductance and capacity, respectively. The e.m.f. required to overcome the effect of inductance leads the current by 90 degrees, and the e.m.f. required to overcome the effect of capacity lags the current by 90 degrees. The e.m.f. required to overcome the resistance is equal to (RI) and it is always in phase with the current. These three e.m.f.'s can be represented by three vectors, as shown in Fig. 284, the counter-clockwise direction of rotation being taken as positive.

385. Total Electromotive Force Required to Produce a Given Alternating Current.—If the two quantities $(2 \times \pi \times f \times L \times I)$ and $(I \div 2 \times \pi \times f \times C)$, Fig. 284, are equal in value, the vectors representing them will be equal in length. The resultant of these two vectors then will be zero, and the only e.m.f. required to produce the current (I) is that to overcome the resistance, which is equal to (RI).

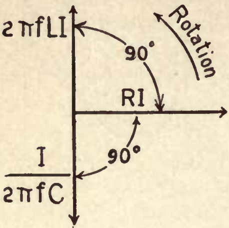


Fig. 284

If, however, the e.m.f. required to overcome the effect of the inductance is greater than that to overcome the capacity, the vector (E_l), Fig. 285, will be greater in length than the vector (E_c). The resultant of these two e.m.f.'s will be equal to $(E_l - E_c)$, and its direction will correspond to that of the larger vector, or (E_l). This resultant must now be combined with (E_r) in order to obtain the total e.m.f. required to produce the current (I), which can be done graphically, as shown in the figure. The resultant (E) is equal to the diagonal of a parallelogram whose sides are $(E_l - E_c)$ and (E_r), and its value is equal to the square root of the sum of the squares of the two sides, or

$$E = \sqrt{E^2 + (E_l - E_c)^2} \qquad (133)$$

Substituting in the above equation the values of (E_l) and (E_c) as given in equations (131) and (132), and the value of (E_r), which is equal to (RI), gives the equation

$$E = \sqrt{(RI)^2 + \left(2\pi f LI - \frac{I}{2\pi f C}\right)^2} \qquad (134)$$

By taking (I) from under the radical sign, this equation can be changed to the form

$$E = I\sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f C}\right)^2} \qquad (135)$$

or

$$I = \frac{E}{\sqrt{R^2 + \left(2\pi fL - \frac{1}{2\pi fC}\right)^2}} \qquad (136)$$

The above equation gives the value of the current (I) in terms of the impressed electromotive force (E), the ohmic resistance of the circuit (R), the inductance (L) in henrys, the capacity (C) in farads, frequency (f) in cycles per second, and the constant (2π), which is equal to (2×3.1416) or 6.2832.

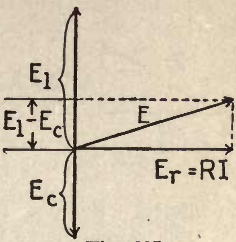


Fig. 285

386. Impedance and Reactance of a Circuit.—The impedance of a circuit in which there is an alternating current is the total opposition offered by the circuit to the flow of the electricity through it. The letter (Z) is usually used to represent the impedance. It is, from equation (136), numerically equal to

$$Z = \sqrt{R^2 + \left(2\pi f L - \frac{1}{2\pi f C}\right)^2} \qquad (137)$$

The impedance of a circuit is composed of two factors, the **resistance** and the **reactance.** The reactance is the quantity which, when multiplied by the current, gives the component of the impressed e.m.f. that is at right angles to the current. The resistance multiplied by the current gives the component of the impressed e.m.f. in phase with the current. The reactance, which is usually represented by the letter (X), is equal to

$$X = 2\pi f L - \frac{1}{2\pi f C} \qquad (138)$$

The above value of (X) is composed of two factors, $(2\pi fL)$ and $(1 \div 2\pi fC)$. The quantity $(2\pi fL)$ is called the **inductance reactance** and is represented by the symbol (X_l), while the quantity ($1 \div 2\pi fc$) is called the **capacity reactance** and is represented by the symbol (X_c). In general:

$$Z = \sqrt{R^2 + X^2} \qquad (139)$$

or

$$Z = \sqrt{R^2 + (X_l - X_c)^2} \qquad (140)$$

The inductance reactance (X_l) is considered as positive and the capacity reactance (X_c) as negative, when they are being combined. The impedance and the reactance of a circuit are measured in ohms just as the resistance is measured in ohms.

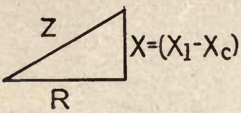


Fig. 286

387. Impedance Diagram.—Since the impedance of a circuit is equal to the square root of the sum of the squares of two quantities, as given in equation (139), a right-angle triangle can be drawn, as shown in Fig. 286, its three sides representing the resistance, reactance, and impedance. Such a figure is called an impedance diagram.

388. Impedances in Series.—Any number of impedances in series can be added by adding their resistances and reactances, respectively, which gives the resistance and the reactance of the resultant impedance. Thus two impedances, (Z_1) and (Z_2) connected in series, may be added as shown in Fig. 287a, both reactances being positive. If one of the reactances be negative, the impedances are added as shown in Fig. 287b,

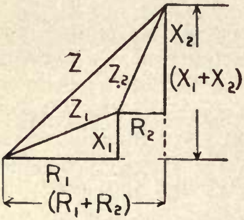


Fig. 287 a

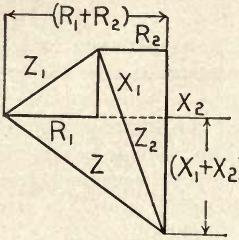


Fig. 287 b

the resultant reactance being negative; it may, however, be positive, depending upon whether the negative reactance is greater or less than the positive reactance. If the resultant reactance is positive, the current lags the e.m.f.; and if the resultant reactance is negative, the current leads the e.m.f. The impedance of a series circuit composed of a number of impedances (Z_1), (Z_2), (Z_3), etc., can be calculated by substituting in the following general equation

$$Z = \sqrt{(R_1 + R_2 + R_3 + \text{etc.})^2 + (X_1 + X_2 + X_3 + \text{etc.})^2} \quad (141)$$

Example.—Calculate the total impedance of a circuit composed of two impedances in series having resistances of 10 and 5 ohms and reactances of 15 and —5 ohms, respectively.

Solution.—The total resistance of the circuit is (10 + 5), or 15 ohms and the resultant reactance is [15 + (—5)], or 10 ohms. Combining the total resistance and the resultant reactance gives

$$Z = \sqrt{(15)^2 + (10)^2} = 18.03\text{—}$$

Ans. 18.03— ohms.

389. Impedances in Parallel.—In calculating the combined impedance of a number of impedances in parallel, an equation is used similar to equation (141), but instead of using the separate resistances and reactances, the **conductance** and **susceptance** of the circuit are used.

The conductance of a circuit is the quantity by which the e.m.f. must be multiplied to give the component of the current parallel to the e.m.f.

The susceptance of a circuit is the quantity by which the e.m.f. must be multiplied to give the component of the current perpendicular to the e.m.f.

Admittance, conductance, and susceptance are all measured in a unit called the **mho.**

The conductance is represented by the letter (G) and it is numerically equal to

$$G = \frac{R}{R^2 + X^2} = \frac{R}{Z^2} \quad (142)$$

The susceptance is represented by the letter (B) and it is numerically equal to,

$$B = \frac{X}{R^2 + X^2} = \frac{X}{Z^2} \quad (143)$$

The reciprocal of the impedance of a circuit is called the **admittance** and is represented by the letter (Y).

$$Y = \frac{1}{Z} \qquad (144)$$

Since

$$Z = \frac{E}{I} \qquad (145)$$

Then

$$Y = I \div E \qquad (146)$$

The admittance of a circuit bears the same relation to the conductance and susceptance as exists between the impedance, resistance, and reactance, or

$$Y = \sqrt{G^2 + B^2} \qquad (147)$$

The total impedance of a number of devices connected in parallel then is equal to the reciprocal of the admittance, which can be determined by the equation

$$Y = \sqrt{(G_1 + G_2 + \text{etc.})^2 + (B_1 + B_2 + \text{etc.})^2} \qquad (148)$$

Example.—Calculate the total impedance of two impedances in parallel having resistances of 8 and 6 ohms, and reactances of 4 and 5 ohms, respectively.

Solution.—Substituting in equation (142) gives the value of the conductance of the first branch (G_1), equal to

$$G_1 = \frac{8}{8^2 + 4^2} = \frac{8}{80} = \frac{1}{10} = .1 \text{ mho}$$

and the conductance of the second branch (G_2) equal to

$$G_2 = \frac{6}{6^2 + 5^2} = \frac{6}{61} = .983 \text{ mho}$$

Substituting in equation (143) gives the value of the susceptance of the first branch (B_1), equal to

$$B_1 = \frac{4}{8^2 + 4^2} = \frac{4}{80} = \frac{1}{20} = .05 \text{ mho}$$

and the susceptance of the second branch (B_2), equal to

$$B_2 = \frac{5}{6^2 + 5^2} = \frac{5}{61} = .0819 \text{ mho}$$

The total conductance (G) of the circuit is equal to ($G_1 + G_2$), or

$$G = .1 + .0983 = .1983$$

and the total susceptance (B) of the circuit is equal to $(B_1 + B_2)$, or

$$B = .05 + .0819 = .1319$$

The admittance may now be obtained by substituting in equation (147), which gives

$$Y = \sqrt{(.1983)^2 + (.1319)^2}$$
$$= \sqrt{.039\,323 + .017\,398}$$
$$= \sqrt{.056\,72}$$
$$= .238 \text{ mho}$$

The impedance is equal to the reciprocal of the admittance, or

$$Z = \frac{1}{.238} = 4.20$$

Ans. 4.20 ohms.

390. Phase Relation of the Current and Potential Drops in a Series Circuit.—The series circuit shown in Fig. 288 is composed of three parts, a resistance (R), an inductance (L), and a condenser (C). The current is the same in all parts of such

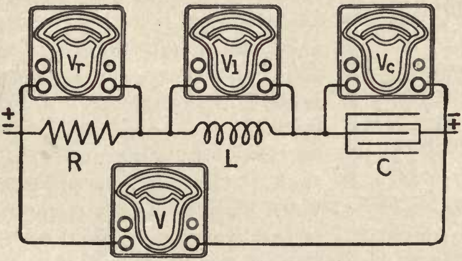


Fig. 288

a circuit and an ammeter, that will operate on alternating current, may be connected in the circuit at any point and it will indicate the current that exists in the circuit.

A voltmeter (V) may be connected across the entire circuit, as shown in the figure, and it will indicate the drop in potential over all three parts of the circuit combined. Three other voltmeters (V_r), (V_l), and (V_c), may be connected across the resistance, inductance and capacity, respectively, as shown in the figure, and their indications will be a measure of the drop in potential over the three parts of the circuit. The sum of the indications of the three voltmeters, (V_r), (V_l), and (V_c), will be greater than the indications of the voltmeter (V) for the following reason: The drop in potential over the resistance is in phase with the current, the drop in potential over the inductance leads the current, and the drop in potential over the capacity lags the current. Since these three drops in potential are not in phase, their resultant is not equal to their numerical sum. The drops over the inductance and capacity may neutralize each other, being opposite in phase, in which case the voltmeter (V_r) would indicate the same drop as the voltmeter (V). In an alternating-current circuit the sum of the drops over the various parts of the circuit is not equal to the impressed voltage except in a circuit containing resistance alone.

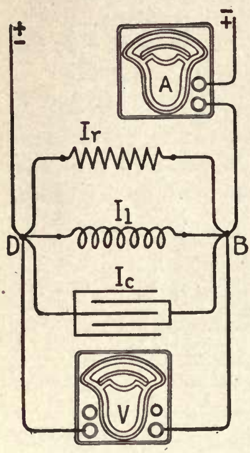


Fig. 289

391. Phase Relation of Currents and Potential Drops in a Divided Circuit.—A divided circuit composed of three branches is shown in Fig. 289. The upper branch is a non-inductive resistance, the middle branch is an inductance, and the lower branch is a capacity. A voltmeter (V) connected between the terminals (D) and (B) indicates the drop in potential over each of the three branches of the divided circuit. The current in any one of the branches is equal to the indication of the voltmeter (V) divided by the impedance of the branch. If the relation between the reactance and the resistance is the same in each branch, the current in the various branches will be displaced in phase from the pressure indicated by the voltmeter (V), the same amount, or the several branch currents (I_r), (I_l), and (I_c) will be in phase. The current (I) indicated on the ammeter (A) connected in the main line is the numerical sum of the branch currents, when they are all in phase, and the vector sum when the branch currents are not in phase.

392. Instantaneous Power in an Alternating-Current Circuit. —The instantaneous power in a circuit at any time is equal to the product of the current and the e.m.f. at that particular instant. The two curves (I) and (E), Fig. 290, represent the current in a circuit and the e.m.f. acting on the circuit. These two curves are in phase and the power in the circuit is represented by the curve (P), its ordinates being proportional to the product of the ordinate of the other two curves. This product is positive in sign at all times since the sign of both the current and the e.m.f. changes at the same time, and both loops of the curve (P) are drawn above the horizontal line. If the current and the e.m.f. be displaced in phase, as shown in Fig. 291, the product of their instantaneous values is not positive throughout the cycle, but it is negative in sign for a portion of the time and, as a result, part of the curve (P) is below the horizontal line. The loops of the curve (P) above the horizontal line represent an output from the source of energy and the loops below the horizontal line represent an input into the source of energy. The actual output then is proportional to the difference in area of an equal number of upper and lower loops. When the current and the e.m.f. are in phase, there

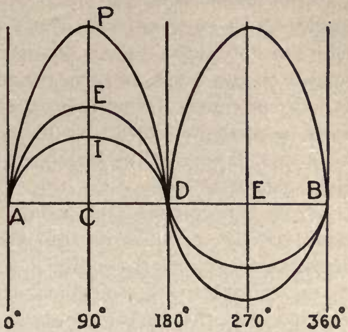


Fig. 290

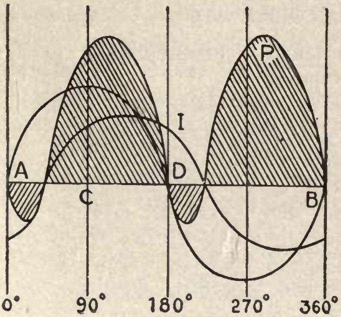


Fig. 291

are no lower loops, and the power in the circuit might be thought of as all being positive. If the current and the e.m.f. be displaced in phase by 90 degrees, the upper and lower loops are equal in area and the resultant power is zero.

The current in any case may be divided into two parts, one part in phase with the e.m.f. and the other part making an angle of 90 degrees with the e.m.f., or at right angles to it. The power output due to the part of the total current at right angles to the e.m.f. is zero, because the area of the upper and the lower power loops are equal. The part of the total current in phase with the e.m.f. is all effective as far as power output is concerned, because the power loops will all be above the horizontal line.

When the current and the e.m.f. are in phase, the power is equal to the product of the effective e.m.f. and the current. If the current and the e.m.f. are displaced in phase, the power is not equal to the product of the effective e.m.f. and the current, but the current must be resolved into two parts, one part in phase with the e.m.f. and the other at right angles to the e.m.f. The part of the current or component in phase with the e.m.f. is equal to (I) times the cosine of the angle (Θ) between the current and the e.m.f. This component of the current times the e.m.f. gives the true power in the circuit, or

$$\text{Power in watts} = E\,I \cos\Theta \qquad (149)$$

in which (Θ) is the angle between the current and the e.m.f. and cos Θ is called the **power factor.**

393. Determining the Value of the Power Factor.—Since the cosine of an angle such as (Θ), Fig. 128, is equal to the ratio of the line (c) to (b) or it is equal to (c÷b), the power factor of a circuit can be easily determined when the constants of the circuit are known. The e.m.f. (E) and the current (I), Fig. 285, are displaced in phase by the angle (Θ). The line (RI) divided by the line (E) gives the cosine of (Θ), or the power factor. Since (E) is equal to (ZI), and $Z = \sqrt{R^2 + X^2}$ the value of the cosine of (Θ) may assume a number of different forms.

$$\text{Power factor} = \frac{RI}{E} = \frac{RI}{ZI} = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + X^2}} \qquad (150)$$

394. A Wattmeter Indicates the True Power in an Alternating-Current Circuit.—The indication of a wattmeter is proportional to the strength of two magnetic fields, one of which is produced by the load current and the other by the impressed pressure. The direction of these two fields must bear a different relation to each other in order that the deflection of the moving system of the wattmeter be in the proper direction. If one field reverses due to a reversal of the e.m.f. or current, the moving system of the wattmeter will tend to move over the scale in the opposite direction to what it did before the one field reversed in direction. If both fields reverse at the same time, the force tending to deflect the moving system does not change in direction. A wattmeter would indicate zero power if the force acting on the moving system acted for the same time in opposite directions. This would be the case when the e.m.f. and the current are displaced in phase by 90 degrees, the upper and the lower power loops being equal in area. When the current and the e.m.f. are in or out of phase, the indication of the wattmeter is proportional to the average of all the values of the instantaneous power for a complete cycle, or the instrument measures the true power. When the e.m.f. and current are displaced in phase less than 90 degrees, the upper and the lower loops of the power curve are not equal. The force acting on the moving system corresponding to the lower loop is opposite to the force corresponding to the upper loop, and the resultant force is thus proportional to the difference in these two forces, which causes an indication corresponding to the true power.

The product of the voltmeter and the ammeter reading, (E) and (I), does not give the true power in an alternating-current circuit unless the current and the e.m.f. are in phase. The product $(E \times I)$ is called the **apparent power.** In general, the wattmeter reading (P), or true power, equals $(E \times I)$, or apparent power multiplied by the power factor.

$$P = E \times I \times \text{power factor} \qquad (151)$$

$$\text{Power factor} = P \div (E \times I) \qquad (152)$$

PROBLEMS ON THE ALTERNATING-CURRENT CIRCUIT

1. A condenser of 132-microfarads capacity and an inductance of .061 henry are connected in series and a 60-cycle e.m.f. of 100 volts is impressed upon the circuit. Calculate the inductance and the capacity reactances, respectively.

Ans. Inductance reactance $(X_l) = 23.0$ ohms.
Capacity reactance $(X_c) = 20.0$ ohms.

2. If a resistance of 4 ohms be connected in series with the circuit given in problem 1, what will be the total impedance of the circuit? What current will be produced by the impressed pressure of 100 volts?

Ans. Impedance of entire circuit $(Z) = 5$ ohms.
Current $(I) = 20$ amperes.

3. Two impedances are connected in series and they each are composed of resistances of 10 and 12 ohms, and reactances of —50 and 70 ohms. Calculate the total impedance of the circuit.

Ans. 29.7 ohms.

4. Calculate the admittance of a circuit having a susceptance and conductance of 3 and 5 mhos, respectively. What is the impedance of the circuit?

Ans. Admittance $(Y) = 5.83$ mhos.
Impedance $(Z) = .171$ ohm.

5. The indication of a wattmeter connected to a certain load is 10 000 watts. An ammeter connected in the line indicates 125 amperes and a voltmeter connected across the load indicates 100 volts. What is the impedance of the circuit and the power factor?

Ans. Impedance $(Z) = .8$ ohm.
Power factor $(PF) = .8$

6. The effective value of a sine alternating current is 10 amperes, what are the average and maximum values?

Ans. Average current $= 9.00$ amperes.
Maximum current $= 14.14$ amperes.

7. A circuit having a resistance of 3 ohms and a resultant reactance of 4 ohms is connected to a 100-volt line. Determine,

(a) the impedance of the circuit, (b) power factor, (c) current, (d) apparent power, (e) true power.

	(a)	Impedance (Z)	= 5 ohms
	(b)	Power factor	= .6
Ans.	(c)	Current	= 20 amperes
	(d)	Apparent power	= 2000 watts
	(e)	True power	= 1200 watts

CHAPTER XVIII

ALTERNATING-CURRENT MACHINERY

395. Alternators.—An alternator is a machine for converting mechanical energy into electrical energy, which is delivered as an alternating current to a circuit connected to the terminals of the machine. The fundamental electrical principle upon which the alternator operates is the same as that of the direct-current generator, namely, electromagnetic induction. Alternators, like direct-current machines, consist of two principal parts, a magnetic field and an armature. The commutator of the direct-current machine is replaced in alternators by slip-rings which are connected to the terminals of the armature winding, and with which brushes make continuous contact and thus conduct the electricity to and from the armature winding.

396. Types of Alternators.—Alternators may be divided into three types, depending upon the mechanical arrangement of the magnetic field and armature, viz,

(A) Alternators with **stationary fields** and revolving armatures.

(B) Alternators with **stationary armatures** and revolving fields.

(C) Alternators with **both armature** and **field stationary** and using a rotating part called the **inductor.** Such alternators are called **inductor alternators.**

Small machines are usually of the revolving armature type, as the e.m.f. generated is usually comparatively low and the current the brushes must carry is small and no difficulty is experienced in properly collecting such a current. A direct-current generator can be converted into a revolving-armature alternator by placing two collector rings on one end of the armature and connecting these two rings to points in the armature winding that are 180 electrical degrees apart. Such a connection for a two-pole, ring-wound armature is shown in Fig. 292. The commutator is not shown in this figure.

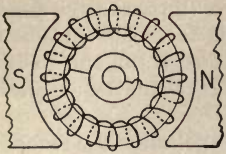


Fig. 292

The necessity of collecting the armature current is overcome by making the armature the stationary part and revolving the field poles, the circuit of the field winding being connected to the source of excitation by means of collector rings and brushes. In such machines the armature winding is placed in a laminated frame that surrounds the revolving field. A revolving-field alternator is shown in Fig. 293.

The construction of the inductor alternator is such that both the armature and the field are stationary. The reluctance of the magnetic circuit in this type of machine is changed in

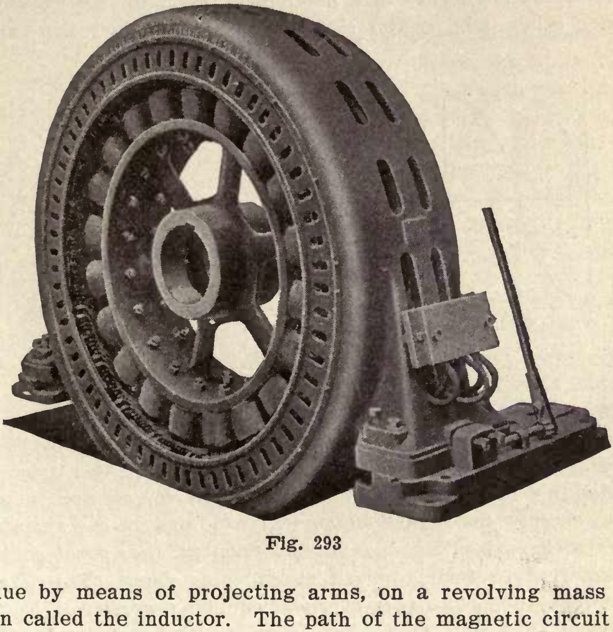


Fig. 293

value by means of projecting arms, on a revolving mass of iron called the inductor. The path of the magnetic circuit is through the armature coils and as a result of the reluctance of this path changing, due to the rotation of the inductor, there will be a varying magnetic flux through the armature winding, which will result in an induced electromotive force in the winding. This induced e.m.f. will be in one direction for an increasing flux through the armature coils, and in the opposite direction for a decreasing flux, resulting in an alternating e.m.f.

Alternators may also be classified into the following groups:

(A) Single-phase Alternators.

(B) Polyphase Alternators.

397. Single-phase and Two-phase Alternators.—A single-phase alternator is one that produces a single electromotive force, and a polyphase alternator is one that produces two or more electromotive forces, which may or may not produce currents in circuits that are electrically independent. The electromotive forces in a polyphase alternator are related to each other only by the element of time, or they are said to

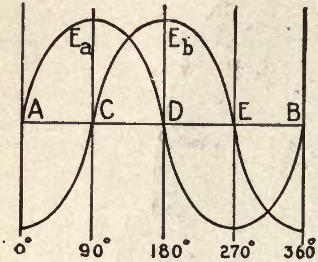


Fig. 294

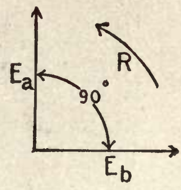


Fig. 295

differ in phase. Thus in a two-phase alternator, there are two electromotive forces which are displaced in phase by 90 degrees, or they are said to be in **quadrature**. The armature inductors in which these electromotive forces are induced may or may not form independent windings on the armature. When these windings are not independent, they must each be connected to two independent collector rings. The e.m.f.'s between these two sets of rings can be represented by two curves (E_a) and (E_b), Fig. 294, which are displaced in phase by 90 degrees, or they may be represented by the two vectors (E_a) and (E_b), Fig. 295, that are at right angles to each other. The arrow (R) in Fig. 295 represents the direction of rotation. The number of collector rings on such a machine can, however, be reduced to three, when they are independent windings on the armature, by using one ring as a common connection for both armature windings. Such an arrangement would constitute a two-phase three-wire system and the one in the previous case would be a two-phase four-wire system. In the two-phase three-wire system, the current in the common lead is equal to the vector sum of the currents in the two outside leads, Fig. 296. When there is the same current in each outside lead and the same phase relation exists between the currents and their e.m.f.'s, the system is said to be balanced. The current in the common lead is not zero for a balanced load, however, as shown in Fig. 296, it being the vector sum of (I_a) and (I_b), or it is equal to (I_n).

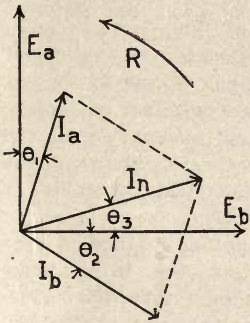


Fig. 296

398. Three-Phase Alternators.—If three single-phase windings be placed upon an armature core and displaced 120 electrical degrees from each other, the electromotive forces induced in these three windings will be displaced in phase 120 degrees, as shown by the curves (E_a), (E_b), and (E_c), in Fig. 297, and by the vectors (A), (B) and (C) in Fig. 298. Each of these windings may be provided with two slip-rings, there being six in all, and connected to electrically independent circuits. Such a system would constitute a three-phase six-wire system. The three circuits connected to the different phases may be kept practically independent of each other by using four leads and connecting three of the collector rings together, as shown in Fig. 299. The lead (4) serves as a common return to the other three. When the three receiving circuits connected between the mains (1), (2), (3), and (4) have the same resistance and reactance, the system is said to be **balanced** and the current in the three circuits are equal and displaced in phase from their electromotive forces by the same angle, the three currents are then 120 degrees apart and their vector sum, which is the current in main (4), is zero. Hence, for a balance load, main (4) carries no current. and this lead can be dispensed with and only three collector rings need be used, the other three being connected together, forming what is called the **neutral point.**

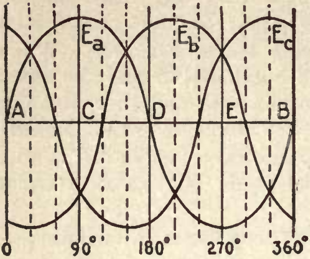


Fig. 297

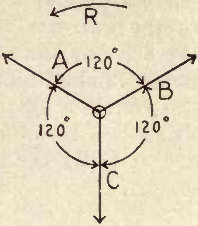


Fig. 298

This arrangement of connections is called the "Y" or "star" scheme of connecting the three windings. Three of the six rings can be dispensed with entirely, one terminal of each of the windings being connected to the neutral point inside the armature, as shown in the symmetrical diagram in Fig. 300.

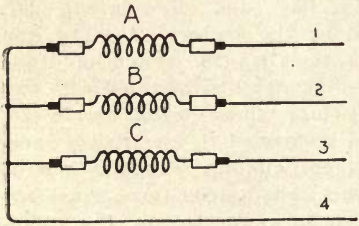


Fig. 299

Another method of connecting the three windings of a three-phase machine is shown in Fig. 301, which is called the "△" (delta) or "mesh" scheme.

399. Relation of E.M.F. and Current in "Y" and "△" Connected Armatures.—The currents in the mains (1), (2), and (3), Fig. 300, are the same as the currents in the three windings (A), (B), and (C).

If the positive direction of the electromotive forces and currents in the windings (A), (B), and (C) be taken in the direction indicated by the arrows in Figs. 300 and 301, then the e.m.f. between the mains (1) and (2) in Fig. 300 will be equal to the vector difference between the e.m.f.'s in windings (A) and (B). (It must be remembered that the direction of the arrows does not represent the actual direction of the e.m.f.'s and currents, but only the assumed positive direction.) The vector difference between the two e.m.f.'s in the windings (A) and (B), which are displaced in phase by 120 degrees, is ob-

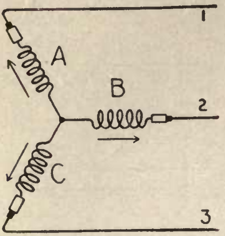


Fig. 300

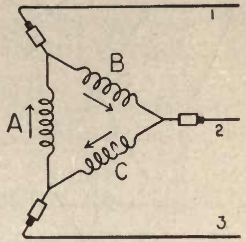


Fig. 301

tained by reversing the direction of the vector (B) and adding it to the vector (A), giving the result (A — B), Fig. 302. The e.m.f.'s between leads (2) and (3), and (3) and (1) are obtained in a similar manner. These resultant e.m.f.'s will be equal to $\sqrt{3}$ times the e.m.f. in any one of the windings, which can be shown by reference to Fig. 303. (E_a) represents the e.m.f. in winding (A) and ($-E_b$) represents the e.m.f. in winding (B). Assuming (E_a) and (E_b) are each equal to 2 units of e.m.f., then (a) will represent 1 unit and (d) will represent $\sqrt{3}$ units of e.m.f. Two (d), which is equal to (A — B), will be equal to ($2\sqrt{3}$) units of e.m.f. when (E_a) and (E_b) are equal to 2 units of e.m.f. Hence (A — B) is equal to the $\sqrt{3}$ times the e.m.f. per winding.

The e.m.f. between leads (1) and (3), Fig. 301, is the same as the e.m.f. in the winding (A), or the e.m.f. between leads for the "△" connection is equal to the e.m.f. in the winding connected to the two leads. The current in lead (1) is equal to the vector difference between the currents in windings (A) and (B). These two currents are displaced in phase 120 degrees and their difference is obtained by reversing (B) and adding it to (A). The current in the other leads are obtained in a similar manner and for a balance load the current in any lead will be equal to $\sqrt{3}$ times the current in any winding.

400. Connecting Receiving Circuits to a Three-Phase System.—When the receiving circuits connected to the various phases of a three-phase system are dissimilar or take unequal current, resulting in an unbalanced load, four mains should be used,

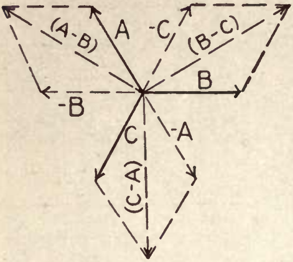


Fig. 302

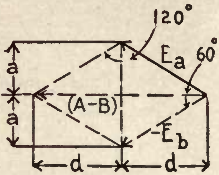


Fig. 303

as indicated in Fig. 299, each receiving circuit then takes current from one of the windings (A), (B), or (C) over the main (4) and one of the outside mains. It is always desirable, however, in the operation of alternators to keep the loads on the various phases as near equal as possible and in practice the different receiving circuits are so distributed between the three phases as to satisfy this condition as nearly as possible. If three single-phase motors, all of the same capacity and carrying the same load, be operated from the three phases of a three-phase system, the system will be balanced and no current will exist in the lead (4) when the connections are made as shown in Fig. 299. Three lighting circuits taking equal currents will result in the same condition. If, however, one of the motors or one of the lighting circuits be disconnected, there will then be a current in lead (4).

When the output of the three-phase alternator is used to drive three-phase induction motors, synchronous motors, and synchronous converters, the currents in each of the three windings will be equal and will be displaced in phase from their respective e.m.f.'s by the same angle, or the system is balanced. For balanced load only three leads are required and either the "Y" connection without the neutral, as shown in Fig. 300, or the "△" connection, as shown in Fig. 301, may be employed.

The current in each receiving circuit in Fig. 304 is equal to the current in the lead connected to it, and the e.m.f. over any one of the receiving circuits in Fig. 305 is equal to the e.m.f. between the leads connected to that particular receiving circuit. The current in each receiving circuit in Fig. 305 is equal to the current in each lead divided by the $\sqrt{3}$, and the e.m.f. over each receiving circuit in Fig. 304 is equal to the e.m.f. between leads divided by the $\sqrt{3}$.

401. Measurement of Power in Single-Phase System.—The connections for the measurement of power in a single-phase

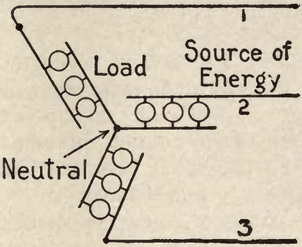


Fig. 304

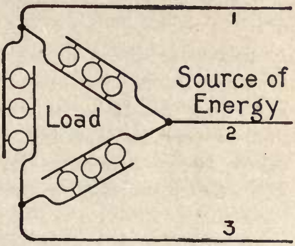


Fig. 305

system are identical to those for the measurement of power in a direct-current circuit. The connections of a Weston indicating wattmeter are given in Fig. 306. The alternator (A) is supplying energy to the lamps (L) as a load.

402. Measurement of Power in a Two-Phase System.—In a two-phase four-wire system, the power is measured in each of the two phases by separate wattmeters as though they were single-phase circuits and the total power is obtained by adding the two wattmeter readings.

In a two-phase three-wire system, the power may be measured by two wattmeters, they being connected as shown in Fig. 307. When the connections are thus made, the upper wattmeter indicates the power in phase (A) and the lower wattmeter indicates the power in phase (B). The total power at any instant is equal to the sum of the indications on the two wattmeters.

A single wattmeter may be used to measure the power in a two-phase circuit by connecting its current coil in the common lead, as shown in Fig. 308, and then noting its indication first, when the pressure circuit is connected to one outside lead,

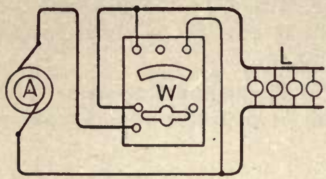


Fig. 306

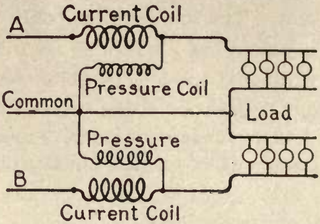


Fig. 307

as shown by the full line in the figure, and second, when the pressure circuit is connected to the other outside lead, as shown by the dotted line in the figure. If the load on the two phases remain constant while these two readings are being taken, the total power output of the two-phase machine will be equal to the sum of the two wattmeter indications.

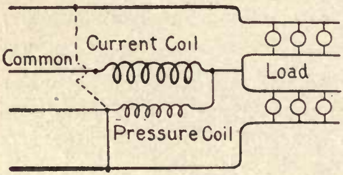


Fig. 308

When the pressure circuit is connected as shown by the dotted line, the wattmeter will not indicate the power delivered by phase (A), nor will it indicate the power delivered by phase (B) when the pressure connection is made as shown by the full line, unless the current in each phase is in phase with its e.m.f. The reason for this can be shown by referring to Fig. 296, in which (E_a) and (E_b) represent the e.m.f.'s of phases (A) and (B), (I_a) and (I_b) represent the currents in the two phases, and these currents are shown displaced in phase from their e.m.f.'s by the angles (θ_1) and (θ_2). The current in the common lead, or in the current coil of the wattmeter, is represented by the vector (I_n), which is the resultant of (I_a) and (I_b). When the pressure coil is connected across phase (A), the wattmeter indication is equal to ($E_a \times I_n \times \sin \theta_3$). The product of ($I_n$) and ($\sin \theta_3$) is equal to the component of (I_n) that is in phase with (E_a). The indication of the wattmeter when the pressure connection is across phase (B) is equal to ($E_b \times I_n \times \cos \theta_3$). The product of ($I_n$) and ($\cos \theta_3$) is equal to the component of (I_n) that is in phase with (E_b). If the component of (I_n) in phase with one of the e.m.f.'s, say (E_a), is equal to the current in phase (A), then the wattmeter will indicate the power in phase (A) when the pressure connection is made as shown by the dotted line. The component of (I_n) in phase with (E_a) will be equal to (I_a) only when the currents in the two phases are in phase with their e.m.f.'s.

403. Measurement of Power in a Three-Phase System.—The power in a three-phase six-wire system can be measured as though it were three single-phase circuits, which in reality it is. The total power output of a machine then is equal to the sum of the wattmeter indications in the three phases. In a three-phase four-wire system the power per phase can be determined by connecting a wattmeter in each of the leads (1), (2), and (3), and connecting their pressure circuits between these leads and the neutral lead (4), Fig. 299. The total power output is equal to the sum of the three wattmeter indications. In a three-phase three-wire system, the power per phase can be determined by connecting three wattmeters as shown in Fig. 309. The total power output of the three phases is equal to the sum of the three wattmeter indications. The above connection will apply equally well when the receiving circuit is connected "Y" or "△," provided the series coils are connected in series with each load and the pressure coils across the loads.

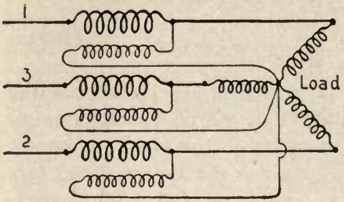


Fig. 309

Two wattmeters may be used in measuring the power in a three-phase three-wire system by connecting them as shown in Fig. 310.

The sum of the two wattmeter readings is the total power delivered to the three receiving circuits. When the power factor is below .5, the reading of one wattmeter will be negative and the total power is then equal to the algebraic sum or numerical difference of the two readings.

All of the above connections apply to either balanced or unbalanced loads, making them applicable to any practical case.

If the system is balanced, only one wattmeter need be used in Fig. 309, and its indication multiplied by three will give the total power, since on a balanced load each of the wattmeters will indicate the same. The power in any balanced three-phase three-wire system is equal to $(\sqrt{3} \times E \times I \times \cos \theta)$, (E) being the e.m.f. between leads, (I) the current in each lead, and $(\cos \theta)$ the power factor.

The power factor of a balanced three-phase circuit can be determined from the two wattmeter readings, when they are connected as indicated in Fig. 310, as follows:

$$\text{Tangent } \theta = \sqrt{3}\,\frac{P_1 - P_2}{P_1 + P_2} \qquad (153)$$

Substituting the values of (P_1), which is the larger reading and will always be positive, and (P_2), which is the smaller reading and may be positive or negative in the above equation, gives the value of the tangent of (θ). The angle (θ) can then be determined from the table of trigonometric functions, Chapter 20, and the cosine of this angle is the power factor.

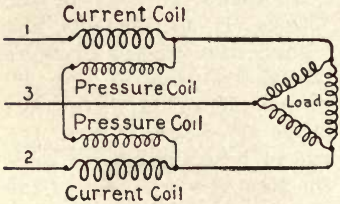


Fig. 310

404. The Synchronous Motor.—In the operation of an alternating-current generator, a mechanical force must be applied to rotate the moving part of the machine, and when a given conductor on the armature is under a north pole of the field, the current in the conductor is in such a direction that the magnetic field exerts a force on it which opposes the movement of the conductor or the rotation of the armature. If the conductor moves out of the field of a north pole and into the field of a south pole, the current will be opposite in direction and, as a result, there is still a force acting on the conductor which opposes the rotation of the armature. If the current output of the generator increases, this opposing force increases and more mechanical power must be supplied to drive the machine.

If the field of an alternator be excited by a direct current, and an alternating current from some external source be sent through its armature, which is revolved by an engine or motor at such a speed that a given inductor in the winding passes from a certain position under a north pole to a corresponding position under the next north pole during the time of one cycle, the motion of the armature will be aided by the current when the direction of the current is such that the force exerted by the magnetic field upon the various conductors aids the motion. Since the current reverses in direction when the inductor passes from one pole to the adjacent pole, which is of opposite polarity, the force exerted by the magnetic field upon the conductor remains constant in direction. If the speed of the alternator has been adjusted so that the above conditions are fulfilled, the engine or motor may be disconnected and the alternator will continue to revolve at a constant speed, which is determined by the frequency of the supplied current and the number of poles comprising the magnetic field of the motor. When an alternator is operated in the above manner it may deliver power to some load by means of a belt or direct connection, and it is called a synchronous motor.

Synchronous motors are designed to operate on single-phase or polyphase circuits, their operation, however, is more satisfactory on polyphase circuits. Motors of this kind are called synchronous because they run in synchronism with the source of supply. Their speed is not necessarily the same as that of the generator driving them, it being the same only when the motor and the generator have the same number of poles. The speed of a synchronous motor can be determined by the use of the equation

$$S = \frac{2 \times f \times 60}{p} \qquad (154)$$

In the above equation (f) is the frequency of the impressed voltage, (p) is the number of poles on the motor, and (S) is the speed of the motor in revolutions per minute.

405. Operation of a Synchronous Motor.—The synchronous motor does not behave in the same way as a direct-current motor. For example: If the field of a direct-current motor be weakened, the motor will speed up in order that its counter-electromotive force may reach the proper value. When the field of a synchronous motor is weakened, there is no change in its speed, since the motor must run in synchronism with the impressed e.m.f. A change in load on a synchronous motor or a change in field strength will result in a change in the phase displacement of the armature current and the impressed voltage When the motor is operating without load, the field current can be adjusted to such a value that the current taken by the motor is very small and its counter e.m.f. is practically in opposition to the impressed voltage. An increase in field current will cause the armature current to lead the impressed voltage, and a decrease in field current will cause the armature current to lag the impressed voltage. If a load be placed on a synchronous motor, its armature will lag a small amount behind the alternator driving it, and this angle will increase with an increase in the load. When the armature of the motor lags, the counter-electromotive force is no longer in opposition to the impressed e.m.f. and a current will be produced which is just sufficient to supply the required torque to enable the motor to carry its load. By increasing the load, the displacement of the armature will become sufficiently great to cause the motor to be thrown out of synchronism, or it will "break down" and stop.

406. Starting Synchronous Motors.—A single-phase synchronous motor cannot be started from rest by sending an alternating current through its armature, the field being excited by a direct current, because the current in the armature is rapidly reversing in direction and tends to cause the armature to rotate first in one direction and then in the other direction. Single-phase synchronous motors must always be brought up to full speed by some outside source of power, such as another motor or engine, before they can be connected to the source of electrical power.

The polyphase synchronous motor may be started by connecting its armature directly to the line, the field circuit of the machine being open. When the machine has reached synchronous speed, the field circuit can be closed and the load gradually thrown on. The motor is usually connected to its load by means of a friction clutch. This method of starting synchronous motors has the great disadvantage that the machine takes an exceedingly large lagging current and this causes an excessive drop in the supply lead and a general disturbance of the distributing system. The taking of a large current from the line can be avoided by the use of an **auto-starter** or **compensator.** The operation of an auto-starter is described briefly in section (415).

Very large synchronous motors are usually started by means of an induction motor that can be operated from the same line the synchronous motor is operated from, or by means of a small engine or direct-current motor, on account of the very small torque exerted by the armature when it is connected to the line.

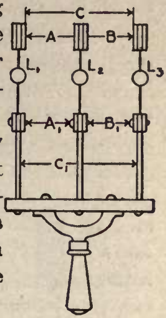


Fig. 311

407. Synchronizing.—In order that an alternator or a synchronous motor may be connected to a line, it must be in synchronism. Synchronizing consists in adjusting the frequency, the phase relation of two e.m.f.'s and their magnitude so that they will coincide when connected together. The general practice in synchronizing is first to adjust the speed of the incoming machine until the frequency of its e.m.f. corresponds to the frequency of the line to which it is to be connected, then to adjust the field current until the machine and the line voltage are the same. Adjust the phase relation of the incoming machine until it is in phase with the line, which can be determined by means of lamps, a synchronoscope, or a voltmeter, and when they are in phase, they may be connected directly together.

When lamps are used in synchronizing, they should be connected as shown in Fig. 311, one in each phase. The switch should be so arranged that it can be closed the instant the machines are in phase and synchronism, viz, when the lamps are dark. Two transformers may be used with their primaries connected across the same leads but on opposite sides of the paralleling switch. Their secondaries may be connected so that their e.m.f.'s are in series or in opposition when the two machines are in phase and synchronism. When they are in opposition and a lamp in circuit, the lamp will be dark when the machines are in phase and synchronism, and if they are connected in series the lamp will be light.

The **synchronoscope** is an instrument that gives an indication of the phase relation of two e.m.f.'s, and the one of higher frequency can be determined by noting the direction in which the pointer on the instrument rotates.

In synchronizing machines it is always best to close the main switch when the incoming machine is coming into proper phase rather than going out of it, as the inertia of the armature in one case assists and in the other retards prompt synchronizing.

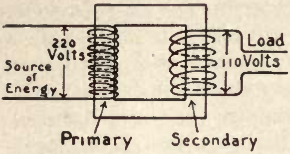


Fig. 312

408. The Transformer.—The transformer in its simplest form consists of two separate and electrically independent coils of wire that are wound upon a laminated iron core that is common to both of the windings. One of the coils is connected to some source of electrical energy which may be high or low voltage, and receives an alternating current from it; and the other coil is connected to a load to which it delivers alternating current at a low or high voltage. The coil of the transformer that is connected to the source of energy is called the **primary coil,** and the one that is connected to the load is called the **secondary coil,** Fig. 312. When the transformer delivers energy at a higher voltage than that impressed upon the primary coil, it is called a **step-up transformer;** when it delivers energy at a lower voltage than that impressed upon the primary coil, it is called a **step-down transformer.**

409. Action of the Transformer without Load.—A transformer is said to be operating on **zero load** when the secondary circuit is open and it is, of course, delivering no current. When there is no current in the secondary winding, there is a very small current in the primary winding for the following reason: The current in the primary winding will cause an alternating magnetic field to be set up through both the primary and the secondary windings, which induces an electromotive force in both of them. This induced e.m.f. is in the opposite direction to the e.m.f. impressed upon the primary winding and very nearly equal to it. It is only this difference in e.m.f. that is available for producing a current in the primary winding, and since this difference is small, there will be a small current in the primary winding when there is no load on the transformer. This current is called the **no-load current** of the transformer. The induced e.m.f. in the secondary coil is in phase with the e.m.f. induced in the primary, and it is in opposition to the impressed e.m.f. on the primary, or the primary and the secondary e.m.f.'s are displaced in phase by 180°.

410. Action of the Transformer on Load.—If the secondary coil of a transformer be connected to a receiving circuit and a delivering current, the transformer is said to be **loaded.** Since the e.m.f. induced in the secondary coil is 180° from the impressed e.m.f. on the primary coil, the current in the secondary coil will produce a magnetizing effect which tends to lessen that produced by the small current already in the primary coil and, as a result, the variations in the magnetic flux passing through both of the coils is decreased, which results in a decrease in the induced e.m.f. in the two coils. This decrease in counter e.m.f. in the primary coil results in an increase in the difference between the impressed e.m.f. and the counter e.m.f., which results in an increase of current in the primary coil. If the load on the secondary coil be increased or decreased there will be a proportional increase or decrease of current in the primary coil.

411. Ideal Electromotive Force and Current Relations in a Transformer.—Neglecting all losses in the transformer, the following relations will exist between the primary and the secondary e.m.f.'s and the primary and the secondary currents. Since it is assumed that the same magnetic flux passes through both the coils, the ratio of the induced e.m.f.'s in the two coils must be the same as the ratio between the number of turns in the two windings. The induced e.m.f. in the primary is equal to the impressed e.m.f. when all losses are neglected, and then

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \qquad (155)$$

Since the magnetizing action of the ampere-turns in the two coils are equal and opposite, neglecting all losses, we have

$$N_p I_p = N_s I_s \qquad (156)$$

or

$$\frac{I_p}{I_s} = \frac{N_s}{N_p} \qquad (157)$$

The above equation states that the primary and the secondary currents are to each other inversely as the number of turns in the two coils.

412. Actual Electromotive Force and Current Relations in a Transformer.—In the previous section the relation of the e.m.f.'s and the currents was based upon the assumption that there were no losses in the transformer, which is not the case in practice. The principal losses to consider in the practical operation of a transformer are:

(A) Loss due to no-load current.

(B) The I^2R loss in the primary and the secondary coils.

(C) Loss due to magnetic leakage.

The part of the no-load current in phase with the impressed e.m.f. on the primary coil represents a loss, and it is the no-load current that affects the ideal relation between the primary and the secondary currents, as given in equation (157).

The resistance of the primary and the secondary coils and magnetic leakage are, on the other hand, the only things that affect to any extent the ideal relation between the primary and the secondary voltages. If all of the magnetic flux created by the current in either the primary or the secondary coils passed through the other coil, there would be no magnetic leakage, which would correspond to an ideal magnetic circuit. Magnetic leakage in its effect is equivalent to an outside inductance that is connected in series with the coils of the transformer. If this inductance be represented by (L), then the e.m.f. required to overcome it when there is a current of (I) amperes in the circuit is equal to ($2\pi fLI$). The effect of coil resistance and magnetic leakage upon the ideal relation between the primary and the secondary voltages is shown by means of a vector diagram.

413. Vector Diagram of a Transformer.—The magnetic flux that passes through both the primary and the secondary coils is represented by the vector (Φ), as shown in Fig. 313, and the no-load current by the vector (I_o). The e.m.f. induced in the primary and the secondary coils will lag the magnetic flux (Φ) 90°.

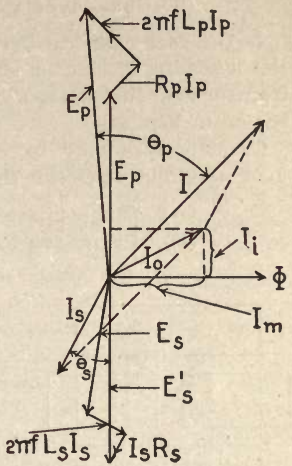


Fig. 313

The e.m.f. impressed upon the primary coil is used in overcoming the resistance of the coil, the counter e.m.f. induced in the coil by the flux (Φ), which passes through both coils, and the effect of magnetic leakage. The e.m.f. to overcome the resistance is in phase with the primary current (I_p), as shown in the figure, the vector (E_p) represents the e.m.f. required to overcome the e.m.f. induced in the primary coil by the flux (Φ), and the vector ($2\pi f L_p I_p$) represents the e.mf. required to overcome the effect of magnetic leakage in the primary, which is 90 degrees in advance of the primary current. The vector (E_p) represents the voltage impressed upon the primary coil. The voltage induced in the secondary winding is represented by the vector (E_s), which bears the same relation to the e.m.f. induced in the primary coil as exists between the primary and the secondary turns, which has been assumed unity in this case. This vector will represent the voltage at the terminals of the secondary coil when there is no load on the transformer. When the secondary coil is supplying a current, the terminal voltage drops on account of the ($I_s R_s$) drop and magnetic leakage. These drops must be subtracted from the total e.m.f. induced in the secondary coil, which gives the terminal voltage equal to (E_s). The drop ($R_s I_s$) is parallel to (I_s), and the drop ($2\pi f L_s I_s$) is perpendicular to (I_s). If the secondary coil is supplying a current (I_s) there will be a current in the primary coil, which combines with the no-load current (I_o), giving the true primary current (I).

414. Types of Transformers.—Transformers may be divided into two types, depending upon the arrangement of the coils and magnetic circuit, viz,

(A) Core-type transformers.
(B) Shell-type transformers.

In the **core-type transformer** the coils are placed outside of the magnetic circuit, as shown in Fig. 314. In the **shell-type transformer** the magnetic circuit surrounds the coils, as shown in Fig. 315.

Transformers may be divided into two types, depending upon the kind of circuit they are to be used on, viz,

(A) Single-phase transformers.
(B) Polyphase transformers.

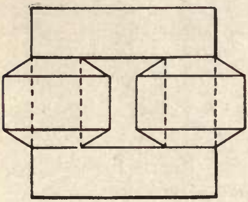


Fig. 314

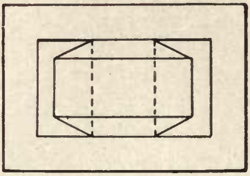


Fig. 315

In a **single-phase transformer** there is only one set of primary and secondary terminals, and the fluxes in the one or more magnetic circuits are all in phase. In the **polyphase transformer** there are a number of different sets of primary and secondary connections. These various sets can be used in the different phases of a polyphase system. In such a transformer there are two or more magnetic circuits through the core, and the fluxes in the various circuits are displaced in phase. It is not necessary to always use polyphase transformers in polyphase circuits, as a number of single-phase transformers may be used, one in each phase.

Transformers may be divided into three types, depending upon the nature of their output, viz,

(A) **Constant-potential transformers.**
(B) **Constant-current transformers.**
(C) **Current transformers.**

The **constant-potential transformer** is one so constructed that the relation of the primary and the secondary voltage remains practically constant, regardless of the load on the transformer.

The **constant-current transformer** is one so constructed that the secondary current remains constant in value, and when the load on the transformer changes, there is a change in the e.m.f. induced in the secondary winding.

The **current transformer** is one so constructed that the secondary current always bears a definite relation to the primary current. These transformers are used principally in connection with instruments where it is desired to send a definite fractional part of the total line current through the instrument. They correspond to the shunt in the direct-current circuit.

415. The Auto-Transformer.—The auto-transformer consists of an ordinary transformer with its primary and secondary coils so connected with respect to each other that the e.m.f. induced in the secondary coils either aids or opposes the e.m.f. impressed upon the primary coil. When the e.m.f.'s of the two windings act in the same direction, it is said to be an **auto-step-up transformation,** and when they act in opposite directions it is said to be an **auto-step-down transformation.**

416. Methods of Cooling Transformers.—In small-capacity transformers the radiating surface is ample to prevent an excessive temperature rise when the transformer is in operation. With an increase in capacity of the transformer, there is a proportional increase in the energy loss, and hence the heat generated, but the radiating surface does not increase at the same rate and, as a result, the temperature rise will, as a rule, be greater in large transformers than it is in small ones, unless some means be provided for cooling them. Transformers may be classified according to the method employed in cooling them as follows:

(A) **Dry-transformers, self-cooling.**
(B) **Oil-filled transformers, self-cooling.**

(C) **Transformers cooled by a blast of air.**
(D) **Transformers cooled by a current of water.**
(E) **Transformers cooled by a combination of the above.**

No special means is ever employed for cooling small transformers, as they are dry.

Large transformers are cooled by filling the space surrounding the coils and core with a good quality of oil, which tends to equalize the temperature of the various parts and to conduct the heat to the containing case of the transformer, where it is radiated. The containing case is often corrugated or made with protruding ribs, which adds to its radiating surface, as shown in Fig. 316.

Fig. 316

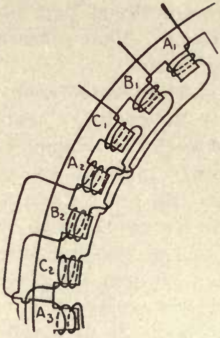


Fig. 317

Large transformers are often constructed so that they can be cooled by forcing a blast of air through them. The coils in such transformers are usually spread apart so as to form ducts through which the air may circulate.

Large transformers are often cooled by circulating water through a pipe which surrounds the coils and core. This method of cooling, however, is usually used in combination with the oil-cooled type.

417. Rotating Magnetic Field.—Suppose the projecting arms or poles on the field frame of a dynamo be divided into three groups, and the poles belonging to one group marked (A_1), (A_2), (A_3), etc., those of another group marked (B_1), (B_2), (B_3), etc., and the third group (C_1), (C_2), (C_3), etc., as shown in Fig. 317. If a winding be placed on the poles belonging to any group, alternate ones being wound in opposite directions, and each of these windings then connected to a source of direct e.m.f., the inner end of the poles will be magnetized alternately north and south. If an alternating e.m.f. be used, the polarity of the poles belonging to any group will be reversed twice per cycle. By connecting the three groups of windings to the different phases of a three-phase circuit, any three poles that occur in succession around the frame will not be magnetized to a maximum polarity of the same time. The time required for the maximum polarity to pass from one pole to the next is one-third of a half cycle or one-sixth of a cycle. The maximum polarity is passed from one pole to the next around the frame, which results in what is termed a **rotating magnetic field**. The speed at which this field rotates can be determined as follows: Let (f) represent the frequency of the impressed voltage, (p) the number of poles per phase, and since two poles correspond to one cycle, the time per revolution of the field will be equal to

$$\text{time per revolution} = \frac{2\,f}{p} \qquad (158)$$

and

$$\text{number of revolutions per second} = \frac{f}{2\,p} \qquad (159)$$

418. Induction Motor.—If a hollow metal cylinder be mounted inside of a rotating field, there will be an e.m.f. induced in it, due to the relative motion of the field and the cylinder, and this e.m.f. will produce a current in the cylinder which reacts upon the magnetic field and causes the cylinder to rotate. The path taken by the induced current is not very well defined in the case of a cylinder and, as a result, it will not all be useful in producing a tangential force. This difficulty is overcome by slotting the cylinder in a direction parallel to the axis about which it rotates. The flux passing between poles of opposite polarity can be greatly increased.

with the same current in the winding, by mounting the cylinder upon an iron core, which should be laminated. This increase in flux will result in a greater e.m.f. being induced in the cylinder and a greater current would result, which would increase the force tending to turn the cylinder. The above principles are those upon which the induction motor operates.

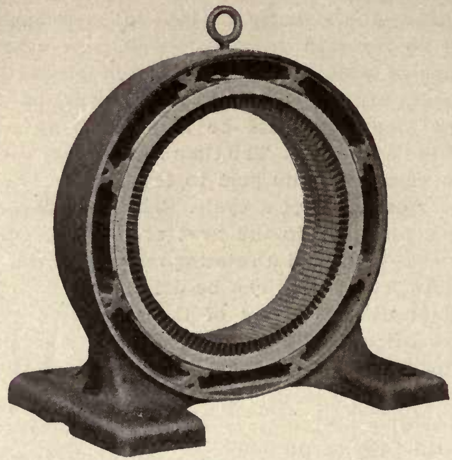


Fig. 318

The winding of an induction motor that is stationary is called the **stator,** and the moving part is called the **rotor.** The stator windings are usually placed in slots cut in what is called the **stator core,** instead of being wound upon poles as shown in Fig. 317. The stator core of a small induction motor is shown in Fig. 318. The rotor in its simplest form consists of copper conductors imbedded in slots in a laminated iron core. These conductors are all connected in parallel by copper collars, one being placed at each end. With this arrangement the current due to the induced e.m.f. passes in a direction parallel to the axis about which the rotor rotates, and its effect in producing rotation is a maximum. This simple form of rotor is called the **"squirrel-cage"** type, Fig. 319. The inductors may or may not be insulated from the core.

In some cases the rotor is provided with a regular winding, and this winding is connected to an external circuit by means of slip-rings.

419. **Operation of the Induction Motor.**—If the stator be connected to a source of energy and the rotor is free to turn, it will run at such a speed that the induced e.m.f. in the rotor winding will produce the current required to drive the rotor. The induced e.m.f. in the rotor depends upon the relative movement of the magnetic field and the rotor winding.

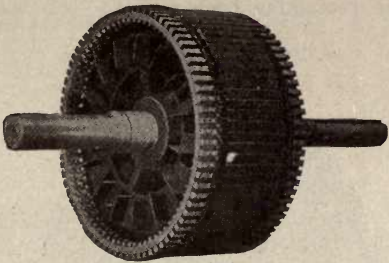


Fig. 319

If the rotor were to run at the same speed that the magnetic field revolves, there would be no e.m.f. induced in its winding. Then in order that there be an e.m.f. induced in its winding, its speed must be less (in the case of a motor) than that of the magnetic field. If (S_f) represents the speed of the field, (S_p) the speed of the rotor, then the difference in speed of the rotor and the magnetic field is (S_f—S_p). This difference in speed divided by (S_p) is called the **slip,** and it is usually expressed as a per cent of the synchronous speed. When the motor is loaded, the rotor speed decreases in order that the current may increase in value, it depending upon the induced e.m.f., which in turn depends upon the ratio of the speeds of the rotor and the magnetic field. A three-phase induction motor is shown in Fig. 320.

420. **Speed Regulation of the Induction Motor.**—The speed of induction motors may be regulated by changing the value of the impressed voltage upon the stator, by changing the connections of the stator winding so as to change the number of poles, or by changing the resistance of the rotor winding.

With a decrease in impressed voltage, the stator flux is lessened and the rotor current decreases if the speed remains constant. If the torque the motor is to generate is to remain constant, it being proportional to the product of the flux and the rotor current, there must be an increase in rotor current on account of the decrease in stator flux, in order that the motor carry its load. The required increase in rotor current is produced by a decrease in rotor speed.

If the stator winding be changed, so as to change the number of poles, there will be a corresponding change in rotor speed, the slip remaining constant.

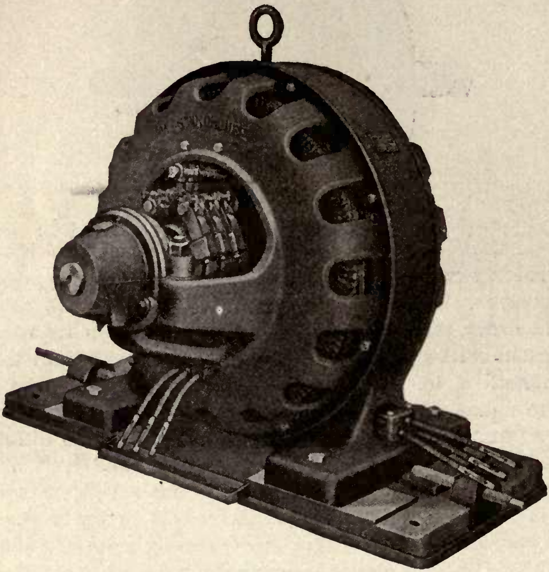


Fig. 320

If the resistance of the rotor be increased, the e.m.f. required to produce a given rotor current must increase, and in order that there be an increase in rotor e.m.f. there must be a decrease in rotor speed.

421. Methods of Starting the Induction Motor.—Polyphase induction motors may be started by connecting their stator windings directly to the line. The current taken from the line, however, is excessive, and an **auto-starter** or **compensator** is usually used.

Single-phase induction motors will not start when their stator windings are connected to a single-phase circuit, unless special provision is made for starting. There are four methods that are employed for starting single-phase motors, viz,

(A) Hand starting.
(B) Split-phase starting.
(C) Repulsion motor starting.
(D) "Shading-coil" starting.

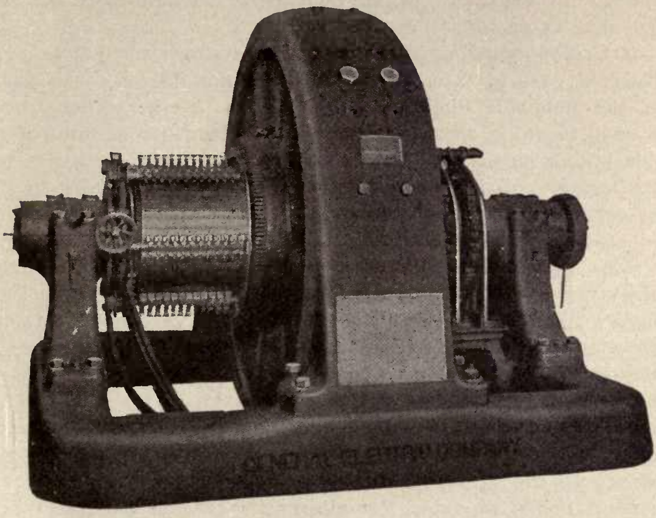


Fig. 321

(A) Very small induction motors may be started by giving them a good start by hand.

(B) In split-phase starting there are two circuits through the motor, and there is a phase difference between the currents in the two branches, if the ratio between the resistance and reactance of the branches is different. This difference in phase of the currents in the two circuits produces the required rotating field to start the motor. The starting torque, however, is very small when the current does not exceed full-load current.

(C) If the field magnets of an ordinary direct-current dynamo be laminated and excited by an alternating current, there would be induced e.m.f.'s set up in the armature winding, provided the brushes were changed from their original position. These induced e.m.f.'s would produce currents which would react upon the alternating magnetic field and produce a torque tending to cause rotation. A single-phase alternating-current motor constructed to operate in the above manner is called a repulsion motor. After the motor is up to speed the brushes are automatically disconnected and it operates as an induction motor.

(D) The "shading-coil" consists of a single turn of copper about a part of each field-pole. The flux through the part of the field-pole enclosed by this turn of wire does not change in value as rapidly as the flux in the remaining portion of the pole, due to the magnetic effect of the current in the copper coil that is produced by the e.m.f. induced in it. As a result of the above condition the flux travels across the pole-face and there will be a torque exerted upon the rotor.

422. Induction Generator.—An induction motor when operating without load takes a very small current from the supply leads and the speed of its rotor is very near that of the magnetic field. If the rotor be connected to some source of power and speeded up to the same speed as that of the magnetic field, the electrical power intake of the stator will be very small, it being equal to the iron loss in the stator. By increasing the speed of the rotor until it is above synchronism, the stator will deliver power to the alternating-current leads, provided the alternating-current generator remains connected to the leads to fix the frequency. When an induction motor is so used it is called an **induction generator.**

423. Frequency Changer.—An induction motor provided with a rotor having a winding with terminals connected to collector rings may be used as a frequency changer, that is, it may be used to change the frequency. When the rotor of the motor is held stationary, the magnetic flux of the stator induces e.m.f.'s in the rotor winding that are of the same frequency as the alternating e.m.f.'s applied to the stator. If the rotor is run at one-half speed, in the direction the magnetic field rotates, the e.m.f.'s induced in the rotor windings will be one-half full frequency. By driving the rotor in the opposite direction to the direction in which the magnetic field revolves, the frequency is raised. Thus, if the rotor be revolved backward at one-half speed, the induced e.m.f.'s in the rotor windings will be one and one-half times the frequency of the e.m.f.'s impressed upon the stator windings.

424. **Synchronous Converter.**—The synchronous converter is a machine for converting alternating-current to direct-current, or *vice versâ*, or it may be used as a double-current generator. The synchronous converter resembles a direct-current generator in general appearance, the chief difference being the addition of a number of collector rings at one end of the armature, and the use of a larger commutator and smaller magnetic circuit than is ordinarily used in a direct-current generator.

When such a machine is driven by an engine or motor, it is capable of supplying either direct or alternating current, or both at the same time. It may be driven as a synchronous motor from an alternating-current source of energy and deliver direct current, or it may be driven from a direct-current source of energy and deliver alternating current.

The synchronous converter may be started as a synchronous motor, as described in section (406), or it may be started from the direct-current end. In starting from the direct-current end, the machine is brought up to a speed a little above synchronous speed and then disconnected from the direct-current source, and when the speed has decreased to synchronous speed the alternating-current end is connected to the alternating-current leads. A synchronous converter is shown in Fig. 321.

CHAPTER XIX

RESUSCITATION FROM APPARENT DEATH FROM ELECTRIC SHOCK

By Augustin H. Goelet, M. D.

Supplement to Electrical World and Engineer, September 6, 1902.

425. Resuscitation.—The urgent necessity for prompt and persistent efforts at resuscitation of victims of accidental shocks by electricity is very well emphasized by the successful results in the instances recorded. In order that the task may not be undertaken in a half-hearted manner, it must be appreciated that accidental shocks seldom result in absolute death unless the victim is left unaided too long, or efforts at resuscitation are stopped too early.

In the majority of instances the shock is only sufficient to suspend animation temporarily, owing to the momentary and imperfect contact of the conductors, and also on account of the resistance of the body submitted to the influence of the current. It must be appreciated also that the body under the conditions of accidental shocks seldom receives the full force of the current in the circuit, but only a shunt current, which may represent a very insignificant part of the whole.

When an accident occurs the following rules should be promptly executed with care and deliberation:

426. Rule (1)—Remove the body at once from the circuit by breaking contact with the conductors. This may be accomplished by using a dry stick of wood, which is a non-conductor, to roll the body over to one side, or to brush aside a wire, if that is conveying the current. When a stick is not at hand, any dry piece of clothing may be utilized to protect the hand in seizing the body of the victim, unless rubber gloves are convenient. If the body is in contact with the earth. the coat-tails of the victim, or any loose or detached piece of clothing may be seized with impunity to draw it away from the conductor. When this has been accomplished, observe Rule (2). The object to be attained is to make the subject breathe, and if this can be accomplished and continued he can be saved.

427. **Rule (2)**—Turn the body upon the back, loosen the collar and clothing about the neck, roll up a coat and place it

Fig. 322

under the shoulders, so as to throw the head back, and then make efforts to establish respiration (in other words, make him breathe), just as would be done in case of drowning. To accomplish this, kneel at the subject's head, facing him as shown in Fig. 322, and, seizing both arms, draw them forcibly to their full length over the head, so as to bring them almost together above it, and hold them there for two or three seconds only. (This is to expand the chest and favor the entrance of air into the lungs.) Then carry the arms down to the sides and front of the chest, firmly compressing the chest walls, and expel the air from the lungs, as shown in Fig. 323. Repeat this manoeuvre at least sixteen times per minute. These efforts should be continued unremittingly for at least an hour, or until natural respiration is established.

428. **Rule (3)**—At the same time that this is being done, someone should grasp the tongue of the subject with a handkerchief or piece of cloth, to prevent it slipping, and

draw it forcibly out when the arms are extended above the head and allow it to recede when the chest is compressed. This manoeuver should likewise be repeated at least sixteen times per minute. This serves the double purpose of freeing the throat so as to permit air to enter the lungs, and also, by exciting a reflex irritation from forcible contact of the under part of the tongue against the lower teeth, frequently stimulates an involuntary effort at respiration. To secure the tongue if the teeth are clenched, force the jaws

Fig. 323

apart with a stick, a piece of wood, or the handle of a pocket knife.

429. Rule (4)—The dashing of cold water into the face will sometimes produce a gasp and start breathing, which should then be continued as directed above. If this is not essential the spine may be rubbed vigorously with a piece of ice. Alternate applications of heat and cold over the region of the heart will accomplish the same object in some instances. It is both useless and unwise to attempt to administer stimulants to the victim in the usual manner of pouring it down his throat.

While the above directions are being carried out, a physician should be summoned, who, upon his arrival, can best put into practice Rules (5), (6) and (7), in addition to the foregoing, should it be necessary.

FOR THE PHYSICIAN SUMMONED

430. Rule (5)—Forcible stretching of the sphincter muscle controlling the lower bowel excites powerful reflex irritation and stimulates a gasp (inspiration) frequently when other measures have failed. For this purpose the subject should be turned on the side, the middle and index fingers inserted into the rectum, and the muscle suddenly and forcibly drawn backwards toward the spine. Or, if it is desirable to continue efforts at artificial respiration at the same time, the knees should be drawn up and the thumb inserted for the same purpose, the subject retaining the position on the back.

431. Rule (6)—Rhythmical traction of the tongue is sometimes effectual in establishing respiration when other measures have failed. The tongue is seized and drawn out quickly and forcibly to the limit, then it is permitted to recede. This is to be repeated 16 times per minute.

432. Rule (7)—Oxygen gas, which may be readily obtained at a drug store in cities or large towns, is a powerful stimulant to the heart if it can be made to enter the lungs. A cone may be improvised from a piece of stiff paper and attached to the tube leading from the tank, and placed over the mouth and nose while the gas is turned on during the efforts at artificial respiration.

CHAPTER XX

LOGARITHMS

433. Definition of Logarithm.—If (a) be any number, and (x) and (n) two other numbers, such that $a^x = n$, then (x) is called the logarithm of (n) to the base (a) and is written $\log_a n$. The logarithm of a number to a given base is the index of the power to which the base must be raised that it may be equal to the given number. Example: Since $10^2 = 100$, therefore $2 = \log_{10} 100$.

434. Laws of Indices.—In algebra the following laws, known as the laws of indices, are found to be true; (m) and (n) are to be any real quantities:

(A) $a^m \times a^n = a^{m+n}$

(B) $a^m \div a^n = a^{m-n}$

(C) $(a^m)^n = a^{m \times n}$

There are three fundamental laws of logarithms corresponding to the above.

(a) $\log_a (m \times n) = \log_a m + \log_a n$

(b) $\log_a (m \div n) = \log_a m - \log_a n$

(c) $\log_a m^n = n \log_a m.$

These three laws expressed in words are:

(a) The logarithm of the product of two quantities is equal to the sum of the logarithms of the quantities to the same base.

(b) The logarithm of the quotient of two quantities is equal to the difference in their logarithms to the same base.

(c) The logarithm of a quantity raised to any power is equal to the logarithm of the quantity multiplied by the index of the power.

435. Common System of Logarithms.—In what is known as the common system of logarithms the base is always 10, so that if no base be expressed, the base 10 is always understood.

436. Definition of Characteristic and Mantissa.—If the logarithm of any number be partly integral and partly fractional, the integral portion is called its **characteristic** and the decimal portion is called its **mantissa.** Thus, the logarithm of 666 is 2.82347, in which 2 is the characteristic and .82347 is the mantissa.

The characteristic of the logarithm of any whole number will be one less than the number of digits in its integral part. Thus, 2457.4 has four digits in its integral part and the characteristic of its logarithm is 3.

The characteristic of the logarithm of any decimal fraction will be negative and numerically greater by unity than the number of ciphers following the decimal point. Thus, .897 has no ciphers following the decimal point and the characteristic will be numerically equal to $(0 + 1)$ or 1, and it will be negative. The fact that the characteristic is negative can be indicated by drawing a horizontal line over it, thus $(\bar{1})$. The characteristic of .00434 is $\bar{3}$ since there are two ciphers following the decimal point.

The mantissa of the logarithm of all numbers consisting of the same digits are the same.

437. How to Obtain the Logarithm of a Number from the Table.—For example, if it is desired to obtain the logarithm of the number 642, we proceed as follows: Run the eye down the extreme left-hand column until it arrives at the number 64. Then pass along the horizontal line of figures until you are in the column vertically beneath the number 2 at the top of the page, and you see the number 80754. This number just obtained is the mantissa of the log of 642 and the characteristic is 2.

$$\begin{aligned} \text{Then } \log\ 642 &= 2.807\,54 \\ \text{and } \log\ 6420 &= 3.807\,54 \\ \log\ 6.42 &= .807\,54 \\ \log\ .00642 &= \bar{3}.807\,54 \end{aligned}$$

438. To Find a Number Whose Logarithm Is Given.—If the logarithm be one tabulated in the table the number is easily found, the procedure being just the reverse of that given in the previous paragraph. Example: Find the number whose logarithm is 68931. Referring to the table, we find the mantissa 68931 corresponds to the digits 489, and the number will be 4890, since the characteristic is 3.

Often the logarithm is not tabulated and the number is then found as follows: Example—Find the number whose logarithm is 3.44741. Referring to the table, we find that the mantissa 44741 is not tabulated, but the nearest mantissae are 44716 and 44871, between which the mantissa 44741 lies. The difference between 44871 and 44716 is 155, and the difference between 44741 and 44716 is 75.

$$\log 2800 = 3.447\,16$$
$$\log 2810 = 3.448\,71$$
$$\text{then } 3.447\,41 = \log (2800 + X)$$
$$X = \frac{75}{155} \text{ of } 10 = 4.99$$

The required number then is (2800 + 4.99) = 2804.99.

EXAMPLES

(A) What is the value of the product of 24 and 19?

$$\log 24 = 1.380\,21$$
$$\log 19 = 1.278\,75$$
$$\log (\text{product}) = 2.658\,96$$
$$\text{then } (24 \times 19) = 456$$

(B) What is the value of $(27)^2$?

$$\log (27)^2 = 2 \log 27 = 2.862\,72$$
$$\text{then } (27)^2 = 729$$

(C) What is the value of the product of .079 and .03?

$$\log .079 = \bar{2}.897\,63$$
$$\log .03 = \bar{2}.477\,12$$
$$\log (\text{product}) = \bar{3}.374\,75$$
$$\text{then } (.079 \times .03) = .002\,37$$

(See note a, page 393)

(D) What is the value of the product of .65 and 48?

$$\log .65 = \bar{1}.812\ 91$$
$$\log 48 = 1.681\ 24$$

$$\log(\text{product}) = 1.494\ 15$$
$$\text{then } (.65 \times 48) = 31.25$$

(E) What is the value of $(.075)^2$?

$$\log .075 = \bar{2}.875\ 06$$
$$2 \log .075 = \bar{3}.750\ 12$$
$$\text{then } (.075)^2 = .005\ 625$$

(F) What is the value of $(79.0)^{1.6}$?

$$\log 79.0 = 1.897\ 63$$
$$\log (79.0)^{1.6} = 1.6 \times 1.897\ 63$$
$$= 2.936\ 208$$
$$\text{then } (79.0)^{1.6} = 863.+$$

(G) What is the value of $\sqrt{656100}$?

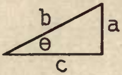
$$\log 656100 = 5.816\ 90$$
$$\tfrac{1}{2} \log 656100 = 2.908\ 45$$
$$\text{or } \log \sqrt{656100} = 2.908\ 45$$
$$\text{then } \sqrt{656100} = 810$$

Note (a)—The characteristic is treated as a negative quantity and the mantissa as a positive quantity.

No.	0	1	2	3	4	5	6	7	8	9
0	....	000 00	301 03	477 12	602 06	698 97	778 15	845 10	903 09	954 24
1	000 00	041 39	079 18	113 94	146 13	176 09	204 12	230 45	255 27	278 75
2	301 03	322 22	342 42	361 73	380 21	397 94	414 97	431 36	447 16	462 40
3	477 12	491 36	505 15	518 51	531 48	544 07	556 30	568 20	579 78	591 06
4	602 06	612 78	623 25	633 47	643 45	653 21	662 76	672 10	681 24	690 20
5	698 97	707 57	716 00	724 28	732 39	740 36	748 19	755 87	763 43	770 85
6	778 15	785 33	792 39	799 34	806 18	812 91	819 54	826 07	832 51	818 85
7	845 10	851 26	857 33	863 32	869 23	875 06	880 81	886 49	892 09	897 63
8	903 09	908 49	913 81	919 08	924 28	929 42	934 50	939 52	944 48	949 39
9	954 24	959 04	963 79	968 48	973 13	977 72	982 27	986 77	991 23	995 64
10	000 00	004 32	008 60	012 84	017 03	021 19	025 31	029 38	033 42	037 43
11	041 39	045 32	049 22	053 08	056 90	060 70	064 46	068 19	071 88	075 55
12	079 18	082 79	086 36	089 91	093 42	096 91	100 37	103 80	107 21	110 59
13	113 94	117 27	120 57	123 85	127 10	130 33	133 54	136 72	139 88	143 01
14	146 13	149 22	152 29	155 34	158 36	161 37	164 35	167 32	170 26	173 19
15	176 09	178 98	181 84	184 69	187 52	190 33	193 12	195 90	198 66	201 40
16	204 12	206 83	209 52	212 19	214 84	217 48	220 11	222 72	225 31	227 89
17	230 45	233 00	235 53	238 05	240 55	243 04	245 51	247 97	250 42	252 85
18	255 27	257 68	260 07	262 45	264 82	267 17	269 51	271 84	274 16	276 46
19	278 75	281 03	283 30	285 56	287 80	290 03	292 26	294 48	296 67	298 85
20	301 03	303 20	305 35	307 50	309 63	311 75	313 87	315 97	318 06	320 15
21	322 22	324 28	326 34	328 38	330 41	332 44	334 45	336 46	338 46	340 44
22	342 42	344 39	346 35	348 30	350 25	352 18	354 11	356 03	357 93	359 84
23	361 73	363 61	365 49	367 36	369 22	371 07	372 91	374 75	376 58	378 40
24	380 21	382 02	383 82	385 61	387 39	389 17	390 94	392 70	394 45	396 20
25	397 94	399 67	401 40	403 12	404 83	406 54	408 24	409 93	411 62	413 30
26	414 97	416 64	418 30	419 96	421 60	423 25	424 88	426 51	428 13	429 75
27	431 36	432 97	434 57	436 16	437 75	439 33	440 91	442 48	444 04	445 60
28	447 16	448 71	450 35	451 79	453 32	454 84	456 37	457 88	459 39	460 90
29	462 40	463 89	465 38	466 87	468 35	469 82	471 29	472 76	474 22	475 67
30	477 12	478 57	480 01	481 44	482 87	484 30	485 72	487 14	488 55	489 96
31	491 36	492 76	494 15	495 54	496 93	498 31	499 69	501 06	502 43	503 79
32	505 15	506 51	507 86	509 20	510 55	511 88	513 22	514 55	515 87	517 20
33	518 51	519 83	521 14	522 44	523 75	525 04	526 34	527 63	528 92	530 20
34	531 48	532 75	534 03	535 29	536 56	537 82	539 08	540 33	541 58	542 83
35	544 07	545 31	546 54	547 77	549 00	550 23	551 45	552 67	553 88	555 09
36	556 30	557 51	558 71	559 91	561 10	562 29	563 48	564 67	565 85	567 03
37	568 20	569 37	570 54	571 71	572 87	574 03	575 19	576 34	577 49	578 64
38	579 78	580 92	582 06	583 20	584 33	585 46	586 59	587 71	588 83	589 95
39	591 06	592 18	593 29	594 39	595 50	596 60	597 70	598 79	599 88	600 97
40	602 06	603 14	604 23	605 31	606 38	607 46	608 53	609 59	610 66	611 72
41	612 78	613 84	614 90	615 95	617 00	618 05	619 09	620 14	621 18	622 21
42	623 25	624 28	625 31	626 34	627 37	628 39	629 41	630 43	631 44	632 46
43	633 47	634 48	635 48	636 49	637 49	638 49	639 49	640 48	641 47	642 46
44	643 45	644 44	645 42	646 40	647 38	648 36	649 33	650 31	651 28	652 25
45	653 21	654 18	655 14	656 10	657 06	658 01	658 96	659 92	660 87	661 81
46	662 76	663 70	664 64	665 58	666 52	667 45	668 39	669 32	670 25	671 17
47	672 10	673 02	673 94	674 86	675 78	676 69	677 61	678 52	679 43	680 34
48	681 24	682 15	683 05	683 95	684 85	685 74	686 64	687 53	688 42	689 31
49	690 20	691 08	691 97	692 85	693 73	694 61	695 48	696 36	697 23	698 10
50	698 97	699 84	700 70	701 57	702 43	703 29	704 15	705 01	705 86	706 72

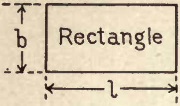
No.	0	1	2	3	4	5	6	7	8	9
51	707 57	708 42	709 27	710 12	710 96	711 81	712 65	712 49	714 33	715 17
52	716 00	716 84	717 67	718 50	719 33	720 16	720 99	721 81	722 63	723 46
53	724 28	725 09	725 91	726 73	727 54	728 35	729 16	729 97	730 78	731 59
54	732 39	733 20	734 00	734 80	735 60	736 40	737 19	737 99	738 78	739 57
55	740 36	741 15	741 94	742 73	743 51	744 29	745 07	745 86	746 63	747 41
56	748 19	748 96	749 74	750 51	751 28	752 05	752 82	753 58	754 35	755 11
57	755 87	756 64	757 40	758 15	758 91	759 67	760 42	761 18	761 93	762 68
58	763 43	764 18	764 92	765 67	766 41	767 16	767 90	768 64	769 38	770 12
59	770 85	771 59	772 32	773 05	773 79	774 52	775 25	775 97	776 70	777 43
60	778 15	778 87	779 60	780 32	781 04	781 76	782 47	783 19	783 90	784 62
61	785 33	786 04	786 75	787 46	788 17	788 88	789 58	790 29	790 99	791 69
62	792 39	793 09	793 79	794 49	795 18	795 88	796 57	797 27	797 96	798 65
63	799 34	800 03	800 72	801 40	802 09	802 77	803 46	804 14	804 82	805 50
64	806 18	806 86	807 54	808 21	808 89	809 56	810 23	810 90	811 58	812 24
65	812 91	813 58	814 25	814 91	815 58	816 24	816 90	817 57	818 23	818 89
66	819 54	820 20	820 86	821 51	822 17	822 82	823 47	824 13	824 78	825 43
67	826 07	826 72	827 37	828 02	828 66	829 30	829 95	830 59	831 23	831 87
68	832 51	833 15	833 78	834 42	835 06	835 69	836 32	836 96	837 59	838 22
69	838 85	839 48	840 11	840 73	841 36	841 98	842 61	843 23	843 86	844 48
70	845 10	845 72	846 34	846 96	847 57	848 19	848 80	849 42	850 03	850 65
71	851 26	851 87	852 48	853 09	853 70	854 31	854 91	855 52	856 12	856 73
72	857 33	857 94	858 54	859 14	859 74	860 34	860 94	861 53	862 13	862 73
73	863 32	863 92	864 51	865 10	865 70	866 29	866 88	867 47	868 06	868 64
74	869 23	869 82	870 40	870 99	871 57	872 16	872 74	873 32	873 90	874 48
75	875 06	875 64	876 22	876 79	877 37	877 95	878 52	879 10	879 67	880 24
76	880 81	881 38	881 95	882 52	883 19	883 66	884 23	884 80	885 36	885 93
77	886 49	887 05	887 62	888 18	888 74	889 30	889 86	890 42	890 98	891 54
78	892 09	892 65	893 21	893 76	894 32	894 87	895 42	895 97	896 53	897 08
79	897 63	898 18	898 73	899 27	899 82	900 37	900 91	901 46	902 00	902 55
80	903 09	903 63	904 17	904 72	905 26	905 80	906 34	906 87	907 41	907 95
81	908 49	909 02	909 56	910 09	910 62	911 16	911 69	912 22	912 75	913 28
82	913 81	914 34	914 87	915 40	915 93	916 45	916 98	917 51	918 03	918 55
83	919 08	919 60	920 12	920 65	921 17	921 69	922 21	922 73	923 24	923 76
84	924 28	924 80	925 31	925 83	926 34	926 86	927 37	927 88	928 40	928 91
85	929 42	929 93	930 44	930 95	931 46	931 97	932 47	932 98	933 49	933 99
86	934 50	935 00	935 51	936 01	936 51	937 02	937 52	938 02	938 52	939 02
87	939 52	940 02	940 52	941 01	941 51	942 01	942 50	943 00	943 49	943 99
88	944 48	944 98	945 47	945 96	946 45	946 94	947 43	947 92	948 41	948 90
89	949 39	949 88	950 36	950 85	951 34	951 82	952 31	952 79	953 28	953 76
90	954 24	954 72	955 21	955 69	956 17	956 65	957 13	957 61	958 09	958 56
91	959 04	959 52	959 99	960 47	960 95	961 42	961 90	962 37	962 84	963 32
92	963 79	964 26	964 73	965 20	965 67	966 14	966 61	967 08	967 55	968 02
93	963 48	968 95	969 42	969 88	970 35	970 81	971 28	971 74	972 20	972 67
94	973 13	973 59	974 05	974 51	974 97	975 43	975 89	976 35	976 81	977 27
95	977 72	978 14	978 64	979 09	979 55	980 00	980 46	980 91	981 37	981 82
96	982 27	982 72	983 18	983 63	984 08	984 53	984 98	985 43	985 88	986 32
97	986 77	987 22	987 67	988 11	988 56	989 00	989 45	989 89	990 34	990 78
98	991 23	991 67	992 11	992 55	993 00	993 44	993 88	994 32	994 76	995 20
99	995 64	996 07	996 51	996 95	997 39	997 82	998 26	998 70	999 13	999 57
100	000 00	000 43	000 87	001 30	001 73	002 17	002 60	003 03	003 46	003 89

TRIGONOMETRICAL FUNCTIONS

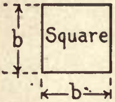


Sine $\theta = \frac{a}{b}$ Cosine $\theta = \frac{c}{b}$ Tangent $\theta = \frac{a}{c}$

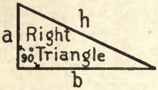
MENSURATION



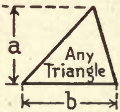
Area = b x l



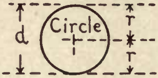
Area = b x b = b^2



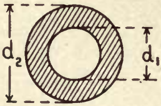
Base = b
Altitude = a
Hypothenuse = h
$h = \sqrt{a^2 + b^2}$
$a = \sqrt{h^2 - b^2}$
$b = \sqrt{h^2 - a^2}$
Area = ½ x a x b



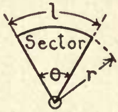
Base = b
Altitude = a
Area = ½ x a x b



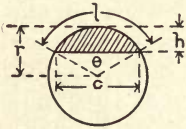
Diameter = d
Radius = r = d ÷ 2
Circumference = π x d
π = 3.1416−
Area = π x r^2
= ¼ x π x d^2



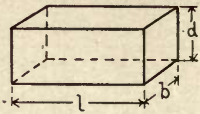
Area Shaded Portion = $\frac{\pi}{4}(d_2^2 - d_1^2)$



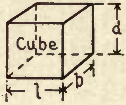
Area = ½ l x r
= $\frac{\theta}{360}$ x π x r^2



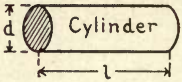
Area Shaded Portion ½[lr − c(r − h)] =
$\frac{\theta}{360}$ x π x r^2 − c(r − h)
c = chord = $2\sqrt{2hr - h^2}$



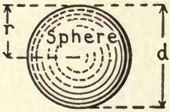
Length = l
Breath = b
Depth = d
Volume = l x b x d
Area surface =
2(d x b) + 2(b x l) + 2(d x l)



l = b = d
Volume = l x b x d



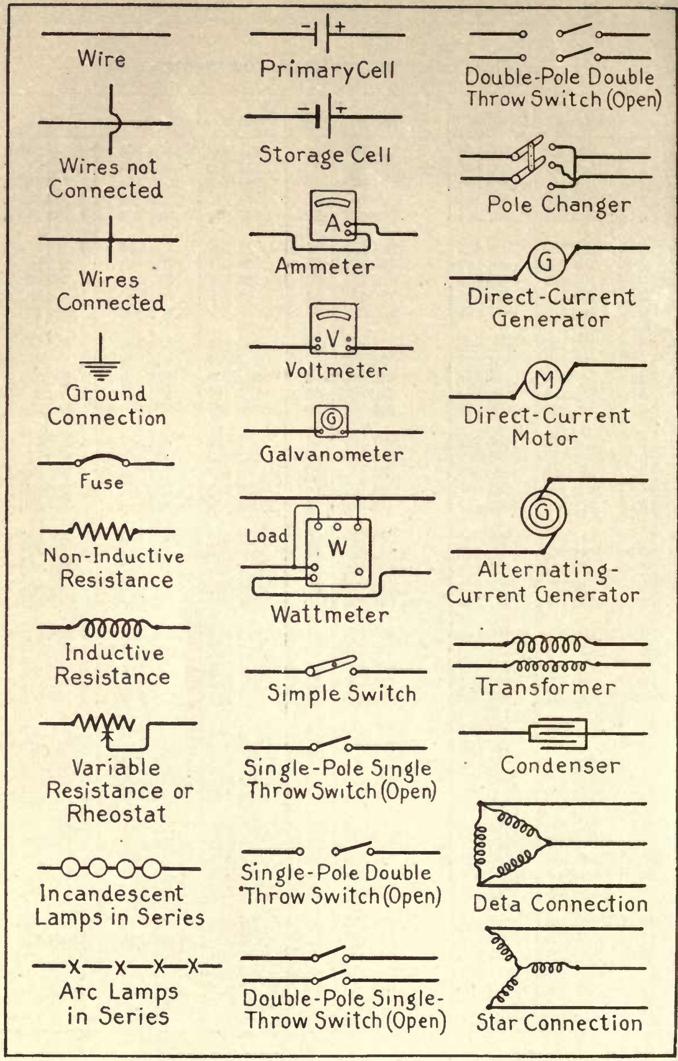
Volume = $\frac{\pi}{4}$ x d^2 x l



Surface =
π x d^2 = 4π x r^2
Volume =
$\frac{1}{6}$π x d^3 = $\frac{4}{3}$π x r^3

NATURAL SINES, COSINES, AND TANGENTS

Angle	Sines	Cosines	Tangents	Angle	Sines	Cosines	Tangents
0	.000 000	1.000 000	.000 000	46	.719 340	.694 658	1.035 530 3
1	.017 452	.999 848	.017 455	47	.731 354	.681 998	1.072 368 7
2	.034 899	.999 391	.034 921	48	.743 145	.669 131	1.110 612 5
3	.052 336	.998 630	.02 408	49	.754 710	.656 059	1.150 368 4
4	.069 756	.997 564	.069 927	50	.766 044	.642 788	1.191 753 6
5	.087 156	.996 165	.087 489	51	.777 146	.629 320	1.234 897 2
6	.104 528	.994 522	.105 104	52	.788 011	.615 661	1.279 941 6
7	.121 869	.992 546	.122 785	53	.798 636	.601 815	1.327 044 8
8	.139 173	.990 268	.140 541	54	.809 017	.587 785	1.376 381 0
9	.156 434	.987 688	.158 384	55	.819 152	.573 576	1.428 148 0
10	.173 648	.984 808	.176 327	56	.829 038	.559 193	1.482 561 0
11	.190 809	.981 627	.194 380	57	.838 671	.544 639	1.539 865 0
12	.207 912	.978 148	.212 557	58	.848 048	.529 919	1.600 334 5
13	.224 951	.974 370	.230 868	59	.857 167	.515 038	1.664 279 5
14	.241 922	.970 296	.249 328	60	.866 025	.500 000	1.732 050 8
15	.258 819	.965 926	.267 949	61	.874 620	.484 810	1.804 047 8
16	.275 637	.961 262	.286 745	62	.882 948	.469 472	1.880 726 5
17	.292 372	.956 305	.305 731	63	.891 007	.453 990	1.962 610 5
18	.309 017	.951 057	.324 920	64	.898 794	.438 371	2.050 303 8
19	.325 568	.945 519	.344 328	65	.906 308	.422 618	2.144 506 9
20	.342 020	.939 693	.363 970	66	.913 545	.406 737	2.246 036 8
21	.358 368	.933 580	.383 864	67	.920 505	.390 731	2.355 852 4
22	.374 607	.927 184	.404 026	68	.927 184	.374 607	2.475 086 9
23	.390 731	.920 505	.424 475	69	.933 580	.358 369	2.605 089 1
24	.406 737	.913 545	.445 229	70	.939 693	.342 020	2.747 477 4
25	.422 618	.906 308	.466 308	71	.945 519	.325 568	2.904 210 9
26	.438 371	.898 794	.487 733	72	.951 057	.309 017	3.077 683 5
27	.453 990	.891 007	.509 525	73	.956 305	.292 372	3.270 852 6
28	.469 472	.882 948	.531 709	74	.961 262	.275 637	3.487 414 4
29	.484 810	.874 620	.554 309	75	.965 926	.258 819	3.732 050 8
30	.500 000	.866 025	.577 350	76	.970 296	.241 922	4.010 780 9
31	.515 038	.857 167	.600 861	77	.974 370	.224 951	4.331 475 9
32	.529 919	.848 048	.624 869	78	.978 148	.207 912	4.704 730 1
33	.544 639	.838 671	.649 408	79	.981 627	.190 809	5.144 554 0
34	.559 193	.829 038	.674 509	80	.984 808	.173 648	5.671 281 8
35	.573 576	.819 152	.700 208	81	.987 688	.156 434	6.313 751 5
36	.587 785	.809 017	.726 543	82	.990 268	.139 173	7.115 369 7
37	.601 815	.798 636	.753 554	83	.992 546	.121 869	8.144 346 4
38	.615 661	.788 011	.781 286	84	.994 522	.104 528	9.514 364 5
39	.629 320	.777 146	.809 784	85	.996 195	.087 156	11.430 052
40	.642 788	.766 044	.839 100	86	.997 564	.069 756	14.300 666
41	.656 059	.754 710	.869 287	87	.998 630	.052 336	19.081 137
42	.669 131	.743 145	.900 404	88	.999 391	.034 899	28.636 253
43	.681 998	.731 354	.932 515	89	.999 848	.017 452	57.289 962
44	.694 658	.719 340	.965 689	90	1.000 000	.000 000	Infinite
45	.707 107	.707 170	1.000 000				


Wire
Wires not Connected
Wires Connected
Ground Connection
Fuse
Non-Inductive Resistance
Inductive Resistance
Variable Resistance or Rheostat
Incandescent Lamps in Series
Arc Lamps in Series
Primary Cell
Storage Cell
A
Ammeter
V
Voltmeter
G
Galvanometer
Load
W
Wattmeter
Simple Switch
Single-Pole Single Throw Switch (Open)
Single-Pole Double Throw Switch (Open)
Double-Pole Single-Throw Switch (Open)
Double-Pole Double Throw Switch (Open)
Pole Changer
G
Direct-Current Generator
M
Direct-Current Motor
G
Alternating-Current Generator
Transformer
Condenser
Deta Connection
Star Connection

RELATION OF METRIC AND ENGLISH MEASURES

Equivalents of Linear Measures

	Meters	English Measures			
		Inches	Feet	Yards	Miles
Millimeter	.001	.039 371	.003 281	.001 094	
Centimeter	.01	3.937 079	.032 809	.010 936	
Decimeter	.1	.328 089	.328 089	.109 363	
Meter	1.	39.370 790	3.280 899	1.093 633	.000 621
Decameter	10.	....	32.808 99	10.936 33	.006 214
Hectometer	100.	....	328.089 9	109.363 3	.062 138
Kilometer	1 000.	....	3 280.899	1 093.633	.621 382

English Measures	Meters	Reciprocals
1 inch	.02539954	39.37079
12 inches=1 foot	.3047945	3.280899
3 feet=1 yard	.9143835	1.093633

Equivalents of Surface Measures

	Square Meters	English Measures		
		Square inches	Square feet	Square yards
Milliare	.1	155.01	1.076	.119
Centiare	1.	1550.06	10.764	1.196
Diciare	10.	15500.59	107.64	11.960
Are	100.	155005.9	1076.4	119.6033
Decare (not used)	1 000.	......	10764.3	1096.033
Hectare	10 000.	......	107643.	11960.33
Square Kilometer	1000 000.	......	......	......

English Measures	Metric Measures	Reciprocals
1 square inch	6.451367 sq. cmt.	.1550059
144 sq. in.=1 sq. ft	.09289968 sq. m.	10.7642996
9 sq. ft.=1 sq. yd	.8360972 sq. m.	1.196033

Equivalents of Weights

	Grams	English Weights			
		Oz. avoir	Lbs. avoir	Tons 2000 lbs.	Tons 2240 lbs.
Milligram	.001				
Centigram	.01				
Decigram	.1				
Gram	1.	.0353	.0022		
Decagram	10.	.3527	.02205		
Hectogram	100.	3.5274	.22046		
Kilogram	1000.	35.2739	2.2046	.001102	.000984

English Weights "Avoirdupois"	Grams	Reciprocals
1 grain	.06479895	15.43234875
24.34375 grains=1 dram	1.771836	.564383
16 drams=1 oz.=437.5 grains	28.349375	.0352739
16 oz.1 pound==7000 grains	453.592652	.00220462

TABLE OF COMPARISON OF CENTIGRADE AND FAHRENHEIT THERMOMETER SCALES

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
0	32.0	26	78.8	51	123.8	76	168.8
1	33.8	27	80.6	52	125.6	77	170.6
2	35.6	28	82.4	53	127.4	78	172.4
3	37.4	29	84.2	54	129.2	79	179.2
4	39.2	30	86.0	55	131.0	80	176.0
5	41.0	31	87.8	56	132.8	81	177.8
6	42.8	32	89.6	57	134.6	82	179.6
7	44.6	33	91.4	58	136.4	83	181.2
8	46.4	34	93.2	59	138.2	84	183.4
9	48.2	35	95.0	60	140.0	85	185.0
10	50.0	36	96.8	61	141.8	86	186.8
11	51.8	37	98.6	62	143.6	87	188.6
12	53.6	38	100.4	63	145.4	88	190.4
13	55.4	39	102.2	64	147.2	89	192.2
14	57.2	40	104.0	65	149.0	90	194.0
15	59.0	41	105.8	66	150.8	91	195.8
16	60.8	42	107.6	67	152.6	92	197.6
17	62.6	43	109.4	68	154.4	93	199.4
18	64.4	44	111.2	69	156.2	94	201.2
19	66.2	45	113.0	70	158.0	95	203.0
20	68.0	46	114.8	71	159.8	96	204.8
21	69.8	47	116.6	72	161.6	97	206.6
22	71.6	48	118.4	73	163.4	98	208.4
23	73.4	49	120.2	74	165.2	99	210.2
24	75.2	50	122.0	75	167.0	100	212.0
25	77.0						

One deg. Fahr.=.5556 deg. centigrade.
One deg. centigrade=1.8 deg. Fahr.
To convert Fahr. to centigrade, subtract 32, multiply by 5 and divide by 9.
To convert centigrade to Fahr., multiply by 9, divide by 5 and add 32.
If temperature is below freezing, the above formula should read "subtract from 32" in place of "subtract 32" and "add 32."

TABLE C

EQUIVALENT CROSS-SECTIONS OF DIFFERENT SIZE WIRES
(Brown and Sharpe Gauge)

Equiv. section	Number of wires of various sizes						
	2	4	8	16	32	64	128
0 000	0	3	6	9	12	15	18
000	1	4	7	10	13	16	One each
CO	2	5	8	11	14	17	1 and 3
0	3	6	9	12	15	18	2 and 4
1	4	7	10	13	16	....	3 and 5
2	5	8	11	14	17	..	4 and 6
3	6	9	12	15	18	..	5 and 7
4	7	10	13	16	..	..	6 and 8
5	8	11	14	17	..	..	7 and 9
6	9	12	15	18	..	..	8 and 10
7	10	13	16	..	..	..	9 and 11
8	11	14	17	..	..	..	10 and 12
9	12	15	18	..	..	..	11 and 13
10	13	16	..	..	..	..	12 and 14
11	14	17	..	..	..	..	13 and 15
12	15	18	..	..	..	..	14 and 16
13	16	..	..	..	..	..	15 and 17
14	17	..	..	..	..	..	16 and 18
15	18	..	..	..	..	..	....

COMPARATIVE TABLE OF WIRE GAUGES

Gauge No.	American Wire Gauge (Brown & Sharpe)		Birmingham Wire Gauge (Stubs)		Standard Wire Gauge	
	Diameter	Area	Diameter	Area	Diam'ter	Area
	Inches	Circular Mills	Inches	Circular Mills	Inches	Circular Mills
7-0	....	....	....	....	0.500	2 50000.
6-0	....	....	....	....	0.404	2 15300.
5-0	....	....	....	....	0.432	1 86600.
4-0	0.460 0	211 600.	0.454	206 100.	0.400	1 60000.
3-0	0.409 6	167 800.	0.425	180 600.	0.372	1 38400.
2-0	0.364 8	133 100.	0.380	144 400.	0.348	1 21100.
1-0	0.324 9	105 500.	0.340	115 600	0.324	1 05000.
1	0.289 3	83 690.	0.300	90 000.	0.300	90000.
2	0.257 6	66 370.	0.284	80 660.	0 276	76180.
3	0.229 4	52 630.	0.259	67 080.	0.252	63500.
4	0.204 3	41 740.	0.238	56 640.	0.232	53820.
5	0.181 9	33 100.	0.220	48 400.	0.212	44940.
6	0.162 0	26 250.	0.203	41 210.	0.192	36860.
7	0.144 3	20 820.	0.180	32 400.	0.176	30980.
8	0.128 5	16 510.	0.165	27 230.	0.160	25600.
9	0.114 4	13 090.	0.148	21 900.	0.144	20740.
10	0.101 9	10 380.	0.134	17 960.	0.128	16380.
11	0.090 74	8 234.	0.120	14 400.	0.116	13460.
12	0.080 81	6 530.	0.109	11 880.	0.104	10820.
13	0.071 96	5 178.	0.095 0	9 025.	0.092	8464.
14	0.064 08	4 107.	0.083 0	6 889.	0.080	6400.
15	0.057 07	3 257.	0.072 0	5 184.	0.072	5184.
16	0.050 82	2 583.	0.065 0	4 225.	0.064	4096.
17	0.045 26	2 048.	0.058 0	3 364.	0.056	3136.
18	0.040 30	1 624.	0.049 0	2 401.	0.048	2304.
19	0.035 89	1 288.	0.042 0	1 764.	0.040	1600.
20	0.031 96	1 022.	0.035 0	1 225.	0.036	1296.
21	0.028 46	810.1	0.032 0	1 024.	0.032	1024.
22	0.025 35	642.4	0.028 0	784.	0.028	784.0
23	0.022 57	509.5	0.025 0	625.	0.024	576.0
24	0.020 10	404.0	0.022 0	484.	0.022	484.0
25	0.017 90	320.4	0.020 0	400.	0.020	400.0
26	0.015 94	254.1	0.018 0	324.	0.018	324.0
27	0.014 20	201.5	0.016 0	256.	0.016 4	269.0
28	0.012 64	159.8	0.014 0	196.	0.014 8	219.0
29	0.011 26	126.7	0.013 0	169.	0.013 6	185.0
30	0.010 03	100.5	0.012 0	144.	0.012 4	153.8
31	0.008 928	79.70	0.010 0	100.	0.011 6	134.6
32	0.007 950	63.21	0.009 0	81.	0.010 8	116.6
33	0.007 080	50.13	0.008 0	64.	0.010 0	100.0
34	0.006 305	39.75	0.007 0	49.	0.009 2	84.64
35	0.005 615	31.52	0.005 0	25.	0.008 4	70.56
36	0.005 000	25.00	0.004 4	16.	0.007 6	67.76
37	0.004 453	19.83	....	....	0.006 8	46.24
38	0.003 965	15.72	....	....	0.006 0	36.00
39	0.003 531	12.47	....	....	0.005 2	27.04
40	0.003 145	9.888	....	....	0.004 8	23.04
41	....	....	....	....	0.004 4	19.36

COPPER WIRE TABLE OF AMERICAN

Giving Weights and Lengths of cool, warm and hot wires,

B. & S. or A. W. G.	Diameter	Area		Lbs. Per Foot	
	Inches	Circular miles	Sq. in. Sq. miles		68° F. 20° C.
0 000	0.460	211 600	166 190	0.640 5	13 090
000	0.409 6	167 800	131 790	0.508 0	8 232
00	0.364 8	133 100	104 518	0.402 8	5 177
0	0.324 9	105 500	82 887	0.319 5	3 256
1	0.289 3	83 690	65 732	0.253 3	2 048
2	0.257 6	66 370	52 128	0.200 9	1 288.
3	0.229 4	52 630	41 339	0.159 3	810.0
4	0.204 3	41 740	32 784	0.126 4	509.4
5	0.181 9	33 100	25 999	0.100 2	320.4
6	0.162 0	26 250	20 618	0.079 46	201 5
7	0.144 3	20 820	16 351	0.630 2	126.7
8	0.128 5	16 510	12 967	0.049 98	79.69
9	0.114 4	13 090	10 283	0.039 63	50.12
10	0.101 9	10 380	8 155	0.031 43	31.52
11	0.090 74	8 234	6 467	0.024 93	19.82
12	0.080 81	6 530	5 129	0.019 77	12.47
13	0.071 96	5 178	4 067	0.015 68	7.840
14	0.064 08	4 107	3 225	0.012 43	4.931
15	0.057 07	3 257	2 558	0.009 858	3.101
16	0.050 82	2 583	2 029	0.007 818	1.950
17	0.045 26	2 048	1 609	0.006 200	1.226
18	0.040 30	1 624	1 276	0.004 917	0.771 3
19	0.035 89	1 288	1 012	0.003 899	0.485 1
20	0.031 96	1 022	802	0.003 092	0.305 1
21	0.028 46	810.1	632.3	0.002 452	0.191 9
22	0.025 35	642.4	504.6	0.001 945	0.120 7
23	0.022 57	509.5	400.2	0.001 542	0.075 89
24	0.020 10	404.0	317.3	0.001 223	0.047 73
25	0.017 90	324.4	251.7	0.000 969 9	0.030 02
26	0.015 94	254.1	199.6	0.000 769 2	0.018 88
27	0.014 2	201.5	158.3	0.000 610 0	0.011 87
28	0.012 64	159.8	125.5	0.000 483 7	0.007 466
29	0.011 26	126.7	99.53	0.000 383 6	0.004 696
30	0.010 03	100.5	78.94	0.000 304 2	0.002 953
31	0.008 928	79.70	62.60	0.000 241 3	0.001 857
32	0.007 950	63.21	49.64	0.000 191 3	0.001 168
33	0.007 080	50.13	39.37	0.000 151 7	0.000 734 6
34	0.006 305	39.75	31.22	0.000 120 3	0.000 462 0
35	0.005 615	31.52	24.76	0.000 095 43	0.000 290 5
36	0.005 0	25.0	19.64	0.000 075 68	0.000 182 7
37	0.004 453	19.83	15.57	0.000 060 01	0.000 114 9
38	0.003 965	15.72	12.35	0.000 047 59	0.000 072 10
39	0.003 531	12.47	9.79	0.000 037 74	0.000 045 45
40	0.003 145	9.888	7.77	0.000 029 93	0.000 028 58

INSTITUTE OF ELECTRICAL ENGINEERS

of Matthiessen's standard of conductivity.

lbs. per Ohm.		Feet per Pound	Feet Per ohm		
122° F. 50° C.	176° F. 80° C.		68° F. 20° C.	122° F. 50° C.	176° F. 80° C.
11 720	10 570	1.561	20 440	18 290	16 510
7 369	6 647	1.969	16 210	14 510	13 090
4 634	4 182	2.482	12 850	11 500	10 380
2 914	2 630	3 130	10 190	9 123	8 232
1 833	1 654	3.947	8 083	7 235	6 528
1 153	1 040	4.977	6 410	5 738	5 177
725.0	654.2	6.276	5 084	4 550	4 106
455.9	411.4	7.914	4 031	3 608	3 256
286.7	258.7	9.980	3 197	2 862	2 582
180.3	162.7	12.58	2 535	2 269	2 048
113.4	102.3	15.87	2 011	1 800	1 624
71.33	64.36	20.01	1 595	1 427	1 288
44.86	40.48	25.23	1 265	1 132	1 021
28.21	25.46	31.82	1 003	897.6	809.9
17.74	16.01	40.12	795.3	711.8	642.3
11.16	10.07	50.59	603.7	564.5	509.4
7.017	6.332	63.79	500.1	447.7	404.0
4.413	3.982	80.44	396.6	355.0	320.3
2.776	2.504	101.4	314.5	281.5	254.0
1.746	1.575	127.9	249.4	223.3	201.5
1.098	0.990 6	161.3	197.8	177.1	159.8
0.690 4	0.623 0	203.4	156.9	140.4	126.7
0.434 2	0.391 8	256.5	124.4	111.4	100.5
0.273 1	0.246 4	323.4	98.66	88.31	98.68
0.171 7	0.155 0	407.8	78.24	70.03	63.19
0.108 0	0.097 46	514.2	62.05	55.54	50.11
0.067 93	0.061 29	648.4	49.21	44.04	39.74
0.042 72	0.038 55	817.6	39.02	34.93	31.52
0.026 87	0.024 24	1 031	30.95	27.70	24.99
0.016 90	0.015 25	1 300	24.54	21.97	19.82
0.010 63	0.009 588	1 639	19.46	17.42	15.72
0.006 683	0.006 030	0 067	15.43	13.82	12.47
0.004 203	0.003 792	2 607	12.24	10.96	9.886
0.002 643	0.002 385	3 287	9.707	8.688	7.840
0.001 662	0.001 500	4 145	7.698	6.890	6.217
0.001 045	0.000 943 6	5 227	6.105	5.464	4.930
0.000 657 5	0 000 593 3	6 591	4.841	4.333	3.910
0.000 413 5	0.000 373 1	8 311	3.839	3.436	3.101
0.000 260 1	0.000 234 7	10 480	3 045	2.725	2.459
0.000 163 6	0.000 147 6	13 210	2.414	2.161	1.950
0.000 102 9	0.000 092 81	16 660	1.915	1.714	1.547
0.000 064 54	0.000 058 24	21 010	1.519	1.359	1.226
0.000 040 68	0.000 036 71	26 500	1.204	1.078	0.972 6
0.000 025 59	0.000 023 09	33 410	0.955 0	0.854 8	0.771 3

COPPER WIRE TABLE OF AMERICAN

Giving Resistances of cool, warm and hot wires,

B. & S. or A. W. G.	Ohms per Pound.		
	68° F. 20° C.	122° F. 50° C.	176° F. 80° C.
0 000	0.000 076 39	0.000 085 35	0.000 094 59
000	0.000 121 5	0.000 135 7	0.000 150 4
00	0.000 193 1	0.000 215 8	0.000 239 1
0	0.000 307 1	0.000 343 1	0.000 380 3
1	0.000 488 3	0.000 545 6	0.000 604 6
2	0.000 776 5	0.000 867 5	0.000 961 4
3	0.001 235	0.001 379	0.001 529
4	0.001 963	0.002 193	0.002 431
5	0.003 122	0.003 487	0.003 865
6	0.004 963	0.005 545	0.006 145
7	0.007 892	0.008 817	0.009 772
8	0.012 55	0.014 02	0.015 54
9	0.019 95	0.022 29	0.024 71
10	0.031 73	0.034 5	0.039 28
11	0.050 45	0.056 36	0.062 46
12	0.080 22	0.089 62	0.099 32
13	0.127 6	0.142 5	0.157 9
14	0.202 8	0.226 6	0.251 1
15	0.322 5	0.360 3	0.399 3
16	0.512 8	0.572 9	0.634 9
17	0.815 3	0.910 9	1.010
18	1.296	1.448	1.605
19	2.061	2.303	2.552
20	3.278	3.662	4.058
21	5.212	5.823	6.453
22	8.287	9.259	10.26
23	13.18	14.72	16.32
24	20.95	23.41	25.94
25	33.32	37.22	41.25
26	52.97	59.18	65.59
27	84.23	94.11	104.3
28	133.9	149.6	165.8
29	213.0	237.9	263.7
30	338.6	378.3	419.3
31	538.4	601.6	666.7
32	856.2	956.5	1 060
33	1 361	1 521	1 685
34	2 165	2 418	2 680
35	3 441	3 845	4 262
36	5 473	6 114	6 776
37	8 702	9 722	10 770
38	13 870	15 490	17 170
39	22 000	24 580	27 240
40	34 980	39 080	43 320

INSTITUTE OF ELECTRICAL ENGINEERS
of Matthiessen's standard of conductivity.

Ohms per foot.			B. & S. or A. W. G.
68° F. 20° C.	122° F. 50° C.	176° F. 80° C.	
0.000 048 93	0.000 054 67	0.000 060 58	0 000
0.000 061 70	0.000 068 93	0.000 076 40	000
0.000 077 80	0.000 086 92	0.000 096 33	00
0.000 098 11	0.000 109 6	0.000 121 5	0
0.000 123 7	0.000 138 2	0.000 153 2	1
0.000 156 0	0.000 174 3	0.000 193 2	2
0.000 196 7	0.000 219 8	0.000 243 5	3
0.000 248 0	0.000 277 1	0.000 307 1	4
0.000 312 8	0.000 349 5	0.000 387 3	5
0.000 394 4	0.000 440 6	0.000 488 3	6
0.000 497 3	0.000 555 6	0.000 615 8	7
0.000 627 1	0.000 700 7	0.000 776 5	8
0.000 790 8	0.000 883 5	0.000 979 1	9
0.000 997 2	0.001 114	0.001 235	10
0.001 257	0.001 405	0.001 557	11
0 001 586	0.001 771	0.001 963	12
0.001 999	0.002 234	0.002 476	13
0.002 521	0.002 817	0.003 122	14
0.003 179	0.003 552	0.003 936	15
0.004 009	0.004 479	0.004 964	16
0.005 055	0.005 648	0.006 259	17
0.006 374	0.007 122	0.007 892	18
0.008 038	0.008 980	0.009 952	19
0.010 14	0.011 32	0.012 55	20
0.012 78	0.014 28	0.015 83	21
0.016 12	0.018 01	0.019 96	22
0.020 32	0.022 71	0.025 16	23
0.025 63	0.028 63	0.031 73	24
0.032 31	0.036 10	0.041 10	25
0.040 75	0.045 52	0.050 45	26
0.051 38	0.057 40	0.063 62	27
0.064 79	0.072 39	0.080 22	28
0.081 70	0.091 28	0.101 2	29
0.103 0	0.115 1	0.127 6	30
0.129 9	0.145 1	0.160 8	31
0.163 8	0.183 0	0.202 8	32
0.206 6	0.230 8	0.255 8	33
0.260 5	0.291 0	0.322 5	34
0.328 4	0.366 9	0.406 7	35
0.414 2	0.462 7	0.512 9	36
0.522 2	0.583 5	0.646 6	37
0.658 5	0.735 7	0.815 4	38
0.830 4	0.927 7	1.028	39
1.047	1.170	1.296	40

TABLE OF CARRYING CAPACITY OF WIRE AS ESTABLISHED BY THE NATIONAL BOARD OF UNDERWRITERS

Copper B. & S. G.	Circular Mils.	Rubber Covered Wires, Amperes	Other Insulations Amperes
18	1 624	3	5
16	2 583	6	8
14	4 107	12	16
12	6 530	17	23
10	10 380	24	32
8	16 510	33	46
6	26 250	46	65
5	33 100	54	77
4	41 740	65	92
3	52 630	76	110
2	66 370	90	131
1	83 690	107	156
0	105 500	127	185
00	133 100	150	220
000	167 800	177	265
0 000	211 600	210	312
	200 000	200	300
	300 000	270	400
	400 000	330	500
	500 000	390	590
	600 000	450	680
	700 000	500	760
	800 000	550	840
	900 000	600	920
	1 000 000	650	1 000
	1 100 000	690	1 080
	1 200 000	730	1 150
	1 300 000	770	1 220
	1 400 000	810	1 290
	1 500 000	850	1 360
	1 600 000	890	1 430
	1 700 000	930	1 490
	1 800 000	970	1 550
	1 900 000	1 010	1 610
	2 000 000	1 050	1 670

The question of drop is not taken into consideration in the above table.

DIAMETER OF WIRE WHICH WILL FUSE WITH GIVEN CURRENT

(W. H. Preece.)

Amp.	Diameter in Mils								
	Copper	Aluminium	Platinium	German silver	Platinoid	Iron	Tin	Tin lead alloy	Lead
1	2.1	2.6	3.3	3.3	3.5	4.7	7.2	8.3	8.1
2	3.4	4.1	5.3	5.3	5.6	7.4	11.3	13.2	12.8
3	4.4	5.4	7.0	6.9	7.4	9.7	14.9	17.3	16.8
4	5.3	6.5	8.4	8.4	8.9	11.7	18.1	21.0	20.3
5	6.2	7.6	9.8	9.7	10.4	13.6	21.0	24.3	23.6
10	9.8	12.0	15.5	15.4	16.4	21.6	33.4	38.6	37.5
15	12.9	15.8	20.3	20.2	21.5	28.3	43.7	50.6	49.1
20	15.6	19.1	24.6	24.5	26.1	34.3	52.9	61.3	59.5
25	18.1	22.2	28.6	28.4	30.3	39.8	61.4	71.1	69.0
30	20.5	25.0	32.3	32.0	34.2	45.0	69.4	80.3	77.9
35	22.7	27.7	35.8	35.6	37.9	49.8	76.9	89.0	86.4
40	24.8	30.3	39.1	38.8	41.4	54.5	84.0	97.3	94.4
45	26.8	32.8	42.3	42.0	44.8	58.9	90.9	105.2	102.1
50	28.8	35.2	45.4	45.0	48.0	63.2	97.5	112.9	109.5
60	32.5	39.7	51.3	50.9	54.2	71.4	110.1	127.5	123.7
70	36.0	44.0	56.8	56.4	60.1	79.1	122.0	141.3	137.1
80	39.4	48.1	62.1	61.6	65.7	86.4	133.4	154.4	149.9
90	42.6	52.0	67.2	66.7	71.1	93.5	144.3	167.1	162.1
100	45.7	55.8	72.0	71.5	76.2	100.3	154.8	179.2	173.9
120	51.6	63.0	81.4	80.8	86.1	113.3	174.8	202.4	196.4
140	57.2	69.8	90.2	89.5	95.4	125.5	193.7	224.3	217.6
160	62.5	76.3	98.6	97.8	104.3	137.2	211.8	245.2	237.9
180	67.6	82.6	105.6	105.8	112.8	148.4	229.1	265.2	257.3
200	72.5	88.6	114.4	113.5	121.0	159.2	245.7	284.5	276.0
225	78.4	95.8	123.7	122.8	130.9	172.2	265.8	307.7	298.6
250	84.1	102.8	132.7	131.7	140.4	184.8	285.1	330.1	320.3
275	89.7	109.5	141.4	140.4	149.7	196.9	303.8	351.8	341.3
300	95.0	116.1	149.8	148.7	158.6	208.6	322.0	372.8	361.7

*TABLE I

RING ARMATURE WINDINGS

Types of Winding	No. Separate Windings = X	No. Circuits in Parallel per Winding $=b_1$	No. Circuits in Parallel through Arm. = b	No. Inductors = Z	Field Step = m	Resultant Pitch = y	Commutator Pitch $=Y_k$	Inductors in Series between Brushes	No. Brush Sets	Angle between Brush Sets	Types of Winding
1	1	p	p	$=gG=gK$	0	$\pm g$	$\pm g$	$Z \div p$	p	$360° \div p$	1
2	1	2	2	$=\frac{gyp \pm 2}{2}$ and $=gG=gK$	1	$\frac{2Z \pm 2}{p}$ and must be odd	$\frac{2K \pm 2}{p}$	$Z \div 2$	Min. 2 Max. p	$360° \div p$ or any odd multiple	2
3	1	b	4, 6, 8, or and other even number greater than 2	$=\frac{py \pm b}{2}$	1	$\frac{2Z \pm b}{2}$	$\frac{2K \mp b}{p}$	$Z \div b$	p	$360° \div p$	3
4	2, 3, 4, or any other whole number	p	X p	$=Xgb=XgK$	0	$\pm gX$	$\pm gX$	$Z \div Xp$	p	$360° \div p$	4
5	ditto	2	2 X	$\frac{gnpy \pm 2n}{2}$	1	$\frac{2Z \mp 2X}{Xp}$	$\frac{2K \pm 2X}{p}$	$Z \div 2X$	Min. 2 Max. p	$360° \div p$ or any odd multiple	5
6	ditto	4, 6, 8, or any other even number greater than 2	Xb_1	$\frac{gnpy \pm 2nb_1}{2}$	1	$\frac{2Z \mp 2Xb_1}{Xp}$	$\frac{2K \pm 2Xb_1}{Xp}$	$Z \div Xb_1$	p	$360° - p$	6

* A key to the meaning of the symbols used is given in section 250.

1. Parallel Grouping (Simplex).
2. Series Grouping (Singly Re-entrant).
3. Series Parallel Grouping (Simplex Doubly or Multiply Re-entrant).
4. Duplex or Multiplex Parallel Grouping.
5. Duplex or Multiplex Series Grouping.
6. Duplex or Multiplex Series Parallel Grouping.

*TABLE J

WAVE-WOUND DRUM ARMATURE WINDINGS

Types of Winding	No. Separate Windings = X	No. Circuits in Parallel per Winding $= b_1$	No. Circuits in Parallel through Arm. = b	Number of Inductors = Z	Field Step = m	Y_f and Y_b	Commutator Pitch $= Y_k$	Inductors in Series	No. Brush Sets	Angle between Brushes	Types of Winding
1	1	2	2	$bY_{av} \pm 2$	1	$\frac{Z \pm 2}{p}$ Must be odd and have no common factor with Z	$\frac{2K \pm 2}{p}$	$Z \div 2$	Min. 2 Max. p	$360° \div p$ or any odd multiple	1
2	2, 3, 4, or any other whole number	2	2X	$XpY_{av} \pm 2X$	1	$\frac{Z \pm 2X}{Xp}$ Where Y_{av} is even, Y_f may $= Y_{av} + 1$, Y_b may $= Y_{av} - 1$	$\frac{2K \pm 2X}{Xp}$	$Z \div 2X$	ditto	ditto	2
3	1	4, 6, 8, or any other even number greater than 2	4, 6, 8, or any other even number greater than 2	$pY_{av}' \pm b$	1	$\frac{Z \pm b}{p}$	$\frac{2K \pm b}{p}$	$Z \div b$	ditto	ditto	3
4	2, 3, 4, or any other whole number	2, 4, 6, or any other even number	Xb_1	$XpY_{av} \pm Xb_1$	1	$\frac{Z \pm Xb_1}{Xp}$	$\frac{2K \pm Xb_1}{Xp}$	$Z \div Xb_1$	ditto	ditto	4

* A key to the meaning of symbols used is given in section 250.

1. Wave Winding—Simplex Singly Re-entrant.
2. Wave Winding—Duplex or Multiplex.
3. Wave Winding—Simplex Doubly or Multiply Re-entrant.
4. Wave Winding—Duplex or Multiplex, Doubly or Multiply Re-entrant.

*TABLE K

LAP-WOUND DRUM ARMATURE WINDINGS

Types of Winding	No. Separate Windings = X	No. Circuits in Parallel per Winding = b_1	No. Circuits in Parallel through Arm. = b	Number of Inductors = Z	Field Step = m	Resultant Pitch = y	Commutator Pitch = Y_k	Front Pitch = Y_f	Back Pitch = Y_b	Inductors in Series	No. Brush Sets	Angle between Brushes	Types of Winding
1	1	p	p	= 2gG	0	±2	1	= 2 or less than Z ÷ p must be odd	$-(Y_f \pm 2)$	Z ÷ p	p	360° ÷ p	1
2	2, 3, 4, or any other whole number	p	p X	= 2gG	0	±2X	±X	ditto	$Y_f - 2X$	Z ÷ pX	p	360° ÷ p	2
3	1	4, 6, 8, or any other even number greater than 2	4, 6, 8, or any other even number greater than 2	= 2gG	0	±b	$\pm\frac{1}{2}b$	ditto	$Y_f - b$	Z ÷ b	p	360° ÷ p	3
4	2, 3, 4, or any other whole number	ditto × 2	Xb_1	= 2gG	0	$\pm Xb_1$	$\pm\frac{1}{2}Xb_1$	ditto	$Y_f - Xb_1$	$Z \div Xb_1$	p	360° ÷ p	4

* A key to the meaning of the symbols used is given in section 250.

1. Lap Winding—Simplex Singly Re-entrant.
2. Lap Winding—Duplex or Multiplex.
3. Lap Winding—Simplex, Doubly or Multiply Re-entrant.
4. Lap Winding—Duplex or Multiplex, Doubly or Singly Re-entrant.

WIRING TABLE FOR TWO PER CENT LOSS ON A 50-VOLT CIRCUIT

Table for 1 Volt Loss

No. of Amperes	DISTANCE IN FEET TO CENTER OF DISTRIBUTION (Wire sizes in B. & S. Gauge)																	
	20	25	30	35	40	45	50	60	70	80	90	100	120	140	160	180	200	250
1	...	...	...	...	...	...	...	...	...	...	......	16	16	15	14	14	13	12
1.5	...	...	...	...	...	...	...	...	...	16	15	15	14	13	13	12	12	11
2	...	...	...	...	...	...	16	16	15	14	14	13	13	12	11	11	10	9
3	...	...	...	16	16	15	15	14	13	13	12	12	11	10	10	9	9	8
4	...	16	15	15	14	14	13	13	12	11	11	10	10	9	8	8	7	6
5	16	16	15	14	13	13	12	12	11	10	10	9	9	8	7	7	6	5
6	16	15	14	13	13	12	12	11	10	10	9	9	8	7	7	6	6	5
7	15	14	13	12	12	11	11	10	10	9	8	8	7	7	6	5	5	4
8	14	13	13	12	11	11	10	10	9	8	8	7	7	6	5	5	4	3
9	14	13	12	11	11	10	10	9	8	8	7	7	6	5	5	4	4	3
10	13	12	12	11	10	10	9	9	8	7	7	6	6	5	4	4	3	2
12	13	12	11	10	10	9	9	8	7	7	6	6	5	4	4	3	3	2
14	12	11	10	10	9	8	8	7	7	6	5	5	4	4	3	2	2	1
16	11	10	10	9	8	8	7	7	6	5	5	4	4	3	2	2	1	0
18	11	10	9	8	8	7	7	6	5	5	4	4	3	2	2	1	1	0
20	10	9	9	8	7	7	6	6	5	4	4	3	3	2	1	1	0	00
25	9	8	8	7	6	6	5	5	4	3	3	2	2	1	0	0	00	00
30	9	8	7	6	6	5	5	4	3	3	2	2	1	0	0	00	00	000
35	8	7	6	6	5	4	4	3	2	2	1	1	0	0	00	00	000	000
40	7	6	6	5	4	4	3	3	2	1	1	0	0	00	000	000	0 000	0 000
45	7	6	5	4	4	3	3	2	1	1	0	0	00	00	000	0 000	0 000	
50	6	5	5	4	3	3	2	2	1	0	0	00	00	000	0 000	0 000		
55	6	5	4	4	3	3	2	1	0	0	00	00	000	000	0 000			
60	6	5	4	3	3	2	2	1	0	0	00	00	000	0 000				
65	5	4	4	3	2	2	1	1	0	00	00	000	000	0 000				
70	5	4	3	2	2	1	1	0	0	00	00	000	0 000					
75	5	4	3	2	2	1	1	0	00	00	000	000	0 000					
80	4	3	3	2	1	1	0	0	00	000	000	0 000	0 000					
90	4	3	2	1	1	0	0	00	00	000	0 000							
100	3	2	2	1	0	0	00	00	000	000	0 000							

WIRING TABLE FOR TWO PER CENT LOSS ON A 110-VOLT CIRCUIT

Table for 2.2 Volts Loss

No. of Amperes	DISTANCE IN FEET TO CENTER OF DISTRIBUTION (Wire sizes in B. & S. Gauge)																		
	20	30	40	50	60	70	80	90	100	120	140	160	180	200	240	280	320	360	400
1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16	15	15	14	14
1.5	..	..	..	..	..	..	..	..	..	..	..	16	15	15	14	14	13	12	12
2	..	..	..	..	..	..	..	..	..	16	15	15	14	14	13	12	12	11	11
3	..	..	..	..	..	..	16	15	15	14	14	13	12	12	11	11	10	9	9
4	..	..	..	..	16	15	15	14	14	13	12	12	11	11	10	9	9	8	8
5	..	..	..	16	15	14	14	13	13	12	11	11	10	10	9	8	8	7	7
6	..	..	16	15	14	14	13	12	12	11	11	10	9	9	8	8	7	7	6
7	..	16	15	14	14	13	12	12	11	11	10	9	9	8	7	7	6	6	5
8	..	16	15	14	13	12	12	11	11	10	9	9	8	8	7	7	6	5	5
9	..	15	14	13	12	12	11	11	10	9	9	8	8	7	7	6	5	5	5
10	16	15	14	13	12	11	11	10	10	9	8	8	7	7	6	5	5	4	4
12	16	14	13	12	11	11	10	9	9	8	8	7	7	6	5	5	4	4	3
14	15	14	12	11	11	10	9	9	8	7	7	6	6	5	5	4	3	3	2
16	15	13	12	11	10	9	9	8	8	7	7	6	5	5	4	3	3	2	2
18	14	12	11	10	9	9	8	8	7	7	6	5	5	4	4	3	2	2	1
20	14	12	11	10	9	8	8	7	7	6	5	5	4	4	3	2	2	1	1
25	13	11	10	9	8	7	7	6	6	5	4	4	3	3	2	1	1	0	0
30	12	10	9	8	7	7	6	6	5	4	4	3	3	2	1	1	0	0	00
35	11	10	8	7	7	6	5	5	4	4	3	2	2	1	1	0	00	00	000
40	11	9	8	7	6	5	5	4	4	3	2	2	1	1	0	00	00	000	000
45	10	9	7	6	6	5	4	4	3	3	2	1	1	0	00	00	000	000	0 000
50	10	8	7	6	5	4	4	3	3	2	1	1	0	0	00	000	000	0 000	0 000
60	9	7	6	5	4	4	3	3	2	1	1	0	0	00	000	000	0 000	0 000	
70	8	7	5	4	4	3	2	2	1	1	0	00	00	000	000	0 000	0 000		
80	8	6	5	4	3	2	2	1	1	0	00	00	000	000	0 000	0 000			
90	7	6	4	3	3	2	1	1	0	00	00	000	000	0 000	0 000				
100	7	5	4	3	2	1	1	0	0	00	000	000	0 000	0 000					
120	6	4	3	2	1	1	0	0	00	00	000	0 000	0 000						

WIRING TABLE FOR TWO PER CENT LOSS ON A 220-VOLT CIRCUIT

Table for 4.4 Volts Loss

No. of amperes	DISTANCE IN FEET TO CENTER OF DISTRIBUTION (Wire sizes in B. & S. Gauge)																		
	20	30	40	50	60	70	80	90	100	120	140	160	180	200	240	280	320	360	400
1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	....	....	......	.....	16
1.5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	....	....	16	15	15
2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	16	15	15	14	14
3	..	..	..	..	..	..	..	..	..	..	..	16	15	15	14	14	13	12	12
4	..	..	..	..	..	..	..	..	..	16	15	15	14	14	13	12	12	11	11
5	..	..	..	..	..	..	..	..	16	15	14	14	13	13	12	11	11	10	10
6	..	..	..	..	..	..	16	15	15	14	14	13	12	12	11	11	10	9	9
7	..	..	..	..	..	16	15	14	14	14	13	12	12	11	11	10	9	9	8
8	..	..	..	..	16	15	15	14	14	13	12	12	11	11	10	9	9	8	8
9	..	..	..	..	15	15	14	14	13	12	12	11	11	10	9	9	8	8	7
10	..	..	..	16	15	14	14	13	13	12	11	11	10	10	9	8	8	7	7
12	..	..	16	15	14	14	13	12	12	11	11	10	9	9	8	8	7	7	6
14	..	16	15	14	14	13	12	12	11	11	10	9	9	8	7	7	6	6	5
16	..	16	15	14	13	12	12	11	11	10	9	9	8	8	7	7	6	6	5
18	..	15	14	13	12	12	11	11	10	9	9	8	8	7	7	6	5	5	4
20	16	15	14	13	12	11	11	10	10	9	8	8	7	7	6	5	5	4	4
25	16	14	13	12	11	10	10	9	9	8	7	7	6	6	5	4	4	3	3
30	15	13	12	11	10	10	9	9	8	7	7	6	6	5	4	4	3	3	2
35	14	13	11	10	10	9	8	8	7	7	6	5	5	4	4	3	2	2	1
40	14	12	11	10	9	8	8	7	7	6	5	5	4	4	3	2	2	1	1
45	13	12	10	9	9	8	7	7	6	6	5	4	4	3	3	2	1	1	0
50	13	11	10	9	8	7	7	6	6	5	4	4	3	3	2	1	1	0	0
60	12	10	9	8	7	7	6	6	5	4	4	3	3	2	1	1	0	0	00
70	11	10	8	7	7	6	5	5	4	4	3	2	2	1	1	0	00	00	000
80	11	9	8	7	6	5	5	4	4	3	2	2	1	1	0	00	00	000	000
90	10	9	7	6	6	5	4	4	3	3	2	1	1	0	00	00	000	000	0 000
100	10	8	7	6	5	4	4	3	3	2	1	1	0	0	00	000	000	0 000	0 000
120	9	7	6	5	4	4	3	3	2	1	1	0	0	00	000	000	0 000	0 000	

STANDARD SYMBOLS FOR WIRING PLANS

AS ADOPTED AND RECOMMENDED BY

THE NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION OF THE UNITED STATES and THE AMERICAN INSTITUTE OF ARCHITECTS.

Ceiling Outlet; Electric only. Numeral in center indicates number of Standard 16 C. P. Incandescent Lamps.

Ceiling Outlet; Combination. 4/2 indicates 4-16 C. P. Standard Incandescent Lamps and 2 Gas Burners. If gas only

Bracket Outlet; Electric only. Numeral in center indicates number of Standard 16 C. P. Incandescent Lamps.

Bracket Outlet; Combination. 4/2 indicates 4-16 C. P. Standard Incandescent Lamps and 2 Gas Burners. If gas only

Wall or Baseboard Receptacle Outlet. Numeral in center indicates number of Standard 16 C. P. Incandescent Lamps.

Floor Outlet. Numeral in center indicates number of Standard 16 C. P Incandescent Lamps.

Outlet for Outdoor Standard or Pedestal; Electric only. Numeral indicates number of Stand. 16 C. P. Lamps.

Outlet for Outdoor Standard or Pedestal; Combination. 6/6 indicates 6-16 C. P. Stand. Incan. Lamps; 6 Gas Burners.

Drop Cord Outlet.

One Light Outlet, for Lamp Receptacle.

Arc Lamp Outlet.

Special Outlet, for Lighting, Heating and Power Current, as described in Specifications.

Ceiling Fan Outlet.

S¹ S. P. Switch Outlet.

S² D. P. Switch Outlet.

S³ 3-Way Switch Outlet.

S⁴ 4-Way Switch Outlet.

S^D Automatic Door Switch Outlet.

S^E Electrolier Switch Outlet.

Show as many Symbols as there are Switches. Or in case of a very large group of Switches, indicate number of Switches by a Roman numeral, thus: S¹ XII, meaning 12 Single Pole Switches.
Describe Type of Switch in Specifications, that is,
Flush or Surface, Push Button or Snap.

Meter Outlet.

Distribution Panel.

Junction or Pull Box.

Motor Outlet; Numeral in center indicates Horse Power.

Motor Control Outlet.

Transformer.

Main or Feeder run concealed under Floor.

Main or Feeder run concealed under Floor above.

Main or Feeder run exposed.

Branch Circuit run concealed under Floor.

Branch Circuit run concealed under Floor above.

Branch Circuit run exposed.

Pole Line.

Riser.

Telephone Outlet; Private Service.

Telephone Outlet; Public Service.

Bell Outlet.

Buzzer Outlet.

Push Button Outlet; Numeral indicates number of Pushes.

Annunciator; Numeral indicates number of Points.

Speaking Tube.

Watchman Clock Outlet.

Watchman Station Outlet.

Master Time Clock Outlet.

Secondary Time Clock Outlet.

Door Opener.

Special Outlet; for Signal Systems, as described in Specifications.

Battery Outlet.

Circuit for Clock, Telephone, Bell or other Service, run under Floor, concealed.
Kind of Service wanted ascertained by Symbol to which line connects.

Circuit for Clock, Telephone, Bell or other Service, run under Floor above, concealed.
Kind of Service wanted ascertained by Symbol to which line connects.

NOTE—If other than Standard 16 C. P. Incandescent lamps are desired, Specifications should describe capacity of Lamp to be used.

SUGGESTIONS IN CONNECTION WITH STANDARD SYMBOLS FOR WIRING PLANS

It is important that ample space be allowed for the installation of mains, feeders, branches and distribution panels.

It is desirable that a key to the symbols used accompany all plans.

If mains, feeders, branches and distribution panels are shown on the plans, it is desirable that they be designated by letters or numbers.

Heights of Centre of Wall Outlets (unless otherwise specified)

Living Rooms	5′ 6″
Chambers	5′ 0″
Offices	6′ 0″
Corridors	6′ 3″

Height of Switches (unless otherwise specified) 4′ 0″

SUMMARY OF DIRECT- AND ALTERNATING-CURRENT RELATIONS

SYNOPSIS OF UNITS AND SYMBOLS IN GENERAL USE

Unit	Name	Symbols	Defining Equations: Direct Current	Defining Equations: Alternating Current
Electromotive Force	Volt	E, e	IR	IZ
Current	Ampere	I, i	E÷R	E÷Z
Resistance	Ohm	R, r	E÷I	$\sqrt{Z^2-X^2}$
Power	Watt	P	EI	EI×p.f.
Impedance	Ohm	Z, z		$\sqrt{R^2+X^2}$
Reactance	Ohm	X, x		$\sqrt{Z^2-R^2}$
Inductance	Henry	L, l	*λ÷I	λ÷I
Capacity	Farad	C, c	Q÷E	Q÷E
Quantity	Coulomb	Q, q	I×time	I×time
Admittance	Mho	Y, y		$I\div Z=\sqrt{G^2+B^2}$
Conductance	Mho	G, g	I÷R	$R\div Z^2=\sqrt{Y^2-B^2}$
Susceptance	Mho	B, b		$X+Z^2=\sqrt{Y^2-G^2}$

* Linkage=turns×magnetic flux.

DIRECT-CURRENT RELATIONS

Electromotive Force, represented by E or e.
Current times resistance I × R.
Watts divided by current P ÷ I.

Current, represented by I or i.
E.m.f. divided by resistance E ÷ R.
Watts divided by e.m.f. P ÷ E.

Resistance, represented by R or r.
E.m.f. divided by current E ÷ I.
Watts divided by square of current $P \div I^2$.

Watts, represented by P.
E.m.f. times current E × I.
Square of current times resistance $I^2 \times R$.
Square of e.m.f. divided by resistance $E^2 \div R$.

Resistances in Series.
The total resistance of a number of resistances in series is equal to the sum of all of them. $R = R_1 + R_2 + R_3 + \ldots$

Resistances in Parallel.

The joint resistance of two resistances in parallel is equal to their product divided by their sum. $R = (R_1 \times R_2) \div (R_1 + R_2)$.

The joint resistance of a number of resistances connected in parallel is the reciprocal of the sum of the reciprocals.

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots .}$$

If conductance is used in place of resistance, the joint resistance is the reciprocal of the sum of the conductances.

$$R = \frac{1}{G_1 + G_2 + G_3 + \ldots ..}$$

ALTERNATING-CURRENT RELATIONS

Impressed e.m.f., represented by E.

Current times impedance $I \times Z$.

Current divided by admittance $I \div Y$.

Inductive e.m.f. divided by sine of lag or lead angle (reactive factor) $E_1 \div$ r.f.

Effective e.m.f. divided by cosine of lag or lead angle (power factor) $E_r \div$ p.f.

The square root of the sum of the squares of the resultant reactive e.m.f. and the effective e.m.f.

$$E = \sqrt{E_r^2 + (E_l - E_c)^2}.$$

Inductive e.m.f., represented by E_1.

6.28 times frequency times inductance reactance $= 2\pi fLI$.

Current times inductance reactance.

Impressed e.m.f. times sine of lag angle (reactive factor) if there is no capacity $E \times$ r.f.

The square root of the square of impressed, minus the square of effective e.m.f. if the current lags and there is no capacity.

$$E_l = \sqrt{E^2 - E_r^2}.$$

Condensive e.m.f., represented by E_c.

Current times one divided by 6.28 times the frequency times the capacity $I \times (1 \div 2\pi fC)$.

Current times capacity reactance $I \times X_c$.

Impressed e.m.f. times sine of lead angle (reactive factor) if there is no inductance $E \times$ r.f.

The square root of the square of the impressed minus the square of the effective e.m.f. if the current leads and there is no inductance.

$$E_c = \sqrt{E^2 - E_r^2}.$$

Effective e.m.f., represented by E_r.
Current times resistance $I \times R$.
Current divided by conductance $I \div G$.
True watts divided by current $P \div I$.
Impressed e.m.f. times cosine of lag or lead angle (power factor) $E \times p.f.$
The square root of the square of the impressed e.m.f. minus the square of the reactive e.m.f.

Current, represented by I or i.
Effective e.m.f. divided by resistance $E \div R$.
Effective e.m.f. multiplied by conductance $E \times G$.
Impressed e.m.f. divided by impedance $E \div Z$.
Impresed e.m.f. multiplied by admittance $E \times Y$.
True watts divided by impressed e.m.f. times power factor (cosine angle of lag or lead) $P \div (E \times p.f.)$.
Reactive e.m.f. divided by reactance.
The square root of true watts divided by resistance

$$I = \sqrt{P \div R}.$$

Impedance, represented by Z or z.
Impressed e.m.f. divided by current $E \div Z$.
Resistance divided by power factor (cosine of lag or lead angle) $R \div p.f.$
Reactance divided by reactive factor (sine of lag or lead angle) $X \div r.f.$
The square root of the sum of the squares of resistance and reactance $\sqrt{R^2 + X^2}$.

Resistance, represented by R or r.
Impedance times power factor (cosine of lag or lead angle) $Z \times p.f.$
The square of effective e.m.f. divided by true watts $E_r^2 \div P$.
Effective e.m.f. divided by current $E_r \div I$.
True watts divided by square of current $P \div I^2$.
The square root of impedance squared minus square of reactance $\sqrt{Z^2 - X^2}$.

Reactance (inductive), represented by X_1.
6.28 times inductance times frequency $2\pi Lf$.
Impedance times reactive factor (sine of lag angle) $Z \times r.f.$

Reactance (condensive), represented by X_c.
1 divided by 6.28 times frequency, times capacity

$$\frac{1}{6.28\,f\,C}$$

Impedance times reactive factor (sine of lead angle) $Z \times r.f.$
Condensive e.m.f. divided by current.

Admittance, represented by Y or y.
One divided by impedance $1 \div Z$.
Current divided by e.m.f. $I \div E$.

The square root of the sum of the squares of conductance and susceptance, $Y = \sqrt{G^2 + B^2}$.

Susceptance, represented by B or b.

Admittance times sine of lag or lead angle (reactive factor) $Y \times$ r.f.

Sine of lag or lead angle divided by impedance, r.f. $\div Z$.

The square root of the square of admittance minus the square of conductance, $B = \sqrt{Y^2 - G^2}$.

One divided by reactance if there is no resistance $1 \div X$.

Conductance, represented by G or g.

Admittance times cosine of lag or lead angle (power factor) $Y \times$ p.f.

Cosine of lag or lead angle divided by impedance p.f. $\div Z$.

The square root of the square of admittance minus the square of susceptance, $G = \sqrt{Y^2 - B^2}$.

One divided by resistance (for direct current) $1 \div R$.

Power (true watts), represented by P.

Effective e.m.f. times current $E_r \times I$.

Impressed e.m.f. times current times power factor $E \times I \times$ p.f.

Square of current times resistance $I^2 \times R$.

Square of current divided by conductance (no reactance) $I^2 \div G$.

Impedance times current squared times power factor $Z \times I^2 \times$ p.f.

Apparent Watts, represented by P.

Impressed e.m.f. times current $E \times I$.

Square of current times impedance $I^2 \times Z$.

Square of current divided by admittance $I^2 \div Y$.

Power Factor.

True watts divided by apparent watts $P \div (E \times I)$.

Resistance divided by impedance $R \div Z$.

Effective e.m.f. divided by impressed e.m.f. $E_r \div E$.

Reactance Factor.

Reactance divided by the resistance $X \div R$.

Reactive Factor.

Wattles volt-amperes divided by the total volt-amperes $X \times I \div Z \times I = X \div Z =$ sine of the angle of lag or lead.

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